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Fracture assessment of polymer concrete in chemical degradation solutions

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ABSTRACT

There are several obstacles to using polymer matrix composites in infrastructure applications due to matrix susceptibility to degradation by moisture, temperature and chemical environments. In this research work the fracture properties of epoxy polymer concrete exposed to different degradation agents was assessed. The experimental program was performed submitting specimens to seven solutions varying pH from 1.2 to 12.8. The fracture results were analyzed by fracture toughness, K_{Ic}, and fracture energy, G_f. Also, the modulus of elasticity, E, was computed. High decrease in the fracture properties, as well in the modulus of elasticity of the samples exposed to corrosive agents was observed. However, even in those samples, the remaining strength values were far higher than those found in mortars prepared with Portland cement concrete and an inorganic binder.

1. Introduction

The idea of a strong material related to its durability is a misleading assumption and for many years research related to construction materials was focused on manufacturing high strength materials. Structures are designated durable if they exhibit the required service properties under the planned service conditions over the project service life with low maintenance costs. Ordinary Portland cement concrete is a ready-to-use, widely available material, but its low durability under some service conditions seems to be the price paid for its universality. The exposure of ordinary cement concrete to acid solutions and alkaline environments brings out a rapid deterioration of the material's external surface [1]. Acid reacts with hydrated and unhydrated compounds and decomposes them and over time, this type of concrete will show signs of wear [2].

Due to the lack of cement concrete structures durability under certain service conditions has drawn the attention to a relative new composite material, polymer concrete (PC). PC is a cementless concrete material formed by a mixture of mineral aggregates with a polymerized monomer. The polymer matrix acts as a binder for the aggregate reinforcement replacing, completely, the hydrated cement paste. Thermosetting resins that cure at ambient temperature, such as unsaturated polyesters, epoxy systems and acrylic resins, are among the most often used polymers in PC materials, although thermoplastic materials such as methacrylate based ones, have also been applied as binders. These binders show good chemical resistance to acid environments and the concrete prepared with these polymers tends to replicate the inherent characteristics of the binders used [3].

Although 3–5 times stronger than ordinary Portland cement concrete, polymer concrete (PC) displays brittle characteristics that have limited its usefulness for load-bearing applications [4]. For many years, PC has been used mainly for industrial flooring, retouching of damage concrete structure, sewer pipes, bridge decks and precast components. Polymer concrete excellent mechanical strength and durability reduce the need for maintenance and frequent repairs required by conventional concrete [5]. According to [6,7], PC bonding with Portland cement concrete is strong originating an excellent choice for coating. Its resistance to abrasion and weathering, its impermeability and the low weight resulting from the small layer thicknesses used.

According to EN 206-1 [8] the severity of chemical attacks in ordinary cement concrete is divided into three exposure classes, see Table 1.

In the case of acids with pH values in the range of XA3 or lower, protective coatings, rather than mix design optimization, are in general necessary to prevent rapid deterioration.

This research deals with the analysis of epoxy polymer concrete fracture properties, i.e. fracture toughness and fracture energy when submitted to different chemical solutions attacks. Chemical attacks were promoted by distilled water, sulfuric, formic, acetic, lactic acids, sodium hydroxide and sodium chloride. All solutions were 5% diluted.

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Table 1
Exposure classes for chemical attack according to EN 206-1.

Property	XA1	XA2	XA3
pH	5.5–6.5	4.5–5.5	4.0–4.5
Severity	Weak	Medium	Strong

2. Materials and methods

2.1. Materials

Polymer concrete formulations were prepared by mixing foundry sand an epoxy resin. Resin content was 12% by weight and no filler was added in formulations. Previous studies carried out by the author [9], considering an extensive experimental program, allowed an optimization of mortar formulations that are now being used in the present work.

The aggregate was foundry quartz sand with a homogeneous grain size, employed in a 40/50 design, produced by JUNDU and used in the foundry industry. The foundry sand was previously dried before added to the polymeric resins in an automatic mixer. The epoxy resin system used here was RR515 from SILAEX, based on bisphenol A diglycidyl ether and an aliphatic amine hardener. This low viscosity system was processed with a maximum mix-to-hardener ratio of 2:1. Binder properties are presented in Table 2.

Polymer concrete fracture specimens were compacted in a steel mold of dimensions of $30 \times 60 \times 240$ mm^3, according to the RILEM specification TC113/PC-2 [10]. The specimens were initially cured at room temperature. The samples were notched using a 2 mm diamond saw to a 20 mm depth, see Fig. 1.

All specimens were allowed to cure for 7 days at room temperature, and then post-cured at 80 °C for 3 h, before being exposed to the defined chemical solutions.

2.2. Degradation procedure

Different degradation methods were evaluated to perform this research work [4,11–13]. Pavlik [11] suspended the specimens with exposed surface facing downwards in chemical solutions to evaluate corrosion depth. Shi and Stegemann [12] perform on cementing materials a similar procedure. Camps et al. [13] also describe a degradation method. The method described in [4] immerses the specimens completely in the acid solution promoting a rapid set of degradation in all specimen surfaces. The test method for degradation follows the procedure presented by Camps et al. [13].

The chemical degradation consisted in, after specimens were fully cured, submitting the samples in 14-day exposure cycle. 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. After each new cycle, the aggressive agent solution was replaced with fresh solution. The aggressive agents used were distilled water, sulfuric, formic, acetic, lactic acids. Also, sodium chloride, NaCl, and sodium hydroxide, NaOH. The pH of the solutions was measured before immersing the specimens and after they were removed as presented in Table 3.

All chemical agents were diluted to 5%. Acid solutions has pH lower than 7, i.e. acidic. Sodium chloride is a neutral solution with pH 7.1 and sodium hydroxide is alkaline with pH higher than 7.

Five exposure cycles were scheduled. After the final exposure cycle, the polymer concrete samples were tested in three-point bending to determine its fracture properties according to RILEM [14,15].

Table 2
Properties of epoxy resin.

Property	Epoxy
Viscosity at 250 °C, μ (cP)	12,000–13,000
Density, ρ (g/cm^3)	1.16
Heat distortion temperature, HDT (°C)	100
Modulus of elasticity, E (GPa)	5.0
Flexural strength (MPa)	60
Tensile strength (MPa)	73
Maximum elongation (%)	4

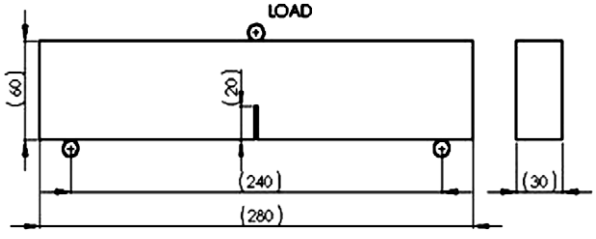

Fig. 1. Specimens geometry and loading set-up.

2.3. Fracture characterization

To determine the fracture properties, three-point bending tests were conducted using a universal testing machine with a crosshead speed of 0.5 mm/min. The crack mouth opening displacement (CMOD) was measured using a COD gauge clipped to the bottom of the beam and held in position by two 3 mm steel knife edges glued to the specimen, as shown in Fig. 2.

Fracture toughness, K_{Ic} and fracture energy, G_f, are the main parameters determined and the modulus of elasticity, E, according to [14,15] is also determined.

To identify fracture toughness of PC, the Two Parameter Method (TPM) [14] was used. This method is a direct method to calculate two size independent fracture parameters, i.e., critical stress intensity factor. K_{Ic} is a measurement of a material's resistance to crack extension when the stress state near the crack tip is predominantly plane strain, plastic deformation is limited, and opening mode monotonic load is applied and can be expressed as, in MPa $\sqrt{\text{m}}$.

The results correspond to the mean values of at least three tests.

According to the RILEM Technical Committee [15], the fracture energy G_f in single edge notched beams when three-point bending tests are performed to specimens can be calculated as

$$G_f = \frac{W_0 - mg\delta_0}{A_{\text{lig}}} \quad (1)$$

where W_0 is the area under the load vs. deflection curve (N/m), mg is the self-weight of the specimen between supports (kg), δ_0 is the maximum displacement (m), and A_{lig} is the fracture area $[d \times (b - a)]$ (m^2); b and d are the height and width of the beam, respectively.

Table 3
Aggressive degradation solutions pH.

Solution type	pH
Distilled water	5.1
Sulfuric acid	1.2
Acetic acid	2.5
Lactic acid	1.9
Sodium chloride	7.1
Sodium hydroxide	12.8

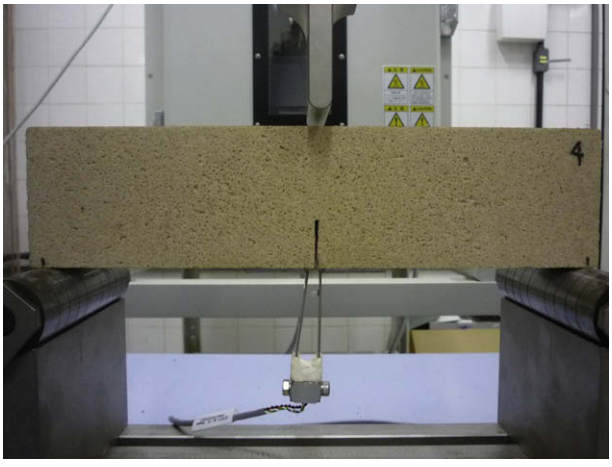

Fig. 2. Three-point bending fracture test set-up.