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Research Article

The use of Waste Materials in Utility Poles, Crossarms, Paver, and Reef Balls Concrete Structures: Advantages and Care

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Industrial residues such as sludge from water treatment plants (Swtp) from centrifuged method; electrical porcelain residues (Pw); silica fume (Sf_1 and Sf_2); tire-rubber waste were evaluated in order to be used in concrete structures of electrical energy and environmental sectors, such as utility poles, crossarms, and reef balls technology. The results showed the necessity for evaluating different recycling concentrations in concrete, concomitantly to physicochemical tests allowing to diagnose natural and accelerated aging.

1. Introduction

One of the most recent challenges of modern society is the research of new alternatives of environmentally responsible technologies for the final disposal of residues generated by industrial, domestic, and commercial sectors.

Governmental entities and international communities have been acting together to promote environment protection and pollution reduction through environmental laws concerning well-stablished residue limits and intensive fiscalization.

These actions result in viable application to diverse residues, which can be converted in useful raw materials. An example is the silica fume byproducts, which were initially considered industrial residues, but nowadays are largely used in civil construction due to its greater pozzolanic reaction capacity compared to most of hydraulic cements. Many other different byproducts can be used, like furnace slag, metakaolin, tire-rubber residues, and others [1–10].

This paper emphasizes the importance of the study of recycling conditions and/or residues disposal in civil construction, by using engineering analyses and science materials evaluation. Thus, four different residues (silica fume, sludge from water treatment plant, electrical insulator porcelain and tire-rubber wastes) were tested in concrete core samples; in reef balls and concrete blocks technology for fishing habitat and for creating biomass (animal or plant life); in typical concrete structures of the electrical energy sector, such as crossarms, utility poles, and dams.

2. Materials and Methods

All used materials were submitted to physicochemical analyses and were pretreated prior to concrete samples casting.

2.1. Cement Materials. Filler-modified and sulfate-resistant (type CPII-F 32), high-early strength (type CPV-ARI RS), pozzolan-modified concrete (type CPII-Z 32), and sulfate-resistant pozzolanic (type CPIV-32 RS) Portland cements were used. Each of these was used in order to meet local standards and extend the durability of the structure in aggressive environments such as seawater and coastal regions.

2.2. Artificial and Natural Fine and Coarse Aggregates. Fine and coarse aggregates consisted of washed natural medium sand and crushed basalt stone with maximum nominal size of 4.8 and 19 mm, respectively. They were tested according to the recommendations of Brazilian standards. Synthetic aggregates from waste samples were crushed to both fine and coarse nominal size and also tested.

2.2.1. Sludge from Water Treatment Plant Swtp. The search for economically and environmentally advantageous solutions for the treatment and sludge disposal of WTP remains a challenge, especially for developing countries, living in severe economic constraints and where health problems require emergency solutions. Monthly, approximately 4,000 tons of WTP sludge dry matters are produced throughout the state of Paraná, southern Brazil. In the city of Curitiba (population of 1.9 million people, approximately), capital of Paraná, the potable water supply is provided by Iguaçu, Tarumã, Irai, and Passaúna WTPs, which account for over 50% of all the production of sludge in the state. Passaúna WTP produces, by centrifugation method, about 360 tons/month of sludge. It is the WTP object of study in this work. For this research, collections of hebdomadaires centrifuged sludge were conducted during two months of the year. Afterwards, the final content was homogenized, oven-dried at 110°C, and disaggregated [3].

2.2.2. Electrical Porcelain Waste (Pw). Artificial aggregates of medium and high voltage electrical porcelain waste were obtained by grinding the product in a hammer mill type. The crushed material was classified into different particle sizes after grinding. The fine particulate portion was used to study its potential alkali reactivity by mortar-bar method [11] and the coarse one was separated in four quotas, thus considered: glazed porcelain (as obtained and grounded) with sulfur cement phases (cement waste from the junction of the porcelain to the metallic part of the insulator); glazed porcelain without sulfur; porcelain with sulfur and without its surface glaze and plain porcelain material [12]. The separation of these parts from the raw material is related to the investigation of their potential contributions to the alkali reactivity in concrete.

2.2.3. Silica Fume (Sf). Condensed silica fume (Sf) is a byproduct usually originated from induction arc furnaces in the silicon metal or ferrosilicon alloy industrial processes, where the reduction of quartz to silicon at temperatures up to 2000°C produces SiO vapors, which oxidize and condense in the low-temperature zone to tiny spherical particles consisting of amorphous or noncrystalline silica. The amount of SiO_2 present in this pozzolan is, invariably, close to 80% and is directly related to the existent production process [1].

Currently, Sf was widely used as a supplementary cement material to enhance the strength and durability of concrete. In this research, Sf was also used in order to lower the pH of the resulting concrete to facilitate settlement of marine organisms.

2.2.4. Waste Rubber from Retreading Tires (Tw). The use of rubber waste in concrete is important from the ecological point of view. Population growth and increased use of disposable materials such as packaging, tires, and PET bottles, among others, have caused the accumulation of large quantities of solid waste, which are limiting the capacity of landfills. In 2005, the city of Rio de Janeiro, southwest of Brazil, tires and rubber products accounted for about 0.5% of urban waste and in São Paulo, this quantity is near 3% [13].

Rubber band scroll waste from retreading tires was used without any pretreatment. The composition of the predominant residue was characterized as styrene butadiene rubber by infrared Fourier transform. The average particle size distribution was 4.8 mm.

2.3. Dosage. Ideal concrete mix proportions (by mass for a concrete mixture (w/w)) are listed in Table 1. For each concrete mix, a reference concrete (RC), without addition, was also produced to serve as comparison. To the concrete mixture Tw, two other ratios were studied as a 5 to 15% (w/w) of rubber addition. However, only the 10% (w/w) Tw was considered due to its performance.

2.4. Specimens Casting. For each mixture and material, different types of specimens were casted:

(1) (100 × 200) mm cylindrical concrete specimens for determining compressive and flexural strength and elastic modulus at 3, 14, and 28 days after casting [14, 15];

(2) (150 × 300) mm cylindrical concrete specimens for permeability testing and determining specific density, absorption, and porosity of concrete after 28 days of curing;

(3) (300 × 100) mm cylindrical concrete plates for abrasion resistance of concrete according to ASTM C1138 [16].

Also, six concrete utility poles and crossarms were casted with Pw_1, RC, and Sf_1 and tested for flexural strength after 28 days of concrete curing and also for electrical properties and visual surface inspection during natural ambient exposition. The poles were double-tee cross-section shaped, B type, 11 m long, and with 300 daN of nominal strength, complying with a Brazilian standard [17].

2.5. Physicochemical Characterization of Samples. Cement and natural and artificial aggregates were characterized by physicochemical analyses, previously to their use in the mixtures. Elemental chemical composition and chemical phases were obtained from energy dispersive spectroscopy (EDS), X-ray fluorescence (XRF), and X-ray diffractometry (XRD) methods. PW 2400 Philips fluorescence equipment was used to determine the elemental chemical composition. XRD of specimens were measured using a Philips (X'Pert MPD) diffractometer with Cu-Kα radiation operating at 40 kV and 40 mA. The diffraction patterns were used to identify the structural phases of the specimens. The micrography analyses of fractured concrete surfaces were done using an XL30

Table 1: Mix ideal proportions (by mass for a concrete mixture) and properties of fresh concrete with admixtures.

Mixture/sample	Materials code					
	Swtp	Pw	Pw_1*	Sf_1**	Sf_2***	Tw
Cement	1	1	1	1	1	1
Sludge (water treatment plant): Swtp (%)	**8**	0	0	0	0	0
Porcelain waste (Pw) (%)	0	**50**	**25**	0	0	0
Silica fume (Sf) (%)	0	0	0	**8**	**15**	0
Tire-rubber waste (Tw) (%)	0	0	0	0	0	**10**
Fine aggregate (natural sand)	1.860	1	347	1.837	1.541	1.820
Fine aggregate (artificial)	0.16	1	347	0	0	0
Natural coarse aggregate (19 mm)	2.980	1.497	512	3.306	1.541	2.620
Artificial coarse aggregate (19 mm)	0	1.497	512	0	0	0
Water/cementitious materials ratio	0.51	0.50	0.5	0.46	0.41	0.50
Superplasticizer	0	0	0	1	0.3	0
Slump (mm)	18	25	25	50	50	14
Unit weight (kg/m^3)	2,247	2,219	2,219	2,357	—	2,220
Air content (%)	3.5	0.5	0.5	—	—	2.4

Notes: Portland cement types: filler modified (CPII-F 32); *high-early strength (CPV-ARI RS); **pozzolan modified (CPII-Z 32); ***sulfate resistant (CPIV-32 RS).

model Philips Scanning Electron Microscope (SEM). Gold was applied to the surfaces by sputtering.

Potential alkali reactivity of cement and aggregate was evaluated according to ASTM specification [11].

Nondestructive method, such as electrical half-cell potential with copper-copper sulfate reference electrode, CSE, was used to verify the service life performance of reinforcing steel in concrete in a 3.4% w/w chloride solution and of concrete utility poles submitted to natural aging condition, according to the literature [18–20]. The metallic rebar of the poles was connected as the working electrode. An average potential from thirty measurements was obtained from the testing at both sides of the bottom region of poles, just above the embedment line.

2.6. Environmental Corrosion Stations (ECSs). A marine ECS was built at Caueira beach, in Itaporanga D'Ajuda district, near Aracaju, SE, in northeastern Brazil. It was located at about 2 m above the high tide line of the Atlantic Ocean [19]. Utility poles, crossarms, and concrete material core samples casted with Sf_1 were submitted to natural aging for approximately 500 days. Also, an urban ECS was built at Curitiba, PR, southern Brazil, to test Pw_1 concrete casted in utility poles and crossarms.

Sf_2 concrete admixtures were cast as thick plates ($20 \times 270 \times 300$) mm to be previously tested in a marine ECS located at 17 m depth, following a perpendicular line of Praia de Leste beach coast until 30 m deep ($25^\circ 30'$ S). Sample plates were periodically tested by flexural strength and by microstructure concrete surface investigated by Scanning Electron Microscope (SEM) and energy dispersive system analyses (EDS). Afterwards, this composition was cast as reef balls and 1 m^3 concrete blocks technology forms. Both of them were tested in a marine shallow shelf at approximately 30 m of depth for approximately five years [21].

The pH of this resultant concrete mix lowered from 12.3 to 11.4. Concrete with this pH generally needs to age in the ocean for 3–6 months before the pH in the surface region approaches the 8.3 pH of seawater and favour marine organism's settlement [22].

3. Results and Discussion

The physicochemical analyses of cements were in accordance to manufacturer specifications and Brazilian standards.

3.1. Concrete Admixtures

3.1.1. Swtp. The major chemical components obtained by XRF tests from the sludge sample were: 16.55% of silica, 13.07% of alumina, 4.15% of ferrite, 49.79% of volatile materials, and 16.44% of humidity. In natura water treatment sludge was identified as kaolinitic group by XRD as shown in Figure 1.

The result of average compressive strength of 8% (w/w) Swtp concretes at 28 days of curing was 27.6 MPa, being superior to setup limit used for concrete structures as poles for electric energy distribution network. The average flexural strength at 28 days was 3.0 MPa, which is in accordance to the literature data for similar admixtures [1, 20]. Increasing the concentration of sludge from water treatment plant to 10% w/w in concrete, the microstructures presented large porosity, poor compressive strength lower than 15 MPa and the slump test results was 0 mm. This turned the concrete workability to be nonsatisfactory.

The average permeability resulted from 8% (w/w) Swtp was 0.9×10^{-10} cm/s. As the permeability of concrete depends on mix proportions, compaction, curing, and microcracks in the core, and also there is a close relationship between the strength and its durability, the results indicated a good

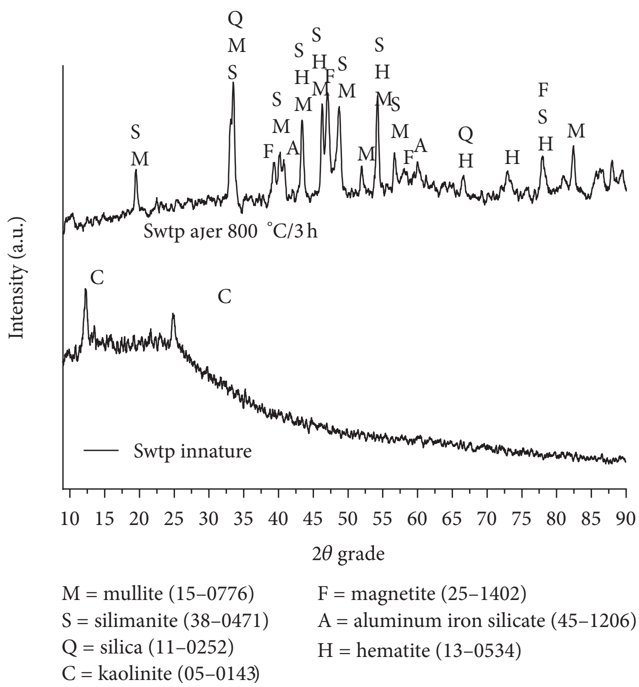

Figure 1: XRD pattern of Swtp phases: “in natura” and after 3 h/800°C treatment.

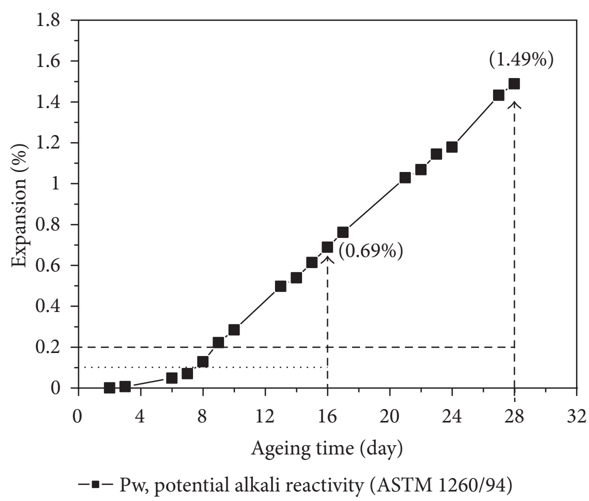

Figure 2: Expansion of Pw admixture mortar sample.

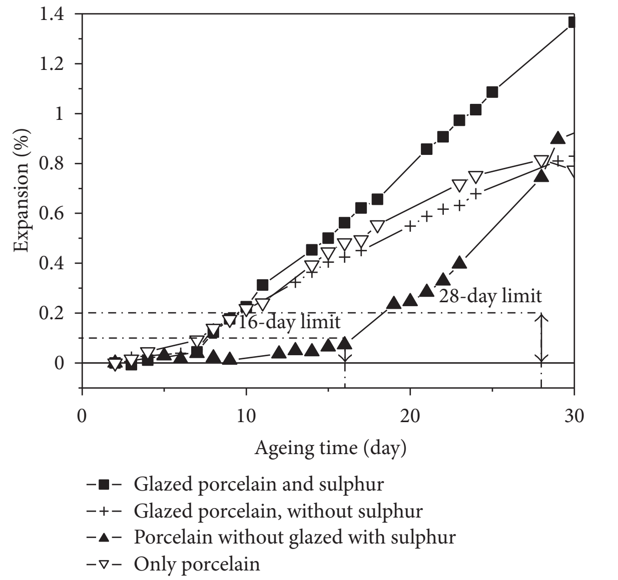

Figure 3: Expansion of mortar admixtures containing porcelain insulator waste.

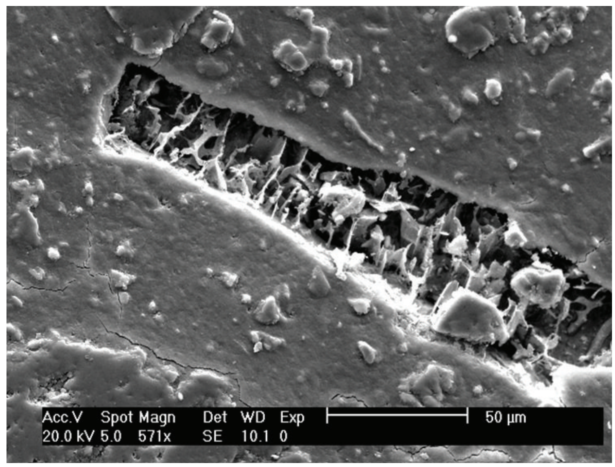

Figure 4: SEM of sulphur cement phase micrography in porcelain concrete admixtures.

performance mixture resultant from kaolinitic group and cement phases.

3.1.2. Pw. Porcelain waste concrete admixture resulted potentially in alkali reactive with CPII-F 32 cement type, as shown in Figure 2.

The expansion tests resultant from different picked-up porcelain material parts and CPII-F 32 cement type showed that porcelain with glazed and sulphur cement phases (as obtained and grounded) is the most damaging to the concrete materials, followed by porcelain parts, porcelain material with glazed but without sulphur cement phase parts, followed by porcelain materials without glazed and with sulphur cement phases. This latest phase presented the lower expansion results, as demonstrated in Figure 3. Sulphur cement phase did not demonstrate larger expansion in its first 16 days agied according to ASTM tests [11]. From 16 to 28 ageing time days, the mortar samples demonstrated positive alkali reaction with an exponential slope expansion results passing to noninnocuous limit, as viewed in Figure 3. Besides, this Pw reinforcing steel samples with sulphur cement phase presented too bulk defects that are capable to enlarge cracking probability risk, as shown in Figure 4, by SEM micrography images.

Pw compressive strength resulted in 30.4 MPa at 28 days of curing, being classified as restrained resistance [14].

Because of the reduced lifespan resulted from the potential reactivity essay with porcelain materials and CPII-F 32

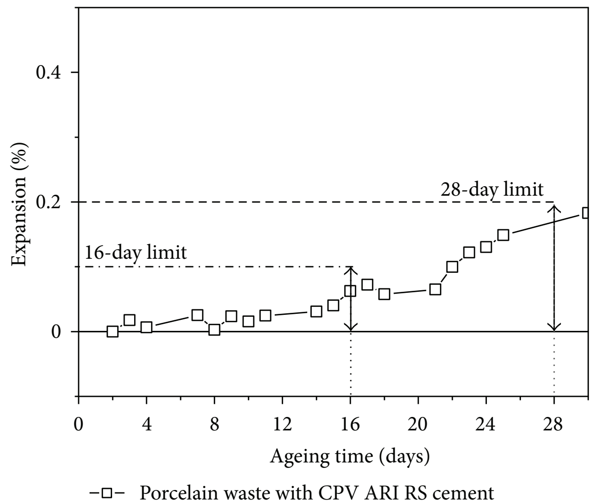

FIGURE 5: Expansion results of Pw mortar casted with high-early strength sulfate-resistant cement (CPV ARI-RS).

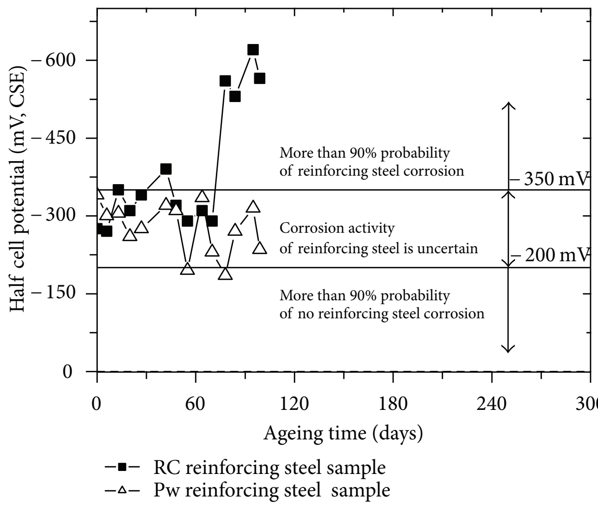

FIGURE 7: Electrical half-cell potential results of RC and Pw reinforcing steel in concrete as a function of aging time in 3.4% NaCl solution.

FIGURE 6: The image shows 3 utility poles and crossarms. Two of them were cast with RC and Pw admixtures (right positions). In detail, is illustrated a CSE system used to measure the seasonal reinforced steel corrosion potential performance.

cement type, the Pw mortar sample was in a second time cast with special sulfate-resistant cement. Portland high-early strength cement (CPV-ARI RS) reduced its expansion limit in 16- and 28-day ageing test to the recommended values (innocuous consideration) as shown in Figure 5. Nevertheless, additional care should be taken because of a positive slope tendence to high delay expansion values.

In Figure 6 is showed an image of utility poles and crossarms under natural ageing in an ECS urban environment located in Curitiba, PR, Brazil. In the right position is a 25% w/w concrete Pw admixture tested with RC utility poles located at the left. In detail is viewed the electrical half-cell potential electrode system for nondestructive test. Even so the utility poles and crossarms were casted using specially cement type (CPV-ARI RS) with 25% w/w porcelain waste in concrete to reduce the probability risk of alkali expansion presented by the 50% w/w Pw one. The rupture of the RC and Pw utility poles by flexural strength was 360 and 440 daN, respectively, being in accordance with the Brazilian specification [15].

Electrical half-cell potential measured during these first five months on urban ambient ECS condition indicated no corrosion activity for RC and Pw structures. As previously reported, both structures are exposed at low aggressive atmosphere.

The electrical results made in RC and Pw reinforcing steel in concrete partially immersed in 3.4% w/w NaCl aqueous solution as function of ageing time are showed in Figure 7. As viewed, Pw reinforcing steel material has been presenting lower corrosion activity performance than RC reinforcing steel.

3.1.3. Sf_1 and Sf_2 Concrete Admixtures. Silica fume admixtures in concrete have been presenting better lifespan performance of concrete structure submitted to salt aggressive environment, as viewed in Figure 8, by electrical half-cell potential rebar measurement results.

Tests made in the reinforcing steel in concrete submitted partially immersed in a 3.4% NaCl aqueous solution have been indicating that Sf_1 samples are having a double lifespan in comparison with RC reinforcing steel, both of them tested at the same laboratory salt aggressive condition.

Visual inspection on Sf_1 and RC utility poles submitted to northeast Brazilian Caueira beach ECS demonstrated that RC structures have been presenting, too, rebar corrosion surfaces with consequently concrete microcracks. Any corrosion

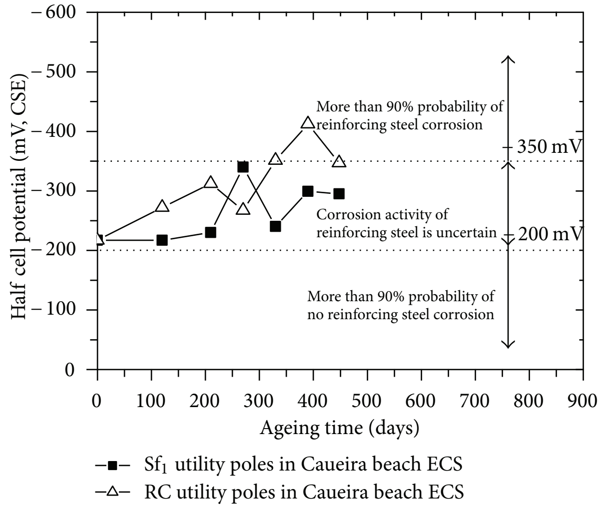

FIGURE 8: Electrical half-cell potential results of RC and Sf_1 utility poles submitted to the natural aging for 480 days in northeast Brazilian Caueira beach ECS.

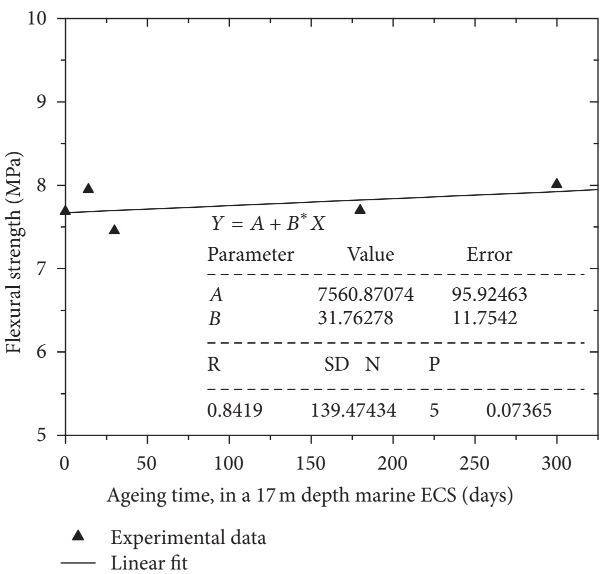

FIGURE 9: Flexural strength of Sf_2 concrete admixture in terms of ageing time in a 17 m depth marine ECS.

FIGURE 10: Sf_2 concrete admixture and other materials thick plates tested in marine ECS located at 17 m depth, at Praia de Leste beach.

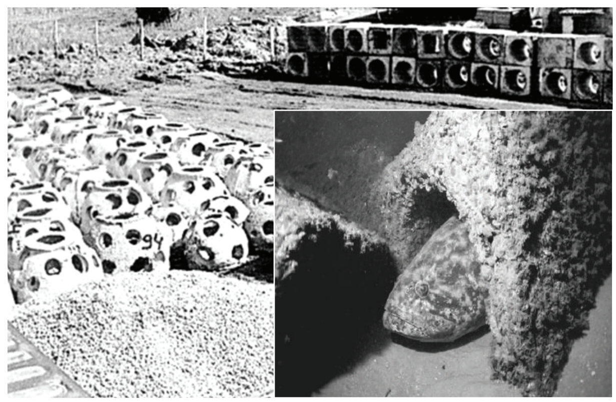

FIGURE 11: Sf_2 reef balls technology and block forms of Sf_1 concrete mixture before installation in a marine shallow shelf at Parana state, southern Brazil. The detail shows nowaday jewfish in the block habitat.

surface defects have been viewed on Sf_1 concrete structures exposed at same environmental condition.

Besides the increase of lifespan concrete structures, the silica fume material causes economical positive effects when compared to a reference concrete. The economical differences lowered from 34% in 28 curing days to 24% in 90 curing days, at the same compressive strength results. This phenomenon had been attributed to pozzolan-modified Portland (CPII-Z 32) cement used to cast both samples [5].

Sf_2 mixes casted in thick plates and tested previously in a 17 m depth marine ECS demonstrated good lifespan performance by flexural strength results in the function of ageing time, as well as in terms of biological marine material habitat, as shown in Figures 9 and 10, respectively.

Sf_2 cast as reef balls technology and 1 m^3 blocks, as presented in Figure 11, has showed also lifespan good performance in the last 10 years old in a Parana marine shallow shelf at southern Brazil. In Figure 11 is also shown in detail a nowaday jewfish habitat [21].

3.1.4. Tw. Tw concretes cast with up to 20% w/w were tested to be used as paver and curb pieces and as repair materials for hydraulic concrete structures of hydroelectric power plants [4]. Until 15% w/w Tw concrete admixtures, the results showed no serious decreasing in fresh and cured concrete properties relative to RC samples, such as the slump test and compressive strength results. Regarding the 10% w/w Tw concrete admixture, its behaviour was even better than the 15% one.

In Figure 12 are presented paver block manufactured with 10% w/w Tw admixture and, in detail, the surface of paver casted with 20% w/w Tw concrete admixture. As shown,

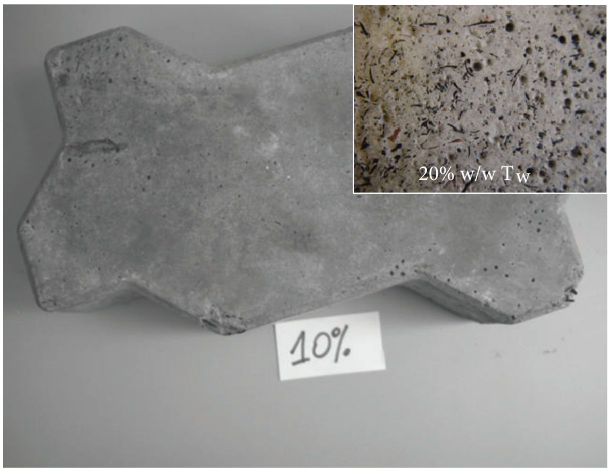

Figure 12: Paver block with 10% w/w Tw concrete mixture. The paver surface view of 20% w/w Tw concrete mixture is shown in detail.

the 20% w/w Tw composition presents larger quantities of rubber-tired concrete surface efflorescence and porous defect, causing poor visual market aspect and lower resistance.

Compressive strength tests in 10% w/w Tw resulted in 20 MPa, presenting at the same time economic benefits and environmental advantages for materials repair in hydraulic structures [4–21].

Abrasion-erosion test results of Tw samples showed that the wearing was 75% lower than RC samples, meaning that they have better performance. In Figure 13 is showed a sample photograph and the wearing surface plot results after testing with three different repair materials concentration, such as: 5% w/w Tw; 10% w/w Tw; 15% w/w Tw. In all cases Tw materials wearing results are lower than the RC substrate.

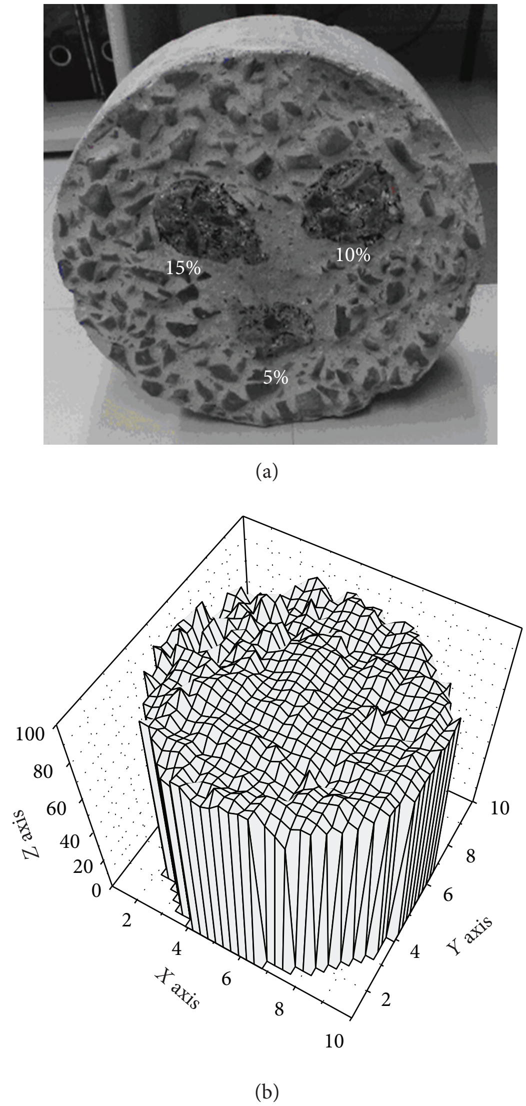

Figure 13: Abrasion-erosion Tw samples image tested and the schematic wearing surface plot results. The wearing surface resulted from three different repair materials concentration: 5% w/w Tw; 10% w/w Tw; 15% w/w Tw.

4. Conclusion

The Swtp obtained by centrifuged method can be used as concrete admixture up to 10%. The best mechanical behaviour was achieved with 8% w/w Swtp concrete mixture, indicating that it can be used in concrete utility poles and crossarms.

Pw concrete admixture cast with CPII-F 32 cement type had its lifespan reduced due to the large potential reactivity values in all partial chemical phases analysed. These alkali aggregate reactions were reduced after the change of the cement type to a high-early strength and sulfate-resistant one (CPV-ARI RS). This composition could be cast in utility poles and crossarms applied in electrical distribution energy until 25% w/w porcelain waste. Even so is strongly recommended laboratory tests previously cast it in civil structures.

Sf_1 and Sf_2 silica fume mixtures cast as utility poles and crossarms, and reef balls technology and cubic concrete blocks showed good resistance performance when used in high salt Brazilian northeast coastal areas and into 17 m depth marine environment, respectively. Poles, crossarms, reef balls structures and cubic concrete blocks with silica fume admixtures (Sf_1 and Sf_2) showed good chemical resistance performance in high salt Brazilian Northeast coastal areas and, into 17 m depth marine environment, during 500 days and approximately 5 years of tests exposition, respectively.

Tw composition up to 15% w/w concrete mixture had good mechanical performance during tests, showing that it can be used as paver, curb pieces, and as repair materials for hydraulic structures concrete dams. The 20% w/w Tw composition presented large quantities of rubber-tired concrete surface efflorescence and porous defect, causing poor visual market aspect and low mechanical resistance.

As observed, the worry on the use of recycled materials is not limited to structural stability, but also their durability in concrete structures, meanly submitted to salt aggressive environment.

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