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Recycling of EPS: A new methodology for production of concrete impregnated with polystyrene (CIP)

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Abstract

A reduction in porosity, with a consequent reduction in permeability, could be an option for increasing the durability of concrete and preserving its surface characteristics. This research was conducted to identify a new material to be economical, efficient and easily applied, as part of Concrete Impregnated with Polystyrene (CIP), so as to reduce the permeability of pre-cast concrete surfaces, thereby, reducing the rate of degradation and increasing overall durability. Additional aims are: (a) using materials which do not affect the visual aspect of the concrete, so that the system can be used on monuments and other elements that are exposed to inclement weather; and (b) developing a new technology that makes use of recycled polymers. The results are promising and show a significant reduction in water permeability, reduction in porosity and, consequently, a reduction in the proliferation of fungus on the surface of the concrete treated with expanded polystyrene (EPS).

Keywords: Modified concrete; EPS; Superficial treatment

1. Introduction

Studies on the degradation of concrete exposed to the environment and to the action of the weather are currently of great importance for the civil engineering. The degradation depends on the permeability, type and geometric form of the concrete construction, as well as the type and aggressiveness of the process. In some cases local effects, like microclimates, can be decisive for the durability of the material and the structural elements [1]. Much of the knowledge on concrete deterioration comes from studies in the environment, because it is difficult to simulate the combination of the long duration conditions in laboratory. According to Ohama [2], in the recent years, technological innovation in the industry of civil construction has progressed considerately, and the research and development of multi-functional materials with high performance have grown in importance. In particular, this trend is marked by the new borders of civil construction, where applications of structures of concrete in critical situations becomes necessary, such as oceanic constructions and lunar platforms. Currently, the development of these materials should be ecologically sound and economically viable. The world-wide interest in the concrete-polymer composite has intensified since 1990, along with congresses and symposiums devoted to the subject area. According to Fowler [3], polymer-impregnated concrete was the first concrete-polymer composite to receive wide-spread attention with some commercial interest. Resistance to acid chemical attacks is one of the several distinguishing properties of this material. With the objective to prove efficiency of the concrete–polymer [4,5] and increase the durability of the concrete, several techniques have been used [6–8]. This research was conducted to identify a new methodology to be economical, efficient and easily applied, as part of a

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project on CIP (Concrete Impregnated with Polystyrene). The main objective is to apply a polymeric treatment that it is transparent, not introducing new visual aspects to the concrete, and in a complementary way, to reduce the permeability and increase the durability of concrete, contributing to the preservation of the surfaces against physical, chemical and biological attacks.

2. Experimental

2.1. Material

Aggregates and cement: The constitution of small aggregate (sand), larger aggregate and cement are indicated in Table 1.

Concrete samples: All the samples (∅5 × 10 cm and ∅10 × 20 cm) had been molded in concrete, in order to verify the real impregnation with polymer. The specifications are indicated in Table 2. The samples had been kept in a humid chamber (90%) for the cure, during a period of 7 days.

2.2. Methods

Polymer solution (*impregnation sample*): The impregnation sample was prepared by the dissolution of EPS in a mixture of acetone and cicloexane. Four tests of solubility had been carried through (Table 3).

The solution prepared with 70% of acetone and 30% of cicloexane was adopted in function of two factors: a) the mixture presents good solubility of the EPS and good transparency; and b) the solution contains minor volume of cicloexane (acetone is a solvent of commercial use and has inferior price in relation to cicloexane). Two solutions with distinct concentrations of EPS had been prepared: 5 and 10% of polymer mass in relation to the total mass of solvent mixture. The impregnation times adopted had been variable. Table 4 describes the prepared samples in function of the concentration of the polymer and the time of treatment.

Table 1
Classification of aggregates and cement

Data	Sand	Larger aggregate	Cement
Method	NBR 7217 NBR 7211 (EB 4)	NBR 7216 NBR 7211 (EB 4)	NBR 5733
Dimension (maximum, mm)	4.8	6.88	–
Classification	Zone 3	Number 1	CPV–ARI
Type	–	Calcareous	High strength

Table 2
Concrete molding data

Dimensions (cm)	Trace (kg/Kg)	Relation A/C (kg/Kg)
Concrete samples: NBR-5738		
∅5 × 10	1:6.0 (52% mortar and 48% Aggregate No 1)	0.60

Table 3
EPS solubility tests in the acetone/cicloexane mixtures

Test	EPS (%) (m/v)	Solvent mixture		Results
		Acetone (% volume)	Cicloexane (% volume)	
1°	10	90	10	Precipitation formation
2°	10	80	20	Not transparent
3°	10	70	30	Transparent
4°	10	60	40	Transparent

Table 4
Description of impregnation times and polymer concentrations

Sample	Polymer concentration (% m)	Impregnation time (min)
CT5ps30	5	30
CT5ps60	5	60
CT5ps120	5	120
CT10ps30	10	30
CT10ps60	10	60
CT10ps120	10	120

Water absorption: the kinetic of water absorption was carried out for treated (CT) and non-treated (CNT) samples, yielding individual curves of water absorption. The calculations were obtained by differencing masses. The curves obtained for entire CT and its respective individual treatments (four curves each for CT5ps30, CT5ps60, CT5ps120, CT10ps30, CT10ps60 and CT10ps120) and CNT (total of 28 curves) were statistically studied and transformed into average curves of water absorption.

Mercury intrusion analysis: The determination of the dimensions of the concrete pores was accomplished in the Autopore II 9220-V3.05 apparatus and by using Eq. (1) (Lowell, 1984):

$$d = \frac{-4\delta \cos\theta}{p} \tag{1}$$

where d is the superficial tension of the mercury; θ is the angle of contact of the mercury meniscus with the material; and p is pressure.

The curve obtained by the applied pressure (psi) as a function of the accumulated volume of mercury in the sample (ml/g) attests to the correct development of these analyses. This methodology also supplies the percentage of porosity contained in the sample. The determination of the dimensions of the concrete pores was accomplished in following samples: CNT 12A, CT5ps30, CT5ps60, CT5ps 120, CT 10ps 30, CT10ps60 and CT10ps120.

Analysis of the depth of penetration of polymer by UV–visible spectroscopy: A new methodology was developed

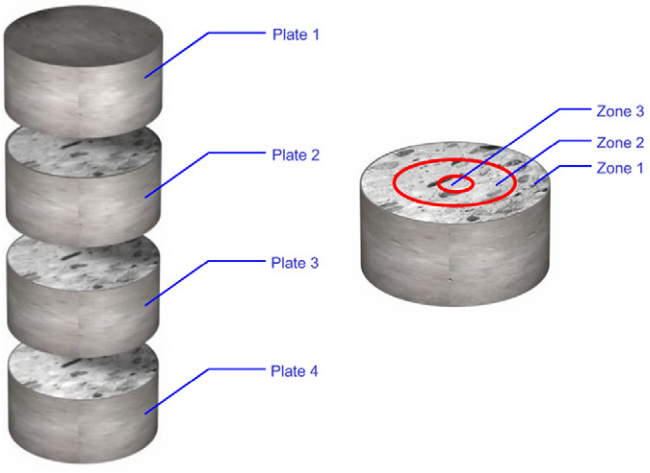

Fig. 1. Transversal and analyzed zones of concrete samples.

in order to verify the depth of polymer penetration in the treated concrete. Polystyrene has an aromatic ring in its structure, which presents a typical band of absorption in the region of 256 nm. The analyses of spectroscopy in the region of UV–visible were done in a HP 8453 spectrometer and the determination of the depth of penetration of the EPS was carried out in following samples: CT5ps120 and CT10ps120. The samples had been cut transversally, getting four distinct plates. The plates no. 1 (top) and no. 4 (base) were rejected. The plates no. 2 and no. 3 were delimited in three radial zones (1, 2 and 3: external zone, intermediate zone and internal zone, respectively), as presented in Fig. 1.

The fragments of the radial zones were removed of concrete and dried at 130 °C during 24 h. After cooling in a dissicator (30 °C), the mortar of each zone was triturated and sprayed. The powder was classified in a sieve no. 70 (ABNT/ASTM) with opening of 212 μm. The samples (ca 3.0 g) were dissolved in 10 ml of THF and agitated in a metabolic bath for 48 h. The supernatant solutions were collected and analyzed in the spectrometer. The quantification was carried through using a calibration curve prepared from EPS standards solutions.

Scanning electron microscopy (SEM): was performed by using and Jeol model JSM 5510-EDS Electron microscope Thermo (with spectrometer of dispersive energy). BEC electrons and secondary electrons had been carried through micrographs. The fragments of mortar (Fig. 2) had been coated with carbon and the assays were carried out according to specifications of the equipment.

3. Results and discussion

During the study, concrete test cylinders with a single water/cement ratio were used, so as to maintain the same porosity index for all test samples. EPS was employed like a modifier agent since this polymer is widely used in industry, principally in the packaging sector. This material presents a number of significant features, including: a low water absorption coefficient; a slow aging process; pathogenic innocuousness (i.e. it does not possess substrata for the proliferation of animals and/or microorganisms); among others. The efficiency of the polymeric treatment was evaluated first by verifying the reduction of the water absorption in the treated samples, when immersed in pure water. The analysis of the average curves of water absorption in the graph of Fig. 3 indicates that the kinetic of water absorption is great in the first minutes of immersion, stabilizing in the long of the time, with trend to the total saturation of the samples. It was also verified that the initial speed of water absorption for the CT was lesser than that presented for the CNT and, in general it is evident that the total water absorption of CT is less than that of CNT.

The second test employed in order to verify the reduction of porosity was mercury intrusion analysis. The curve

Fig. 2. Fragments of concrete samples used to SEM analyses.

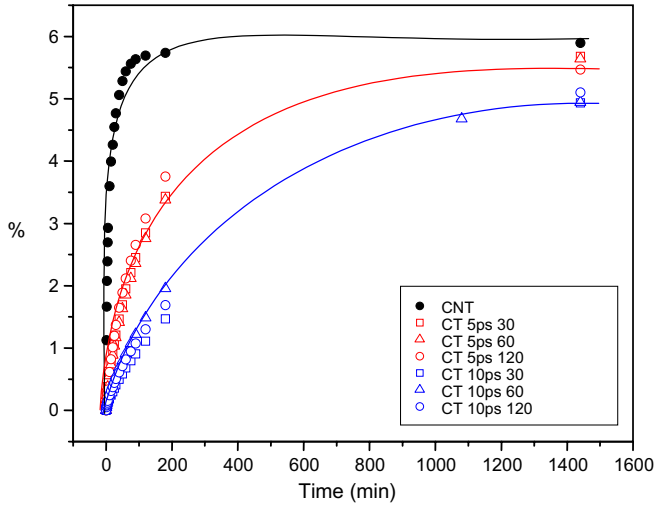

Fig. 3. Kinetics of water absorption (middle curves).

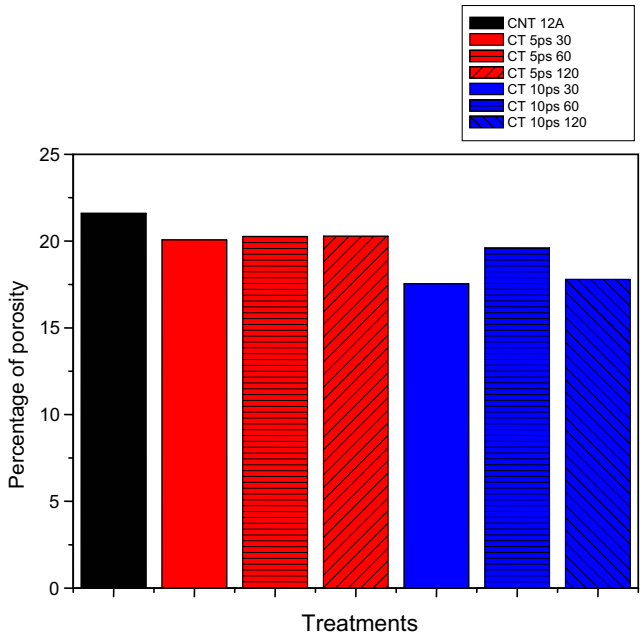

Fig. 4. Analysis of porosity for the treated and untreated samples.

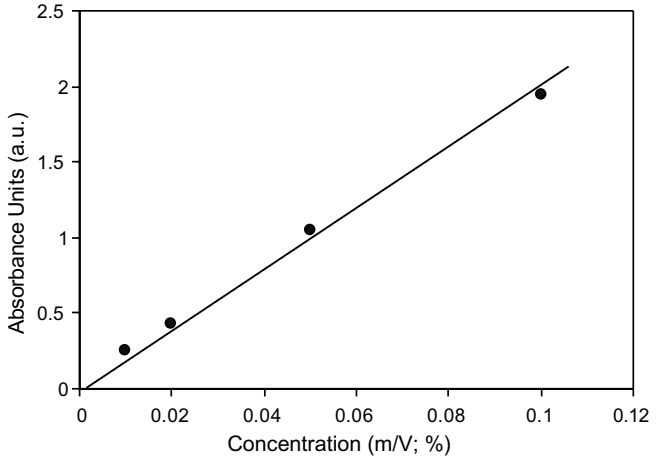

Fig. 5. Calibration curve from UV analysis.

Table 5
Percentages of EPS in the zones of concrete samples

Sample	Absorbance (a.u.)	Concentration of EPS in the sample (% m/m)
CT 5ps 120 zone 1	4.15	0.216
CT 5ps 120 zone 2	1.93	0.099
CT 5ps 120 zone 3	1.46	0.075
CT 10ps 120 zone 1	3.13	0.162
CT 10ps 120 zone 2	0.66	0.032
CT 10ps 120 zone 3	0.51	0.024

obtained by the applied pressure (psi) as a function of the accumulated volume of mercury in the sample (ml/g) attests to the correct development of these analyses. This methodology also supplies the percentage of porosity contained in the sample. The values of the porosity percentages are represented in Fig. 4. The analysis of the figure demonstrates that there was a reduction of the porosity of CT when compared with that of CNT. The deposition of polymer in the porous of the concrete samples is responsible for the reduction observed.

The reduction of the porosity was larger in samples impregnated with solution of 10% of EPS and this result is in accordance with the results obtained by the water absorption experiments. It can be concluded that the impregnation performed with 10% of EPS is more efficient than realized with 5% of EPS. It was verified that the treatments do not provoke a complete waterproofing of the concrete. This factor becomes important, because the vaporizable water can be extracted from the concrete (in vapor form), in cases of rise of the temperature. Fig. 4 shows that the time of immersion in the solution (30, 60 or 120 min) does not influence the efficiency of the treatment for same concentrations of EPS (5 or 10% of EPS).

The assays in the region of the ultraviolet show the presence of different polymer concentrations in the different analyzed zones of the samples. Fig. 5 shows the linear calibration curve obtained from the solutions EPS standard, and that it was employed in the calculations of the polymer concentrations in the interior of the material. Table 5 shows the values of the percentage of EPS in each radial zone.

Considering that the CT has 25 mm of ray (∅50 mm), each radial zone has, approximately, 8.3 mm of radial extension. The calculations of penetration depth indicate a bigger penetration in zone 1, or either, the superficial layer. However, concentrations of EPS were also verified in zones 2 and 3, which indicates that the impregnation reached all the extension of the CTs. The penetration was more efficient in the impregnation carried through with 5% of EPS. Fig. 6 shows the typical micrographs for a sample not treated, while the micrographs presented in Fig. 7 have been obtained from the CT10ps60 sample.

Fig. 6a shows the cement mortar. Figs. 6b and c show a silica particle (sand) embedded within the cement mortar. Figs. 6d–f show micro-trinkets in the cement mortar.

Figs. 7a–g show the behavior of the EPS films on the cement mortar. In these micrographs it is noticed that the EPS film recovers the lateral surface, penetrating for the interior of the mortar. In the micrograph 7(b) it is noticed that the EPS solution penetrated in the micro-fissure and appears more internally, in the radial direction of the sample. In the micrograph 7(h) the EPS deposition is visible in form of particles. In the micrograph 7(i) the EPS deposition is noticeable in the form of lamellas. Micrographs 7(j), 7(k) and 7(l) show that the EPS film recovers the superior surface of the sample. In the micrographs 7(k) and 7(l) it is possible to verify that the thickness of the EPS film is approximately 5 μm.

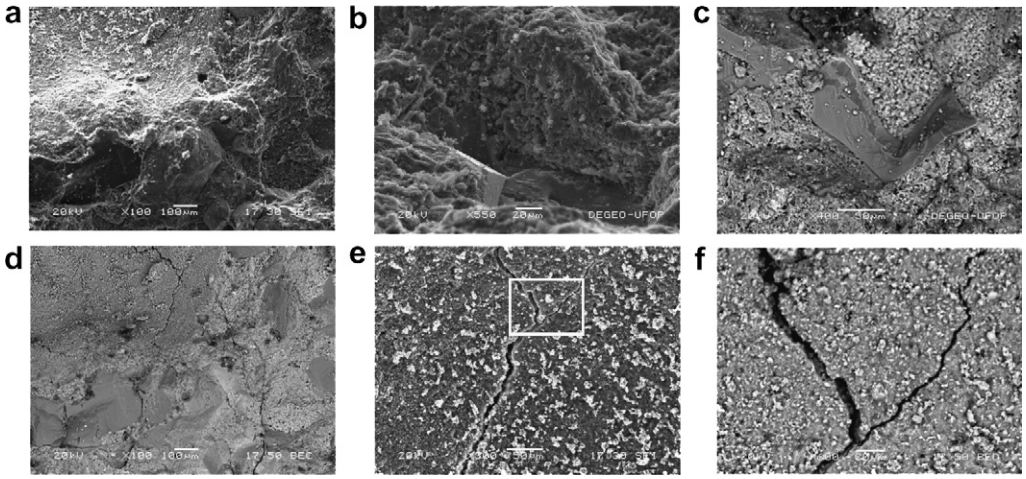

Fig. 6. SEM microphotographs of CNT 12A.

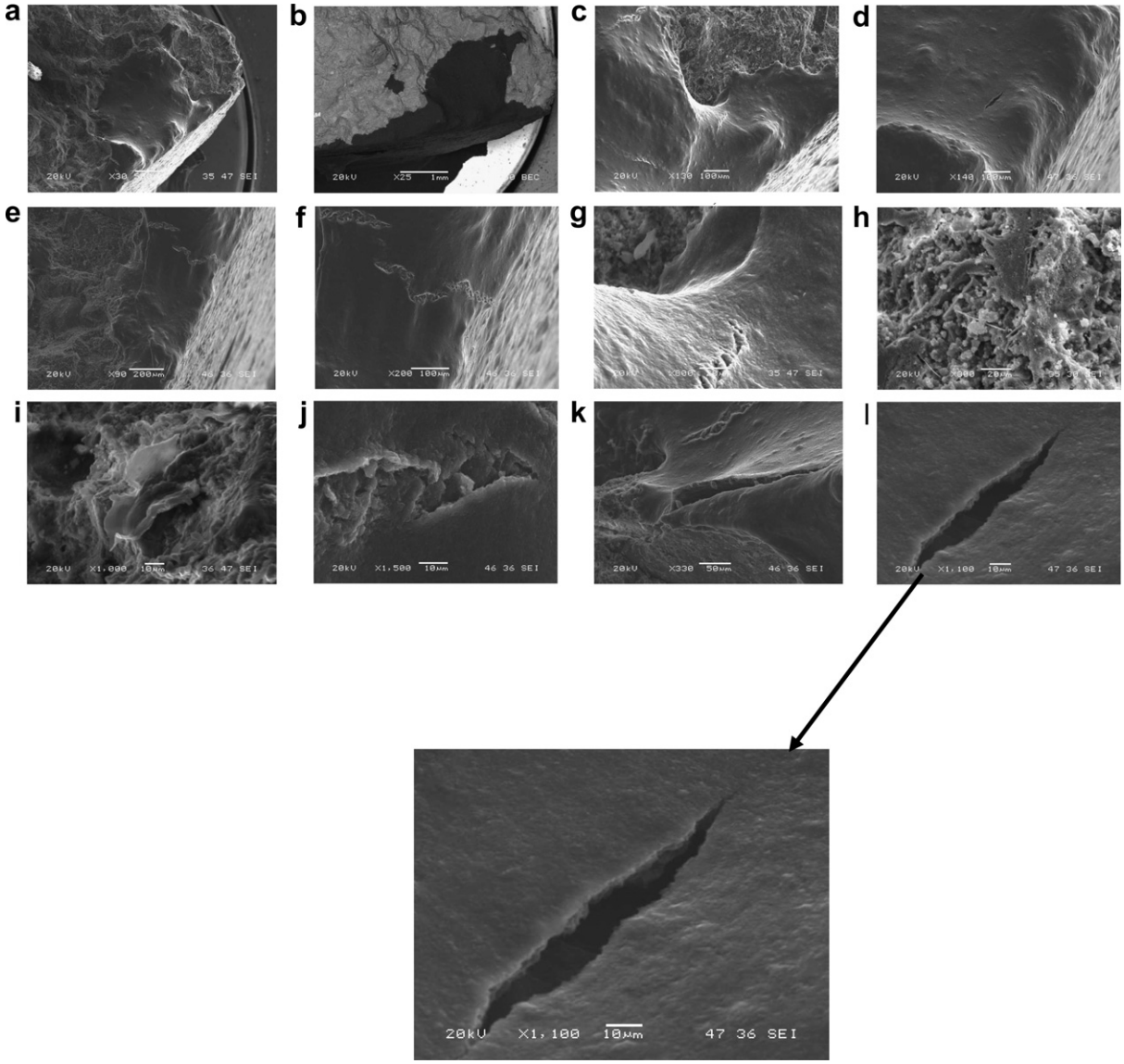

Fig. 7. SEM microphotographs of CT 10ps 60.

4. Conclusions

Concrete impregnated with recycled EPS, compared with the process conventional CIP, is simpler, involves little technological resources and consumes less energy. The results of the efficiency of the impregnation with recycled EPS for water absorption demonstrated positive effects for the treated samples and that the impregnation performed with 10% of EPS is more efficient than realized with 5% of EPS. The depth of penetration of the impregnation was satisfactory for both treatments (5 and 10% of EPS). However, the penetration was more efficient using it solution 5% of EPS attributed to the lesser viscosity of this solution.

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