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NEUTRON RADIOGRAPHIC TESTING OF SAMPLES OF SPECIAL CONCRETE CONTAINING RECYCLED PET GRANULES AS AGGREGATE

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ABSTRACT

This study aimed at inspecting microcracks in test specimens of special concrete, through neutron radiography tests. The thermal neutron flux used was extracted from the J-9 irradiation channel, placed in the thermal column of Argonauta/IEN/CNEN/RJ reactor, where a neutron radiographic system is installed. The test specimens inspected were molded in a cylindrical shape, with standard concrete and modified concrete where coarse sand was substituted by granules of recycled PET. They were submitted to compression in a SHIMADSU UH F 1000 press, causing microcraks. Then, slices of 50 μm thickness were obtained using an electrical saw. Gadolinium nitrate was used as contrast liquid in order to enhance the visualization of those microcracks. The Neutron Radiography technique proved to be appropriate for this kind of inspection, allowing to clearly visualizing the microcracks. Recycled PET granules met ABNT standards, and may be used in the construction of low income people houses, as structural concrete (25 % PP) or house floors (25% to 50% PEAD). The mechanical properties of compression and elasticity demonstrated for this special concrete, on Civil Engineering conventional tests, and by the neutron radiographic images obtained, showed that its use is viable even for civil construction in areas subject to seismic events.

1- INTRODUCTION

Many actions of man have damaged the ecosystem, relative to the increase in global temperature, pollution of the seas, rivers, by sewage and toxic waste, and the air, through the release of carbonic gas, sulfur and other gases, not less dangerous, into the atmosphere.

Plastics have also greatly contributed to the environmental disaster. Included in the species of plastics is polythylene terephthalate (PET), developed by the chemists Whinfrild and Dickson, in 1941, and vastly used in the manufacturing of bottles and packaging, is one of the largest polluters, as it is not biodegradable.

The objective of this study was to perform Non-Destructive Tests of samples using the technique of thermal neutron radiography [4] , relevant in testing samples of compressed cement blocks, prepared according to the ABNT Standards, where part of the coarse sand is substituted by plastic bottles granulates, aiming to, besides the recycling of this material: environment preservation, reduce the cost of civil construction; reduce the structural weight with this special mixture of concrete; determine the granulated quantity to be used to guarantee the resistance of concrete required by the referred standards; besides the verification of micro-cracks [1], formed in the very curing of the concrete or after submitting the samples to various compression loads.

To perform Neutron Radiography, a beam of thermal neutrons was extracted from channel J-9, located in the thermal column of the Argonauta/IEN/RJ reactor, where the neutron radiographic system is installed [3]. The inspected test specimens were composed of standard concrete and modified concrete, substituting the coarse sand for granules of recycled PET molded in a cylindrical shape. Neutron radiography tests of the blocks that were made from this special compressed concrete, prepared in accordance with ABNT Standards, should display the micro-cracks that formed as consequence of the compression load applied and the quantity and quality of PET granules used in the mixture.

2- MATERIALS AND METHODS

The special concrete used to manufacture the samples consisted in the substitution of one of the composites (coarse sand) in the structure of the reference concrete, for recycled PET granules (Polypropylene- PP and High Density Polyethylene - HDPE). Cylindrical test specimens, with 10.0 cm in diameter and 20.0 cm in height were manufactured , according to [8] (molding and curing of samples) to analyze the performance of the test specimens manufactured with the mixture in comparison with the reference concrete, as well as inspecting the internal structure, with relation to failures, such as: micro-cracks and voids resulting from the compression of the concrete itself, the cylinders used for the tests were chosen randomly from each lot of fifteen to determine mechanical resistance, and they were submitted to compression to the order of MPa, in a SHIMADSU UH F 1000 KN press, sufficient to provoke the micro-cracks. They were then cut with an electric saw, such that, from each specimen a slice from the central part of the cylinder, with 50.0 mm thickness was removed and subjected to superficial polishing.

In addition to the neutron radiography tests on the slices, previously bathed in a solution of gadolinium nitrate, a contrasting agent used to accentuate the visualization of micro-cracks [2], evaluations of the thermoplastic properties of the special concrete, such as resistance to rupture, high resistivity to compression and resistance to temperature [6], were performed and compared with the performance of the reference structural concrete.

To perform the Neutron Radiography, a beam of thermal neutrons (most probable energy of 30 meV) was extracted from the J-9 irradiation channel, located in the thermal column of the Argonauta/IEN/RJ reactor, where the neutron-graphic system is installed, making available a flux of 4.46 x 10^5 n/cm^2 s, when the power of the reactor is 340 W [5]. A gadolinium metal screen, with 50 µm thickness was used as neutron converter and a Kodak Industrex AA 400 sheet of film was used to register the image [7]. The time used for each neutron radiography exposure was 60 minutes [3]. After the developing process, the Neutron Radiographies, relative to the test specimen slices made with percentages of 25 % and 50 % of PP and HDPE and with reference concrete were digitized. The images were processed, using the Image Pro-Plus software, to allow measuring the widths of the micro-fissures.

3-RESULTS

Initially, the compression curves were obtained, in KN unit as a function of time, with reference to the mixtures of special concretes using granules with 25% PP in substitution of coarse sand and those that use granulated HDPE at 25% and 50%, as well as the concrete of reference. For the compression tests Standard [9] was observed. It deals with procedures involving compression tests on cylindrical specimens, generating the compression curves in function of time and deformation, presented in Figures 1 and 2, respectively. With these data, the module of elasticity relative to the special mixtures and to the concrete of reference was obtained, shown in Table 1.

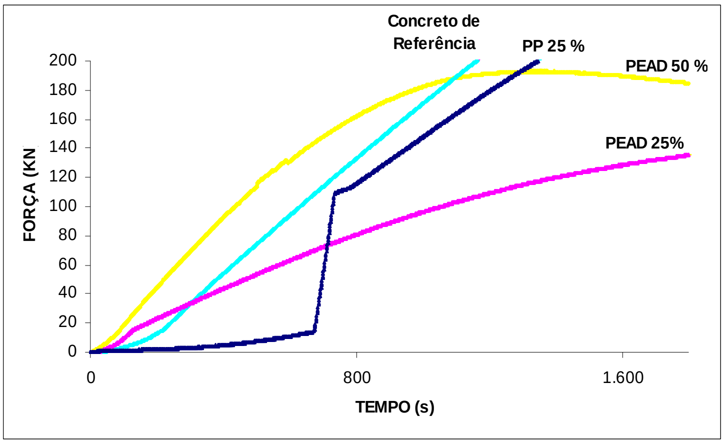

Figure 1. Temporal response of the different samples under compression stress of 100% of the rupture value.

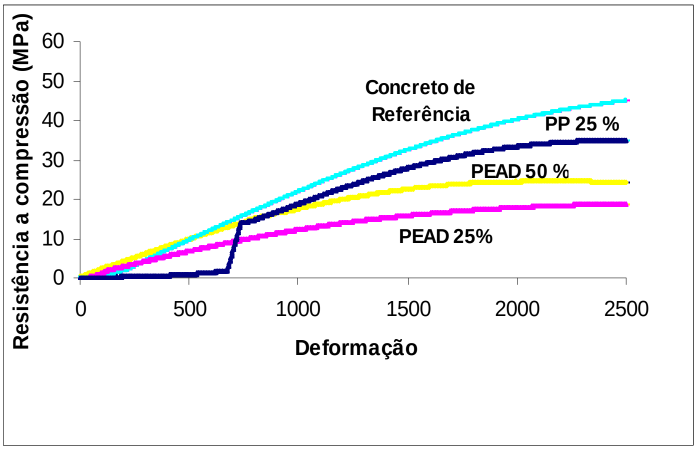

Figure 2. Resistance to compression, in function of the deformities of the test specimens, when submitted to compression equal to 100% of the rupture value.

Table 1: Parameters relative to compression equal to 100% of the Test Specimens.

Parameters relative to compression	25 % of PP	25 % of HDPE	50 % of HDPE	Reference Concrete
Time (s)	224.20	244.95	221.50	178.90
Force (kN)	259.33	134.27	170.54	373.24
Elasticity	18.08	6.14	9.65	21.33

Neutron radiography analysis consisted, initially, of selecting two of the more visible cracks in each image. Then, five measurements were taken of their respective widths, along the length of each micro-crack, using the Image Pro-Plus program. Additionally, other data were analyzed, such as: the width of the micro-crack in each position; smallest and largest width, average width; and associated standard deviation, the values of which are listed in the pictures to the right of each image. In each of the pictures one of the fissures stands out, in a way that illustrates the procedure previously described, as indicated by the arrow in Figure 3.

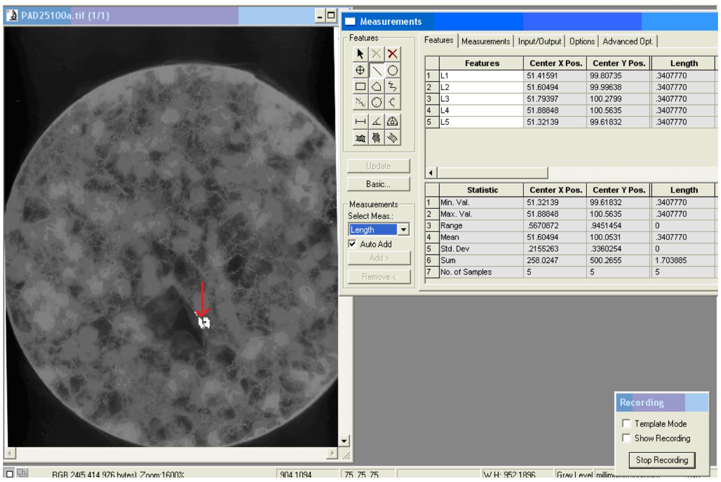

Figure 3: Neutron Radiography Image of test specimen with 25% of HDPE, after a compression of 100% of the rupture value (measured in mm).

Figure 4 shows the neutron radiography of the test specimen containing HDPE granules, in a 25% proportion, substituting coarse sand, after submitted to a compression of 100% of its rupture value, where ten measurements along different concurrent micro-cracks were taken, with these measurements divided equally in two distinct areas.

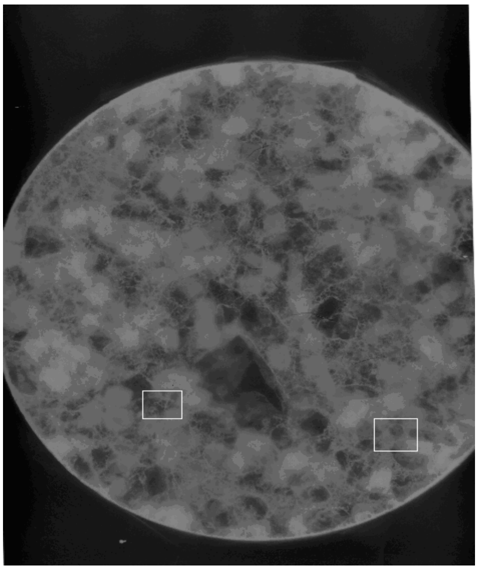

Figure 4: Neutron Radiography Image of the test specimen with 25% HDPE, after compression of 100% of the rupture value, indicating the areas where the measurements were taken.

Figure 5 indicates, in detail, the area marked down at the right side in figure 4, where five measurements were taken along two or more concurrent micro-cracks.

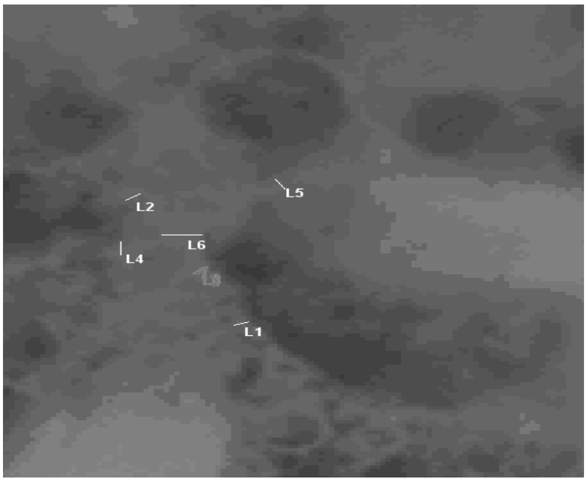

Figure 5: Enlarged image of the discriminated area in the previous figure, in detail, indicating where the five measurements were taken along the width of the fissures.

In Table 2, the widths of the micro-cracks in figure 5 are displayed in relation to each marked position. Additionally, the largest and smallest widths, average width and associated standard deviation are supplied, observing that the relative variation between the minimum and maximum widths was in the vicinity of 65%.

Table 2: The widths of micro-fissures displayed in Figure 5.

Microfissures	Widths (µm)
L_1	298
L_2	340
L_4	378
L_5	340
L_6	756
Minimum Width	298
Maximum Width	756
Average Width	422
Standard Deviation	93

4. CONCLUSIONS

It was verified that the number of micro-cracks was greater when the compression load increased, as was to be expected. The count of the existing micro-cracks, in each test specimen inspected, after submitted to different compression loads indicated this behavior.

For example, the sample composed of 25% of granulated PP, when exposed to a compression of 60% of the rupture value, registered 7 micro-cracks. When the load was increased to 80% of the rupture value, 16 micro-cracks were observed. For a compression load of 100% of the rupture value, there were 26 of them. Relative to the other samples, the neutron radiographies indicated that the behavior was similar, in other words, the number of micro-cracks increased when the compression load increased.

Relative to the average width of the micro-cracks, it was noted that they too widened with the increase of the compression load. Despite this, considering the widths of the micro-cracks, it was concluded that, after measuring the widths, along them, in five different positions, the relative variations between the minimum and maximum values of the micro-crack widths were small, as demonstrated in the neutron radiography images.

It was concluded that the test specimen containing 25% PP proved to be more resistant against a force of 135 kN, versus 83.57 kN of a test specimen containing 25% HDPE and 115.14 kN of that containing 50% HDPE. However, it was surpassed, by the Reference Concrete which resisted a force of 178 kN, when submitted to the same conditions.

In relation to the elasticity module of the test specimens, the one containing 25% PP attained an elasticity module of 18.33 MPa, versus 1.79 MPa of those containing 25% HDPE; 6.22 MPa of that containing 50% HDPE and 10.33 MPa of Reference Concrete, respectively, demonstrating to be more elastic, which is advantageous for its use in civil construction, in locations subject to seismic tremors, for example.

In relation to a compression of 80% of the rupture value applied to the test specimens, the one containing 25% PP (10.01 MPa), continued displaying a better performance, in terms of elasticity, relative to the sample containing 50% HDPE, the third in performance. However, the response to the compression of concrete with 25% PP had results very close to the Reference Concrete (10.33MPa), having the second best performance.

Analysis of the test specimens submitted to 100% of the rupture value demonstrated that the Reference Concrete had the best resistance (21.33MPa), followed by the test specimen composed of 25% granulated PP (18.08 MPa), and the test specimens composed of 25% HDPE and 50% HDPE having had much lower resistances: 6.14 MPa and 9.65 MPa, respectively.

In the face of this, it can be affirmed that the special concrete, containing 25% granulated PP, fits into the category of structural concrete, and all the others classified as concrete destined to other applications in Civil Engineering, such as, coatings and floors, according to standard [10].

It was also observed that the test specimens containing granulated HDPE, improved their performance, when the concentration was increased from 25% to 50%.

One advantage observed in the special concrete analyzed, relative to the Reference Concrete, was that they are lighter. Their use in civil projects would reduce the load on the area of construction.

The neutron radiography technique proved to be efficient, as concerns the visualization of micro-cracks, in the special concretes containing PP and HDPE and, therefore, with different concentrations of hydrogen in the samples tested.

In relation to the tests with compression loads on test specimens, the neutron radiography images has shown that the number of micro-cracks increased with the increase of the compression load.

In relation to the average width of the micro-cracks, it was observed that they became wider with the increase of compression load. The relative variation between the maximum and minimum values of micro-crack widths proved to be small, as seen in the neutron radiography images presented in Figures 3 and 4.

The widths of the micro-cracks tend to increase when one or more micro-cracks concur at one point, indicating a critical point where a rupture can occur.

The values obtained of the Edge Spread Function (ESF) demonstrate that the use of Neutron Radiography is appropriate for this type of inspection.

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