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Viability of Production and Application of Concrete with Addition of Fibers of Polyethylene Terephthalate (PET) Bottles for Construction

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Abstract: *Concrete is the main material used in the construction industry not only for the ability to produce infinite variety of shapes for precast forms and for its characteristics of high resistance to compression, but primarily for their low manufacturing cost. Nonetheless, the production by mixing cement, fine aggregate, coarse aggregate and water, using natural raw materials such as stone, sand and water, despite being plentiful, represent the consumption of millions of tons of natural resources. Thus, the continuous search for new solutions is fundamental in order to not only further lower the manufacturing costs of this essential component in construction, but also to seek alternative materials, those of origin in processes of sustainability.*

Keywords: *Recycling, Polyethylene Terephthalate, Sustainability, Construction, Materials, Concrete, Cement, Fibers, Mixing, Production, Application.*

1 Objectives

A great amount of PET bottles that were once discarded damaging the environment are gaining a new function in the construction market, and their use as fibers in concrete, an alternative that hasn’t been widely studied so far, can replace the use of glass fibers, polyethylene, polypropylene and even steel. Thus, this work aims to present an analysis on the sources of the recycling of PET (Polyethylene Terephthalate) to determine the possibilities for the production and availability of PET fibers that are appropriate for the concrete mixture of Portland cement, minimizing the use of sand in the civil construction industry; to review the physical mechanical behavior of the concrete with the addition of PET bottle fibers; and verify the best application of this concrete in the construction of buildings, aiming at reducing costs and ensuring the sustainability of the sector while maintaining the necessary quality. To achieve the desired goal, initially the possibilities of production and availability of PET fibers in the Brazilian market will be determined. Following, it will reviewed the mechanical and physical behavior of concrete with the addition of PET bottle fibers, analyzing the results of workability, its axial compression strength and diametral compression tensile strength. Finally, with all the foundation generated in the previous steps, it will be analyzed the possibilities of application in civil construction.

2 Methodology

The methodology used has included laboratory tests with the molding, curing, grinding and rupture of specimens to verify the behavior of the concrete with PET fibers in relation to its axial compression strength and diametral compression tensile strength, when compared to the fiber-free concrete.

The theoretical and conceptual basis of this work was based on the analysis of the improvement of the concrete resistance properties with the addition of fibers. The study of the bibliographic material on concretes was based, mainly, on the Brazilian standards where the step by step of the execution of the experiments carried out in this work is illustrated, contributing also to the standardization of the tests.

3 Results

3.1 PET Recycling in Brazil

The recycling of PET in Brazil is one of the most developed in the world, presenting a high productivity rate. According with the Brazilian Census of Recycling of PET, Brazil in 2006 exceeded the score of 50% recycling rate and, in 2012, 331,000 tons of PET packaging were collected. Brazil also already have more than 90% of recycling companies with more than 5 years of activity.

With the help of the advanced taken by the Brazilian national solid waste policy, there has been a growth of cooperatives decreasing the difficulty of obtaining bottles to recycle. As indicated by Business Commitment for Recycling (CEMPRE), from 2004 to 2015 the level of recovery of materials increased by 29% and the volume of packages deposited in landfill was reduced by 21.3%. In addition, in relation to cooperatives and voluntary delivery points (VDP): 802 cooperatives were supported from 2012 to 2017, 4,487 cooperatives structuring actions carried out and 364 municipalities attended in 21 states; and 2,082 PEV were installed from 2012 to 2017; 7,826 PEV structuring actions carried out and 240 municipalities attended in 24 states.

3.2 PET fibers Brazilian Production

The Brazilian industry of PET flakes has a production capacity from 2,500 kg/h to 4,500kg/h including moderns grinding lines with optical separator systems, super washing and fines screening for the production of colorless PET flake, hot-wash PET recycling system covering all the production steps including label and lid removal and separation, grinding, hot-washing and drying. Also, the Brazilian industry of PET flakes developed a national technology for PET flake super washing, providing highest level of decontamination and final quality to the PET raw material marketed. This technology could also produces PET flakes with some specials specifications: standard colors: Crystal, Blue and Green; particle size between 8.0 and 12.0 mm; PVC contamination of less than 80 ppm; contamination by olefins and non-ferrous metals of less than 100 ppm; bulk density between 350 and 500 g/L; maximum humidity of 1,0%; and absence of PET powder.

3.3 Laboratory Tests

The cement agglomerate used was the CP II E32 of the MAUÁ brand and it was weighed on a WELMY mechanical scale. The sand used in the manufacturing process of the specimens was classified as the average sand of the MARQUES BROTHERS, sifted, whose maximum allowable granulometry is 1.41 mm and weighed on a WELMY mechanical scale. For the characterization of the sand, a specific mass test was performed based on the standard NBR NM 52 – 2009 – Fine aggregates, using a Chapman Vial. The unit mass test followed the standard NBR NM 45 – 2006 – Aggregates. The test on the sand's granulometry was performed as prescribed by NBR NM 248 – 2003. The coarse aggregate used was Gravel I of the brand IRMÃOS MARQUES and the sample was weighed on a WELMY mechanical scale.

The PET fibers used in this analysis were obtained from the recycling of soda bottles that were discarded in nature, then washed and cut with the aid of a ruler, scissors and guillotine in the dimensions of 30 mm x 3 mm. The fibers were weighed on a Bel electronic scale.

For the concrete dosage characteristics, the calculations were made according to the method of the Brazilian Association of Portland Cement (ABCP) by means of a technical study (ET-67), with the title "Concrete Dosing Parameters", authored by the public engineer Penna Firme Rodrigues (revised in 1995) that presents an eminently experimental feature.

The materials measurement was made from the mortar basic trace of 1: 1.5: 1.82: 0.47 a/c (cement, sand, gravel, water, respectively). It is worth noting that the basic trace represents a proportion of each material as is usually used in the civil construction.

For compression and diametral compression tests performance, cylindrical specimens were molded with dimensions of 100x200 mm, as well as, the procedures of density and healing were performed according to ABNT NBR 5738-2015.

The consistency of the fresh concrete was determined by the slump test of a concrete cone, according to NBR NM 67: 1998.

For the axial compression test, the I-3001-C 100 Tf digital hand press produced by Contenco was used. For the evaluation of the Axial Compression Strength test, the guidelines of ABNT NBR 5739: 2007 - Concrete - Compression test of cylindrical specimens were followed.

The test of determination of tensile strength by diametral compression was performed according to ABNT NBR 7222: 2011, considering the ages of 7 and 28 days. The press used in the test was the I-3001-C 100 Tf digital hand press produced by Contenco.

The fresh concrete test has showed the slump of the concrete cone specimen come was 90 mm for concrete without the addition of PET fibers, characterizing a rich concrete, while for the trait with 2% PET fiber, the slump was 20 mm indicating a poor concrete of very low workability, as shown in Figure 1.

Figure 1. Slump test of a concrete cone.

According to Mheta and Monteiro (1994), in concrete with fibers, compressive strength is not the most important contribution of reinforcement. Figures 2 and 3 present the results of axial compressive strength according to NBR 5739 (ABNT, 2007). It can be observed that there was not much difference in the deformation presented by concrete with addition of PET fiber to concrete without fiber. Both presented type of D - conical and sheared rupture, as specified in Annex A of NBR 5739.

Figure 2. Specimen with PET fibers after cracking under axial compression.

Figure 3. Specimen with no PET fibers after cracking under axial compression.

The axial compressive strength test has demonstrated that the mixture with addition of PET fibers (2% content) showed a small reduction in axial compressive strength in relation to concrete without fiber addition at the age of 28 (3.27% reduction). In contrast to what be observed at the age of 7 days, when fiber-reinforced concrete showed higher axial compressive strength results than fiber-free concrete (an increase of 1.18%), which can be seen in the comparison with the results in Figure 4.

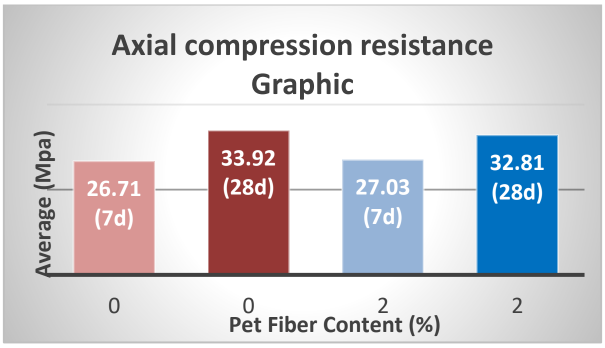

Figure 4. Comparative results of axial compression resistance tests.

The Figure 5 illustrates the specimen with PET fibers after the diametric compression test. According to NBR 7222 (ABNT, 1994), it can be observed that the crack propagated easily at the top and with some resistance at the bottom, holding the parts together. Thus, an excess load is required to break it completely. However, this is not the case with concrete without the addition of PET fiber, where the crack propagated throughout the body and abruptly breaking it, as shown in Figure 6.

Figure 5. Specimen with PET fibers after cracking under diametral compression.

Figure 6. Specimen with no PET fibers after cracking under diametral compression.

In the diametrical compression tensile strength test, we observed an increase in tensile strength by diametral compression with increasing control age (7 to 28 days), as expected. On the order hand, the results for axial compressive strength, PET fiber-reinforced concretes have presented a 18.38% increase in diametral tensile strength in relation to non-PET-reinforced concrete at both ages, which can be seen in the comparison of the results in Figure 7.

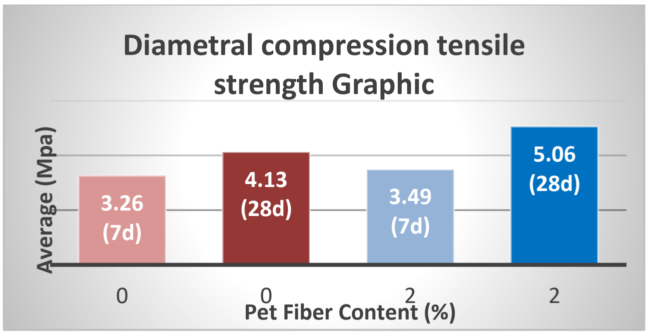

Figure 7. Comparative results of diametral compression tensile strength tests.

3.4 Application of Concrete with PET Fibers

The results have demonstrated that the greatest gains obtained with the use of fibers are associated with the increased strength of concrete to tensile stress. By adding PET fiber to concrete, it is no longer a fragile material. This is due to the increased bonding of the matrix to the concrete (transition zone), causing an increase in its mechanical characteristics, such as modulus of elasticity (Gpa), and tensile strength (MPa). Additionally, its filaments work as adhesion point of tensions between the cracks, preventing their propagation, thus making the concrete more resistant and ductile, with a post-fissure capacity.

With these results, important applications for concrete obtained from mixtures with PET fibers would be in pavement structures, hydroelectric plants, tunnel coverings, dams, slabs, which have a volumetric control of shrinkage, which would make it possible to reduce the possibilities of cracks, besides offering good protection.

In addition, there are other applications of PET fibers in construction that may be used more intensely in the future as repair materials (MRs) for degraded hydraulic surfaces, for example, to provide a satisfactory performance at lower cost compared to materials generally employed in these cases, with the advantage of an appropriate final disposal of these solid wastes.

4 Conclusions

From the analyzed aspects, the use of recycled PET fibers in concrete definitely provided considerable changes in the physical properties of the material.

- Regarding workability, the conventional concrete was workable and cohesive. It was noted a loss of rebate in the trait with 2% content of PET (20 mm slump), proving to be very consistent, a fact that, however, did not compromise the casting of the concrete;
- Regarding the axial compression strength, concrete with the addition of PET fibers at 7 days of age had a strength gain of 6.59% and a loss of 5.54% at 28 days of age. Regarding the mechanical test for axial compression at 28 days of age, there has been no significant difference for fiber-reinforced concrete compared to non-fiber concrete; and
- However, a significant increase in the results of tensile by diametral compression to 2% PET fiber concrete has been obtained with increasing control age (from 7 to 28 days), as expected. The result of increasing tensile strength was then successfully achieved. Thus, different to what has been observed in the axial strength results, the concrete with

addition of PET fiber presented a 18.38% increase in tensile strength compared to concrete with no fiber addition.

The results allow us to conclude that there is possibility of production and availability of PET fibers that are suitable for mixing in concrete, since the results of the mechanical physical behavior of the concrete were satisfactory for the performed mixing condition.

It is noteworthy that further studies are necessary to prove its applicability in structural use, aiming at a future revision of NBR 8953 (2015).

Thus, even though it has been well demonstrated academically that the tensile strength property of this technology proves superior to conventional concrete, the viability of its use at the industrial level will only occur with more government support and incentives through an infrastructure that can guarantee the stability of the production of PET fibers, establishing the necessary logistics to guarantee its offer for the civil construction, allowing construction companies to use this material for the preservation of our planet. As mentioned in the beginning of this study, the waste from PET bottles generates a major environmental problem, and any appropriate end we can find for this waste returns a great benefit to nature.

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