

EVALUATION OF FRACTURE PROPERTIES OF POLYMER CONCRETE IN DEGRADATION SOLUTIONS

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Abstract. *A study has been conducted to investigate the fracture properties of polymer concrete submitted to chemical degradation in acid solutions. PC origins from mixing fine aggregates to a polymeric resin as binder, instead of ordinary cement and water. While this material is becoming popular in the manufacture of manhole and drainage components, little is known about its durability. In this study, the fracture toughness and fracture energy of polymer concrete were determined by using three-point flexural testing methods. After exposure and mechanical tests a decrease in fracture strength 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.*

Keywords: *Fracture, Polymer Concrete, Chemical Degradation*

1. INTRODUCTION

Significant efforts and resources have been devoted to seek more durable materials, condition assessment, rehabilitation and repair of deteriorating infrastructure. Durability of a material by definition is capability of withstanding wear and tear or decay. Until recently, there was a wrong assumption that a strong material is a durable material and as a result, the developments in construction material technology have concentrated on achieving higher and higher strengths.

In the last few decades, polymers have been used in the production of a unique composite material with improved mechanical strength and durability according to Fowler (2001, 1999). This concrete like composite material has a polymeric resin as binder instead of portland cement and water. Polymer mortars displays high flexural and compressive strength, as well as improved chemical resistance to degradation environments, especially when compared to ordinary portland cement concrete, Gorninski et. al. (2007). 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.

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, Steinberg (1973). However, due to polymeric binder, polyester, epoxy, vinyl, methylmetacrylate resins, PM 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 Gorninski et. al. (2007).

Comparing with conventional cement concretes, this unique composite material offers a number of advantages that justify their growing applications, such as higher strength, especially in bending and compression, better chemical resistance to a wide range of corrosive agents, mainly due to its lower permeability and hermetic nature of resin matrix, faster curing times, with a quick development of mechanical strengths; and an exceptional adhesion to most surfaces.

Gorninski et al. (2004) believe polymer concrete is an example of a relatively new high performance material. Its excellent mechanical strength and durability reduce the need for maintenance and frequent repairs required by conventional concrete. PC is the material of choice for coatings because of its strong bonding with Portland cement concrete, its impermeability, its resistance to abrasion and weathering, and the 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, Fowler (2004).

Most polymeric materials undergo degradation on exposure to UV radiation and aggressive chemicals. Vipulanandan and Paul (1990) 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.

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

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

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.

2. MATERIALS AND METHODS

2.1. Materials

Polymer concrete formulations were prepared by mixing foundry sand and epoxy resin. Resin content was 12% by weight and no filler was added in formulations. Previous studies carried out by Reis (2009) 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.

Table 2 - Properties of Epoxy Resin

Property	Epoxy
Viscosity at 25°C μ (cP)	12000-13000
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

Polymer concrete fracture specimens were compacted in a steel mold of dimensions of 30 x 60 x 240 mm³, according to the RILEM specification TC113/PC-2. The specimens were initially cured at room temperature. The samples were notched using a 2mm diamond saw to a 20mm depth, see figure 1.

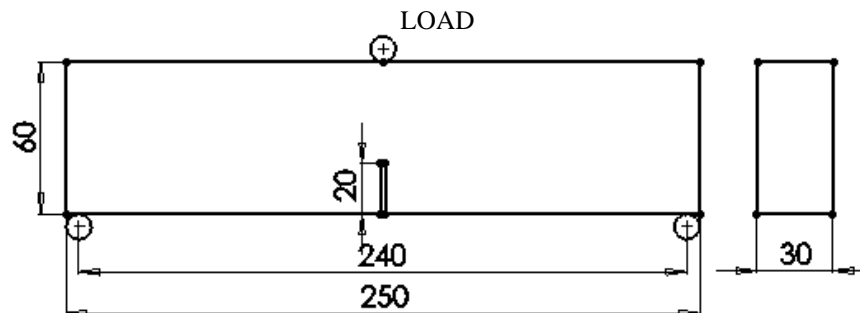


Figure 1 - Specimens geometry and loading set-up

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. Pavlik (1994) suspended the specimens with exposed surface facing downwards in chemical solutions to evaluate corrosion depth. Shi et al. (2000) perform on cementing materials a similar procedure. Camps et al. (1990) also describe a degradation method. The method described by Griffith et al. (2000) 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. (1990).

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 acid 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.

Table 3 - Aggressive degradation solutions pH.

Solution type	pH
Distilled water	5.1
Sulfuric acid	1.2
Sodium hydroxide	12.8

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. Three exposure cycles were scheduled. After the final exposure cycle, the polymer concrete samples were tested in three-point bending to determine its fracture properties.

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 figure 2.

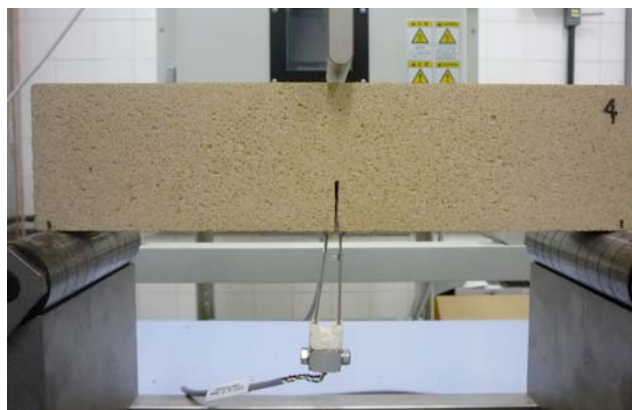


Figure 2 – Three-point bending fracture test set-up

Fracture toughness, K_{Ic} and fracture energy, G_f , are the main parameters determined and the modulus of elasticity, E , according to Jeng et al. (1985) and RILEM (1985) is also determined. To identify fracture toughness of PC, the Two Parameter Method (TPM), according to Jeng et al. (1985), 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 $(\text{MPa}\sqrt{m})$

The results correspond to the mean values of at least three tests. According to the RILEM Technical Committee (1985), the fracture energy G_f in single edge notched beams when three point bending tests are performed to specimens can be calculated as

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

where W_0 is the area under the load vs. deflection curve (N/m), $m.g$ 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.

3. RESULTS AND DISCUSSION

After all degradation cycled specimens were tested statically. Mass changes, after each immersion period, were calculated and this variation is presented in figure 3.

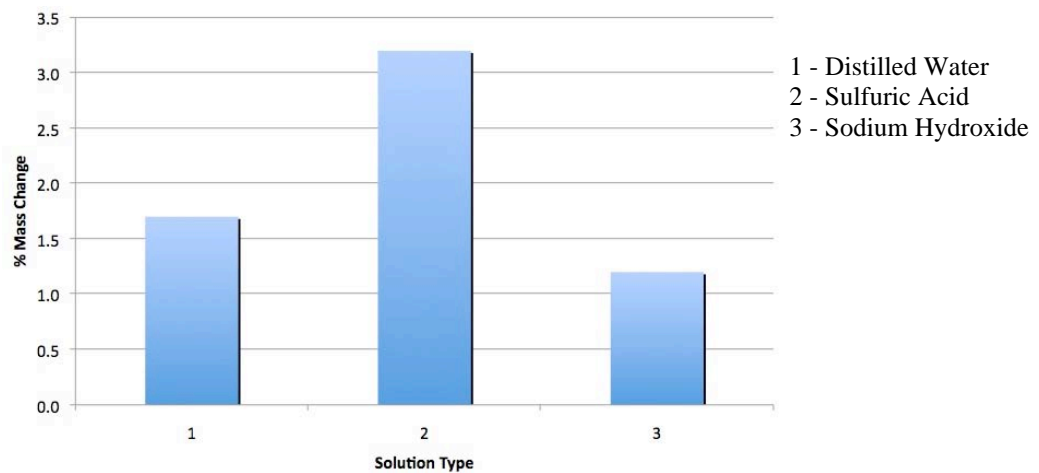


Figure 3 – Mass change for different solution types

All test specimens after 5 exposure cycles have less than 4% mass change in weight. When compared to ordinary Portland cement concrete, the weight loss reported, under the same conditions of degradation cycles reported by Kulakowski (1997) was 32%, showing the low fluid absorption by polymer concrete. Fracture properties, toughness, K_{Ic} , and energy, G_f , for each degradation solution is presented in table 4. Also, the modulus of elasticity, E , according to Jeng et al. (1985) is displayed.

Table 4 – Fracture Test Results (Average \pm St. Dev.)

Solution Type	K_{Ic} ($\text{MPa}\sqrt{m}$)	G_f (N/m)	E (GPa)
Reference	1.58 ± 0.07	779.6 ± 78.3	12.68 ± 0.98
Distilled water	0.37 ± 0.10	240.9 ± 26.3	1.86 ± 0.04
Sulfuric acid	0.59 ± 0.17	318.8 ± 12.53	4.86 ± 0.25
Sodium hydroxide	0.55 ± 0.17	357.9 ± 31.34	3.88 ± 1.27

According to three-point bending test results and analyzing the fracture properties of polymer concrete exposed to different chemical solution presented in table 4, distilled water and sodium hydroxide are the most aggressive environment for polymer concrete when fracture toughness was analyzed. The fracture energy also represents the degradation pattern but with inverse results, lower G_f was measured for distilled water followed by sulfuric acid. Polymer concrete aggregate has in its composition silica. Aggregates containing certain forms of silica will react with alkali hydroxide in concrete to form a gel that swells as it adsorbs water from the surrounding cement paste or the environment. These gels can swell and induce enough expansive pressure to damage concrete.

Figure 4 displays the fracture toughness, K_{Ic} , comparison between all degradation solutions.

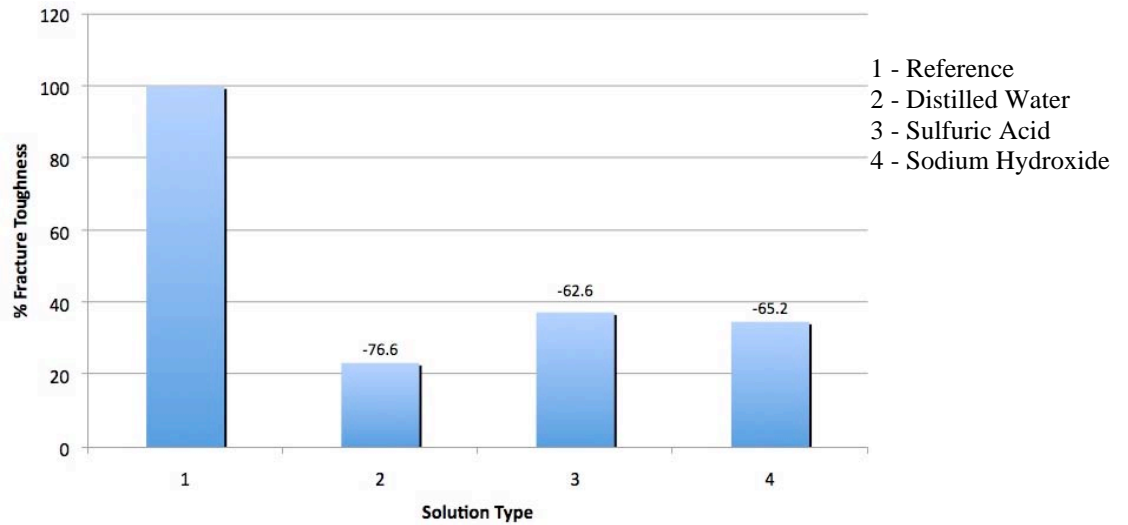


Figure 4 – Polymer concrete fracture toughness comparison

A decrease of 76.6% in the fracture toughness of polymer concrete when exposed to distilled water is observed followed by 65.2% of sodium hydroxide 5% solution. The lowest calculated value for fracture toughness was 62.6% for polymer concrete submitted to sulfuric acid solution degradation cycles.

Figure 5 presents the fracture energy variation when polymer concrete was exposed to degradation solutions. Distilled water degrades polymer concrete fracture energy in 69.1% and a diminish of 59.1% was observed for sulfuric acid degradation solution. Sodium hydroxide solution produces the lower loss of fracture energy, 48.9%.

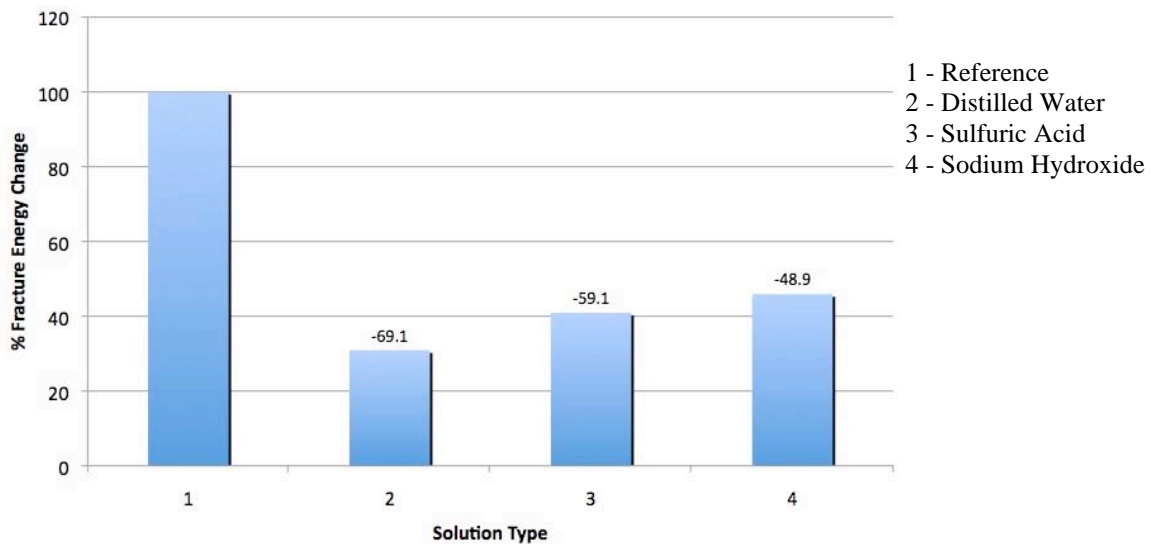


Figure 5 – Polymer concrete fracture energy comparison

4. Conclusions

The present work investigates the fracture behavior of polymer concrete when submitted to different aggressive agents. This was performed by means of a degradation cycles and static tests in samples of epoxy polymer mortars exposed to three different solutions.

High damage was measured and elevated diminish of fracture properties of polymer concrete were observed after distilled water and sodium solution were used as degradation agents. Also, significant damage was observed when specimens were submitted to the others degradation solutions.

Visually, polymer concrete was hardly affected excepted by sulfuric acid, where severe surface damage was observed. Compared to ordinary cement concrete, the fracture properties of polymer concrete were higher than typical values obtained in the literature.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

- Camps, J.P., Laplanche A. and Al Rim K, 1990, "Corrosion of concrete by sequestrating agents of detergents", In: Proceedings of protection of concrete, Dundee (UK), pp. 63–73.
- Fowler, D.W., 2001, "Polymers in Concrete - Where Have We Been and Where Are We Going?". Proceedings of the 10th International Congress on Polymers in Concrete, Hawaii, USA.
- Fowler, D.W., 1999, "Polymers in concrete: a vision for the 21st century". Cement Concrete Composites, vol 21, pp.449–452.
- Fowler, D.W., 2004, "State of the art in concrete–polymer materials in the U.S". In: Maultzsch M, editor. Proceedings of the 11th international congress on polymer in concrete. Berlin, p. 597–603.
- Gorninski, J.P., Dal Molin, D.C. and, Kazmierczak, C.S., 2007, "Strength Degradation of Polymer Concrete in Acidic Environments. Cement and Concrete Composites", vol. 29, pp.637-645.
- Gorninski, J.P., Dal Molin, D.C. and, Kazmierczak, C.S., 2004, "Comparative assessment of the properties of polymers concrete compounds with isophthalic and orthophthalic polyester". In: Maultzsch M, editor. Proceedings of the 11th international congress on polymer in concrete, Berlin, p. 256–63.
- Griffiths, R., Ball, A., 2000, "An assessment of the properties and degradation behaviour of glass-fibre-reinforced polyester polymer concrete", Composites Science and Technology, vol.60, pp.2747-2753.
- Jeng, Y.S. and Shah, S.P., (1985), "Two parameters fracture model for concrete", Journal of Engineering Mechanics, vol.111, pp.1227-1241.
- Pavlik, V., 1994, "Corrosion of hardened cement paste by acetic and nitric acids: Part I. Calculation of corrosion depth", Cement and Concrete Research, vol.24 pp.551–62.
- Reis, J.M.L., 2009, "Effect of textile waste on the mechanical properties of polymer concrete", Materials Research vol. 12, pp.63-69.
- RILEM. PC-2: Method of making polymer concrete and mortar specimens. Technical committee TC-113. Test methods for concrete-polymer composites (CPT). International union of testing and research laboratories for materials and structures; 1995.
- RILEM 50-FMC Recommendation. Determination of fracture energy of mortar and concrete by means of three-point bend test on notched beams. Mater Struct 1985;18:285–90.
- Shi, C. and Stegemann, J.A., 2000, "Acid corrosion resistance of different cementing materials", Cement and Concrete Research, vol.30, pp.803–808.
- Steinberg, M., 1973, "Concrete Polymer materials and its worldwide development", Proceedings of International symposium on polymers in concrete, Detroit, USA, p.123-137.
- Vipulanandan, C. and Paul, E., 1990, "Performance of epoxy and polyester polymer concrete", ACI Materials Journal, p. 241-251.
- Kulakowski, M.P., Dal Molin, D.C., 1997, "Relatório Convênio Camargo Corrêa Industrial – NORIE/CPGEC/UFRGS", Porto Alegre, Brazil.

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