A comparative assessment of polymer concrete strength after degradation cycles

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Abstract

A comparative study of the influence of chemical degradation effects on flexural and compressive strength of polymer concrete was performed. For this purpose, specimens of epoxy polymer mortars were exposed to four different degradation agents represent those that often account for corrosive processes in industrial environments. Some compositions in the study showed evidence of physical surface changes and weight loss. A decrease in the flexural and compressive strength of the samples exposed to corrosive agents was observed. However, even in those samples, the remaining strength values remained far higher than those found in mortars prepared with Portland cement, an inorganic binder.

Keywords: composite materials, polymer concrete, chemical degradation.

1 Introduction

Significant efforts and resources have been devoted to condition assessment, rehabilitation and repair of deteriorating infrastructure. In the last few decades, polymers have been used in the production of a unique composite material with improved mechanical strength and durability [1, 2]. This concrete like composite material has a polymeric resin as binder instead of Portland cement and water. Polymer Concrete (PC) displays high flexural and compressive strength, as well as improved chemical resistance to degradation environments, especially when compared to ordinary Portland cement concrete [3].

Portland cement concrete hydration products are alkaline and when submitted to acid environments they react. When exposed to a certain period of time those concretes will show sign of wear [4]. However, due to polymeric binder, polyester, epoxy, vinyl, methylmetacrylate resins, PC shows good chemical resistance to degradation environments and composite materials manufactured with thermoset resins as binder tends to reproduce their inherent characteristics of the unreinforced matrix [3].

For Rebeiz and Fowler [5] PC is the material of choice for coatings because of its strong bonding with Portland cement concrete, its resistance to abrasion and weathering, its impermeability and the

Mechanics of Solids in Brazil 2009, H.S. da Costa Mattos & Marcílio Alves (Editors)
Brazilian Society of Mechanical Sciences and Engineering, ISBN 978-85-85769-43-7

low weight resulting from the small layer thicknesses used. PC also shows good sound and thermal insulation properties because of its low thermal conductivity and good dampening characteristics. In hydraulic structures such as dams, dikes, reservoirs and piers, PC creates a highly abrasion-resistant surface [6].

Fowler [1] observed that in the United States, the most common applications of PC are found in highway surfaces and bridge decks as well as in the petrochemical industry. In Canada and Japan, PC is often used in underground constructions and road surfaces, mainly because of severe weather conditions. In Europe, however, a large share of the applications is represented by precast materials for the civil construction sector, in the metal-mechanical industry as a replacement for cast metals and in the construction of reservoirs and coating materials in the chemical and food industry.

Most polymeric materials undergo degradation on exposure to UV radiation and aggressive chemicals. Vipulanandan and Paul [7] have investigated degradation of polymer concrete without fiber reinforcement. They found that polymer concrete specimens immersed in alkaline solutions lost considerable strength after even short exposures. Water is also known to cause degradation of polymer concrete. In this study, the effect on strength of exposure to seawater, sulfuric acid, distilled water and soft drink in detail. Since the motivation for the research was to determine the durability of polymer concrete, it was considered important to simulate the types of aggressive environments that could conceivably be brought into contact with the material.

2 Materials and experimental procedure

To perform this research, PC formulations were prepared by mixing aggregates with thermosetting resins. The aggregate used was foundry sand, which consists in quartz sand, designed by 40/50, with a uniform granulometry.

The epoxy resin system used is based on a diglycidyl ether bisphenol A and an aliphatic amine hardener with low viscosity (500-700 MPa.s), which cluster the sand. Epoxy resin produces a high performance polymer concrete, which results in durability, low permeability and fast cure. Resin content used was 12% by weight. Previous studied performed by the author showed the lowest binder concentration that would deliver an optimal cost/performance ratio [8, 9].

With these binder formulations and mix proportions, polymer concrete were mixed and molded. For flexural tests prismatic (40x40x160 mm^3) specimens were manufactured, as illustrated in Fig. 1, and cylindrical specimens (φ 50x100 mm) were produced for compression tests, see figure 2, according to the RILEM standard CPT PC-2 [10]. All specimens were allowed to cure for 7 days at room temperature and then postured at 60ºC for 4h, before being submitted to corrosive environment.

The test method for degradation followed the procedure presented by Camps *et al.* [11]. After specimens production a 14-day exposure cycles were started. Each exposure cycle consisted of immersing the samples for 7 days in a chemical solution and then allowing them to dry for 7 days. The specimens were weighed before the beginning of each test cycle. After the immersion cycle, the specimens were washed with pressurized water in order to simulate the effect of mechanical abrasion and to remove any corrosion products from their surface. The specimens were then allowed to dry in a controlled laboratory atmosphere for 7 days. At the end of the drying cycle, the specimens were again weighed

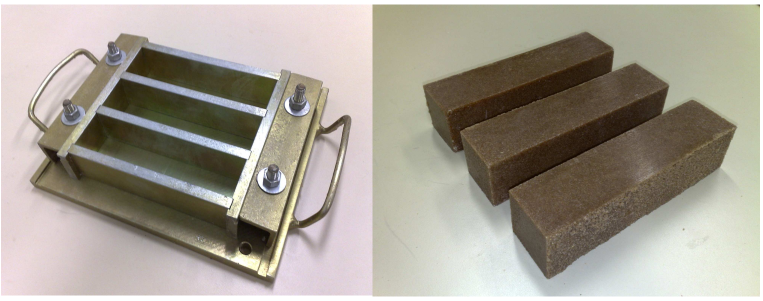

Figure 1: Flexural test specimens.

Figure 2: Compression test specimens.

thus completing the 14-day cycle. After each new cycle, the aggressive agent solution was replaced with fresh solution. The pH of the solutions was measured before immersing the specimens and after they were removed. The aggressive agents used were lactic acid, sulfuric acid, cola soft drink and distilled water. Lactic and sulfuric acid were diluted to 5%. The ph solutions are presented in table 1.

Table 1: pH from all aggressive solutions.

Solution	pH
Distilled Water	5.1
Sulfuric Acid	1.1
Lactic Acid	1.9
Seawater	8.2

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Five exposure cycles were scheduled. The volume of aggressive solutions amounted to 4 times the specimen's volume. After the final exposure cycle measurements of polymer concrete under different loading conditions quasi-static tests were performed in flexural and compression to evaluate how each degradation solution affect polymer concrete mechanical strength. Prismatic polymer concrete beams were tested in three-point bending up to failure at the loading rate of 1 mm min-1, with the span of length of 100 mm, according to RILEM CPT PCM-8 standard test method [12]. The specifications of this standard, in terms of specimen geometry a span length, are similar to those specified in ASTM C348-02, standard test method for flexural strength of hydraulic cement mortars [13]. In both mentioned standards, shear effect is not taken into account on calculation procedure of flexural strength. Despite the very short span compared to the thickness, shear effect is disregarded. Polymer concrete is considered an isotropic material and the theory of plane cross-section was used. Flexural strength, considered as the strength under normal stress, was determined applying the following equation:

$$\sigma_f = \frac{3Pl}{2bh^2} \tag{1}$$

where σf is the flexural strength; P is the maximum load recorded, l is the span length; b and h are respectively, the width and height of the prismatic specimens.

Cylinder polymer concrete specimens were tested in compression at the loading rate of 1.25 mm/min according to ASTM C39-05 standard [14].

Compressive strength were calculated according the following equation:

$$\sigma_c = \frac{F}{A} \tag{2}$$

where σc is the compressive strength; F is the maximum load recorded; and A is the cross-sectional area of cylinder specimens.

Both flexural and compressive testing set-up, are presented in figure 3.

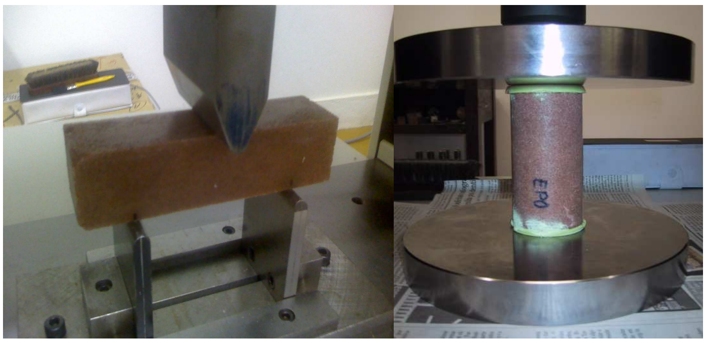

Figure 3: Flexural and compression test set-up.

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3 Test results and discussion

Flexural and compressive test results in order to obtain polymer concrete mechanical strength are discussed in this section. Table 2 represents the flexural strength test results of polymer concrete subjected to degradation environments compared to reference (no degradation) results.

Table 2: Flexural strength of polymer concrete after degradation cycles.

Solution Type	Mean Strength (MPa)	% Flexural Strength Loss	% Weight Gain
Reference	24.734	-	
Distilled Water	23.364	5.54	0.3
Sulfuric Acid	22.158	10.41	0.6
Lactic Acid	-	-	0.7
Seawater	23.035	6.87	0.3

After three-point bending tests, when compared to reference values, polymer concrete displayed a decrease in the flexural strength. Specimens submitted to sulfuric acid degradation solution decreased 10.41% and a loss of 6.87% and 5.54% were obtained for seawater and distilled water degradation solutions respectively. A severe damage was observed to specimens subjected to lactic acid solution and tests could not be performed.

Table 3 displays the compressive test results of polymer concrete after degradation exposure.

Table 3: Compressive strength of polymer concrete after degradation cycles.

Solution Type	Mean Strength (MPa)	% Compressive Strength Loss	% Weight Gain
Reference	52.845	-	
Distilled Water	51.937	1.7	0.2
Sulfuric Acid	51.723	2.1	1.1
Lactic Acid	-	-	1.7
Seawater	49.145	7.0	0.4

When specimens submitted to seawater degradation solution a reduction of 7.0% in polymer concrete compressive strength were measured. A decrease of 2.1% was obtained by specimens submitted to sulfuric acid solution and for specimens degraded in distilled water a 1.7% loss was observed when compared to reference polymer concrete specimens. Again a severe damage was observed to compressive specimens and tests could not be perfomed.

For flexural test specimens low percentages of weight variation were observed, lower than 1% and for compressive blocks a higher gain in weight were recorded. For sulfuric and lactic acid solutions specimens increased its weight by 1.1 and 1.7% respectively.

Polymer concrete surface changes after 5 degradation cycles when exposed to sulfuric and lactic acid. Figure 4 displays polymer concrete specimens after lactic acid degradation cycles. A severe damage was observed in the specimens and flexural and compressive test could not be performed.

Figure 4: Specimens after lactic acid degradation.

A higher loss of strength was observed on flexural strength compared to compressive strength of polymer concrete. The solution which most affected polymer concrete was lactic acid and the less aggressive was distilled water, for both types of specimens tested, in flexure and in compression.

When the loss of strength of polymer concrete is compared to ordinary cement concrete, it becomes clear that large percentages losses are observed [3]. The remaining strength level after degradation cycles is higher than the values observed in cement concrete with no chemical attack.

It is reasonable to believe that the polymer matrix used in the polymer concrete production did not suffer significant losses. The loss of strength can be attributed to an increase of porosity in PC samples with increased capillary diffusion of solutions, which weakens the bond between the aggregate and the matrix.

4 Conclusions

The present study aimed to investigate the degradation of polymer concrete when submitted to different aggressive agents.

The values of both flexural and compressive strength after exposure were quite high when compared to typical values of high strength cement concrete. Unlike what is observed in ordinary Portland cement concrete compounds [15].

No significant weight loss but visual changes were observed, especially when specimens were exposed to sulfuric and lactic acid.

Lactic acid produces a severe damage to polymer concrete structure. Sulfuric acid with low pH did not degraded polymer concrete like lactic acid with higher pH proving that lower ph does not affect directly epoxy binder nor the mixture.

This study produces information for epoxy polymer concrete users in industrial or commercial environments. The results reveal the weakness of the material and provide important information for design and applications of polymer concrete.

Acknowledgements

The financial support of FAPERJ under the JOVEM CIENTISTA DO ESTADO program is gratefully acknowledged.

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