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Mechanical characterization of polymer mortars exposed to degradation solutions

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ABSTRACT

A comparative study of the influence of chemical degradation effects on flexural and compressive strength of polymer mortars was performed. For this purpose, epoxy polymer mortars specimens were exposed to eight different degradation agents represent those that often account for corrosive processes in industrial environments. After exposure and mechanical tests a decrease in flexural and compressive 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.

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 [1,2]. 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 [3]. 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 [4]. 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 [3].

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 [5] 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 [5]. 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].

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.

In this study, the effect on flexural and compressive strength of PC when exposed to eight different degradation agents, namely,

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seawater, sulfuric, lactic, acetic, citric and formic acids, distilled water and soft drink are investigated. 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, since PM strength is strongly affected by the adhesion between matrix and aggregates at interface, and it is also dependent of the nature and packing level of aggregates.

2. Materials and methods

Polymer mortar 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 [8], considering an extensive experimental program, allowed an optimisation of mortar formulations that are now being used in the present work. Optimization of mix design, regarding flexural and compressive strength properties, was performed considering the influence of the following material parameters: resin type and resin content, aggregate grading and curing treatment.

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 (500–700 MPa) system was processed with a maximum mix-to-hardener ratio of 2:1.

Polymer mortar samples were cast into prismatic ($40 \times 40 \times 160$ mm) for bending test purposes and cylindrical ($\phi 50 \times 100$ mm) specimens for compression tests according to the RILEM specification TC113/PC-2 [9]. 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 environmental conditions.

Different degradation methods were evaluated to perform this research work [10–15]. Metha, [10] performed degradation tests with different acid solutions, Shi et al. [13] perform on cementing materials a similar procedure described by Pavlik [14], Camps et al. [15] also describes a degradation method. The specimens described in [14] were hung vertically on a string, with the reaction surface facing upward, i.e. it was measured the depth of corrosion. The method described in [14] 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. [15]. The specimens for flexural and compression tests were moulded for the test, cured and then the 14-day exposure cycles 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 thus completing the 14-day cycle. After each new cycle, the aggressive agent solution was replaced with fresh solution. The aggressive agents used were distilled water, cola soft drink, seawater, sulphuric, acetic, formic, citric and lactic acids. The pH of the solutions was measured before immersing the specimens and after they were removed as presented in Table 1.

Acid formulations were diluted to 5%. Seawater is a very complicated environment for degradation because micro-organisms, animal, salt, sunlight, fluctuation of water, rain, etc.

Table 1
Aggressive degradation solutions pH.

Solution type	pH
Distilled water	5.1
Soft drink	2.6
Sulfuric acid	0.1
Seawater	8.1
Lactic acid	1.9
Citric acid	2.0
Formic acid	1.9
Acetic acid	2.5

Five exposure cycles were scheduled. The volume of aggressive solutions amounted to four times the specimens volume. After the final exposure cycle measurements of polymer concrete under different loading conditions were performed in flexural and in compression.

Measurements of polymer mortars, after degradation cycles, under different loading conditions were taken under flexion and compression. Prismatic polymer mortar beams were tested by three-point bending up to failure at a loading rate of 1 mm min^{-1}, with a span length of 100 mm, according to the RILEM specification TC113/PCM-8 [16]. In terms of specimen geometry and span length, are similar to those of the ASTM C348-02 standard testing method for flexural strength of hydraulic cement mortars [17]. Neither of the aforementioned standards takes into account the shear effect in the calculation of flexural strength. Despite the very short span compared to the thickness, shear effect was disregarded. Polymer mortar is considered an isotropic material and the plane cross-section theory was assumed. Flexural strength, i.e., strength under normal stress, was determined from the following equation:

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

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

Cylindrical polymer mortar specimens were tested under compression at a loading rate of 1.25 mm min^{-1}, according to the ASTM C39-05 standard [18].

Compressive strength was calculated from the following equation:

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

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

Prior to compressive strength test, PM cylinders were taken from the solution, dried, capped by sulphur compound, and using the average strength of three specimens for each data point.

3. Results and discussion

Test results, in terms of mass change, flexural and compressive strength changes (average values), for each test solution, are shown in Figs. 1–3.

The results and statistical analysis of the mechanical strength of polymer concrete are discussed in this section. Table 2 represents the flexural and compressive strength test results of polymer

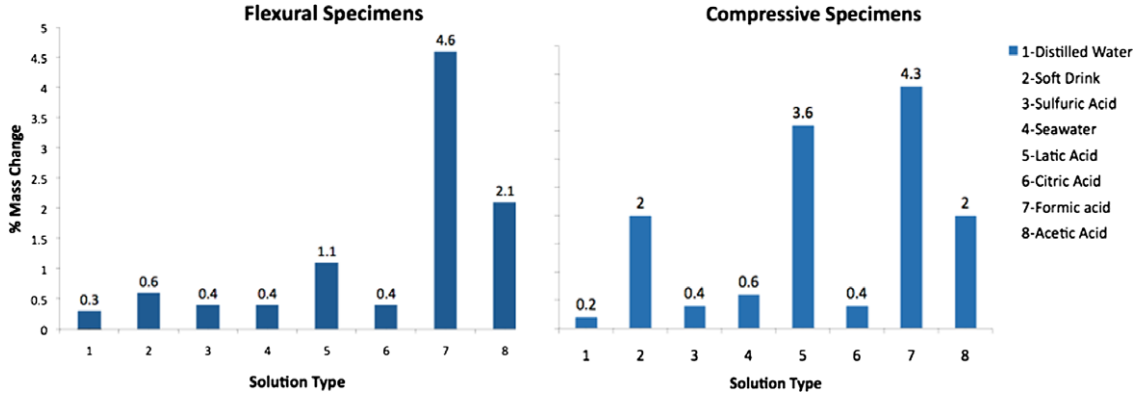

Fig. 1. Mass change % in flexural and compressive specimens of PM for different solution type.