International Journal of Engineering

Journal Homepage: www.ije.ir

RESEARCH NOTE

Flexural Behavior of Polyester Polymer Concrete Subjected to Different Chemicals

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P A P E R I N F O

Paper history:
Received 14 January 2015
Received in revised form 17 May 2015
Accepted 11 June 2015

Keywords:
Polyester Resin
Polymer Concrete
Flexural Strength
Chemical Aggressive
Durability

A B S T R A C T

Polymer concrete (PC) is a composite material prepared by resin and aggregates. Advantages of polymer concretes include rapid curing, high flexural and compressive strengths, suitable chemical resistance and low permeability. In this research, a comparative study was performed on degradation of polyester resin concrete in different chemical solutions. Polymer concrete specimens were examined for flexural strength and flexural toughness after two and four months of exposure to the chemicals (i.e. sulfuric acid, sodium hydroxide, sodium sulfate, nitric acid, hydrochloric acid, citric acid, demineralized water, potable water, potassium hydroxide, gas oil). Results showed that the highest decrease in flexural strength occurred in sodium hydroxide solution after two months of exposure. Comparing acid attack to the specimens it was found that citric acid as an organic acid, despite of higher pH, had the highest impact on flexural strength. The flexural strength of PC specimens decreased considerablly in all chemicals (except in gas oil). There was not significant difference between two and four months of exposuring, therefore, the main degrading processes start during the first 60 days of exposuring.

***doi**: 10.5829/idosi.ije.2015.28.07a.03*

1. INTRODUCTION

The development of new composite materials increased strength and durability compared to conventional types which these are major requirements for repairing materials and infrastructural applications. Polymer concrete(PC) is an example of a relatively new materials with such high performances [1]. PC is a composite material in which resin is used as binder for aggregates instead of Portland cement [2]. Polymer concretes are used increasingly in construction and manufacturing applications requiring versatile, high-strength, enduring concretes. It has the potential for widespread use in corrosive environments (for bridges, tunnel linings, etc.) and in the electric power industry (as a possible replacement for porcelain) [3]. Application of these materials was particularly popular in the construction industry during the early 1950s [4]. It is reported to have used in a range of civil and structural applications such as bridge decking, concrete crack repair, pavement overlays, hazardous waste containers, waste water pipes and decorative construction panels [5]. In conventional concretes, the alkaline Portland hydraulic cement forms voids and cracks during hydration. Aggressives can intrude through these defects and degrade concrete bulk. In PC, however, the more compact polymer binder tends to eliminate open voids [3]. This cause improved water permeability and chemical resistance.

Industrial applications of unsaturated polyesters (UPs) began in the 1940s. Unsaturated polyester resin (UPR) is one of the binders used in polymer concretes providing excellent adhesion to solid particulate fillers, good stiffness, dimensional stability and a high damping ratio [6, 7]. Unsaturated polyestester resins have unsaturated carbon-carbon bonds in polymer backbone. These unsatturated bonds make these polymers thermoset and help them to be cured at room temperature using curing agent and accelerator.

Polymer concrete's excellent mechanical strength and durability reduce the need for maintenance and frequent repairs required by conventional concrete. An

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additional advantage of PC is its fast curing time, which is an asset in the production of precast parts [1].

Several researches have been performed on the physical and mechanical properties of polymer mortars and concretes based on polyester and epoxy resins. Polyester mortars manufactured by siliceous sand were studied [4-7]. It has been demonstrated that flexural properties depend on test temperature and thermal cycles.

The optimal content of epoxy and polyester resin in polymer concrete has also been investigated [8]. The results showed that the optimal quantity of resin is between 14 and 16%. It has been demonstrated that the exposure of both polymer mortars to temperatures below 110 ˚C does not affect significantly the overall mechanical properties although bending properties seemed more sensitive to thermal exposure than those in compressive properties.

The application of nano particles in polymer concrete was studied by Reis et al. [9]. It was found that mechanical properties of polymer mortar (PM), with different weight fraction of nano-Al_2O_3(alumina) and nano-Fe_2O_3(hematite) were lower than plain polymer mortar but a considerably stiffness increase was observed for all formulations tested.

The effect of atmospheric exposure of epoxy and fiber-reinforced epoxy polymer concrete was investigated to evaluate its fracture properties, such as stress intensity factor, K_{Ic} , and fracture energy, G_f [10]. The fracture properties of PC were evaluated by three-point bending tests after exposure to different weather conditions.

Flexural and compressive strength of PC when exposed to eight different aggressive conditions including; seawater, sulfuric, lactic, acetic, citric and formic acids, distilled water and soft drink has been investigated [11]. The flexural and compression test specimens were exposed to 14-day exposure cycles. Each exposure cycle consisted of immersing the samples for 7 days in a chemical solution and then 7 days in dry conditions. 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.

In this paper, flexural behavior of Orthophatalic unsaturated polyester polymer concrete after two and four months of immersion in ten chemical solutions including sulfuric, hydrochloric, nitric and citric acids, demineralized and potable water, sodium sulfate, gas oil, sodium and potassium hydroxides were assessed. The specimens tested after two and four months of exposure time. Polymer concrete beams were tested by three point bending apparatus up to failure.

2. EXPERIMENTAL PROGRAM

2. 1. Materials Orthophthalic unsaturated polyester resins were selected as binder in this research. The physical and mechanical properties of the resin are listed in Tables 1 and 2.

• **Resins**

TABLE 1. Physical properties of the polyester resin

Property	Value	Unit	TM
Viscosity	450-550	mPa.s	ASTM D2196
Acid value	20-25	mgKOH/g	ASTM D1639
Appearance	Clear	-	-
Colour	Max 2	Gardner	ASTM D1544
Solid content	65-67	%	ASTM D1259
Gel time	15-20	min	
Cure time	19-25	min	ASTM D7029
Peak temperature	150-190	˚C	
Shelf life	6	month	-
Density	1.1-1.2	g/cm^3	ASTM D1298
Water content	0.05-0.10	%	ASTM D4672
Flash point	35	˚C	ASTM D1310

TABLE 2. Thermal and mechanical properties of the resin

Property	Value	Unit	TM
Tensile strength	70-75	MPa	ASTM D638
Tensile modulus	3	GPa	ASTM D638
Elongation at break	2.5	%	ASTM D638
Flexural strength	110	MPa	ASTM D790
Flexural modulus	3.5	GPa	ASTM D790
Moulding shrinkage	8	%	ASTM D2566
Hardness	45-50	Barcol	ASTM D2583
HDT	82	˚ C	ASTM D648
Water abs.	0.19	%	ASTM D570

• **Aggregates**

Crushed gravel and sand were used as coarse and fine aggregate respectively. The properties of the aggregates are shown in Table 3. The maximum particle size of the aggregates was 10 millimeters.

TABLE 3. Physical properties of aggregate

Type of aggregate	Specific gravity	Absorption (%)	Fineness modulus
Sand	2.53	2.6	2.7
Coarse	2.56	2.46	6.5

2. 2. Methods

• **Mix design**

The mix proportions of polymer concrete formulations are presented in Table 4.

TABLE 4. Mixture proportions

Ingredients	(Kg/m^3)
Polymer	438
Sand	912
Gravel	842
Density	2192

• Flexural Test

The SANTAM Co. Universal Test Apparatus STM-150 used for flexural strength test in this study (Figure 1). The specimens were produced at dimensions of 100 mm *100 mm *500 mm [2 and 4]. The test was performed at loading rate of 2 mm / min according to the RILEM CPT PCM2 and PCM 8 standard test methods [12, 13].

Figure 1. SANTAM universal test Machine used in this study

• Chemical Aggressive

Ten different chemical solutions were selected as shown in Table 5 [7, 11]. Polymer concrete is considered an isotropic material and the plane cross-section theory was assumed. Three polymer concrete beams were used to determine Flexural strength of each sample.

TABLE 5. Chemical aggressive used in this study

Chemical aggressive	Concentrations of the solutions (wt.%)	pH of the solutions
H_2SO_4	5	0.45
HCl	5	0.1
HNO_3	5	0.5
Citric acid ($C_6H_8O_7$)	5	2.8
KOH	5	12.7
NaOH	5	13.5
Na_2SO_4	5	8.22
Gas oil	-	-
Potable water	-	8.3
Demineralized water	-	7.7

3. RESULTS AND DISCUSSIONS

The Flexural strength of specimens tested after two and four months of exposure time. Test results, in terms of flexural strength and flexural toughness (average values), are shown in Figure 2-13.

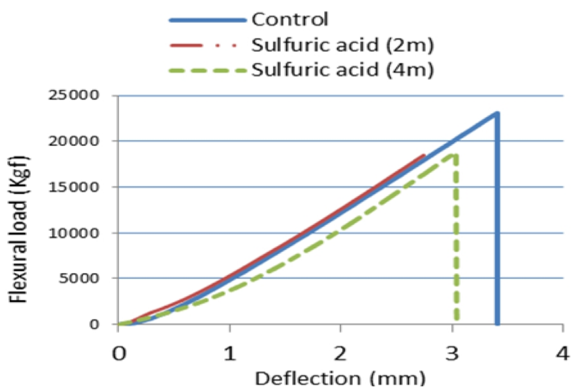

Figure 2. Flexural strength of the PC specimens against sulfuric acid after 2 & 4 months of exposures

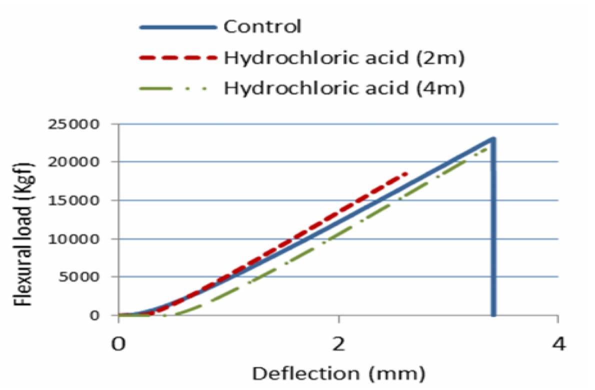

Figure 3. Flexural strength of the PC specimens against Hydrochloric acid after 2 & 4 months of exposures

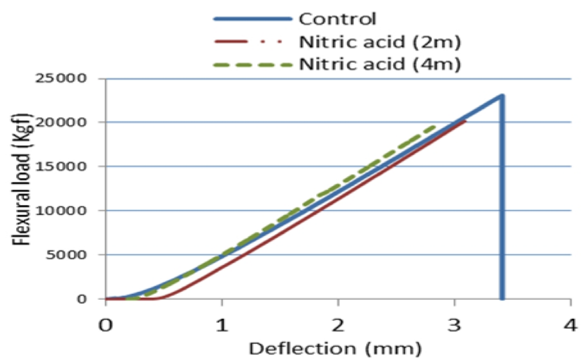

Figure 4. Flexural strength of the PC specimens against Nitric acid after 2 & 4 months of exposures

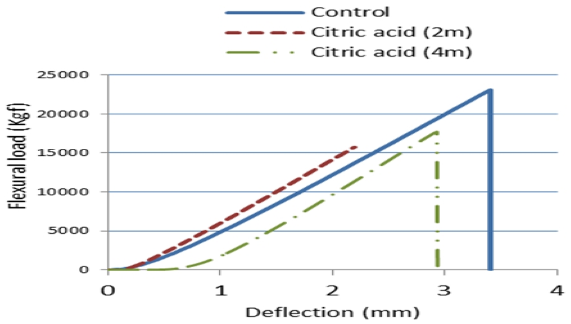

Figure 5. Flexural strength of the PC specimens against Citric acid after 2 & 4 months of exposures

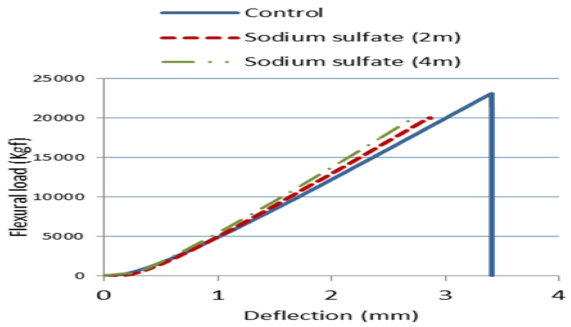

Figure 6. Flexural strength of the PC specimens against Sodium sulfate after 2 & 4 months of exposures

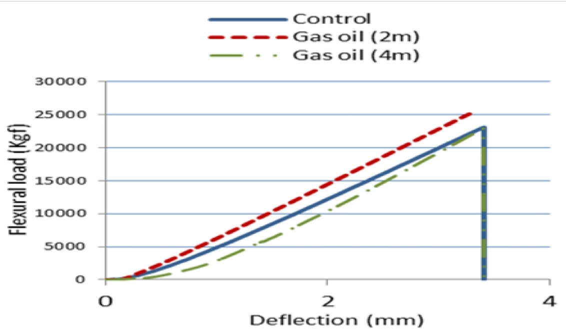

Figure 7. Flexural strength of the PC specimens against Gas oil after 2 & 4 months of exposures

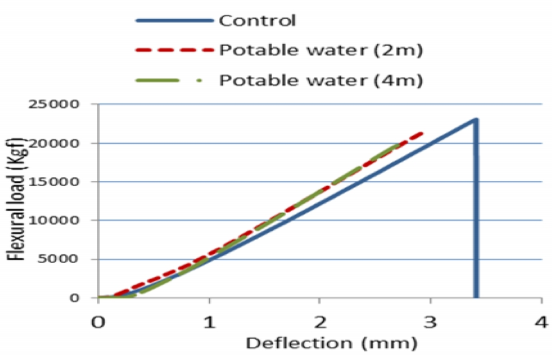

Figure 8. Flexural strength of the PC specimens against Potable water after 2 & 4 months of exposures

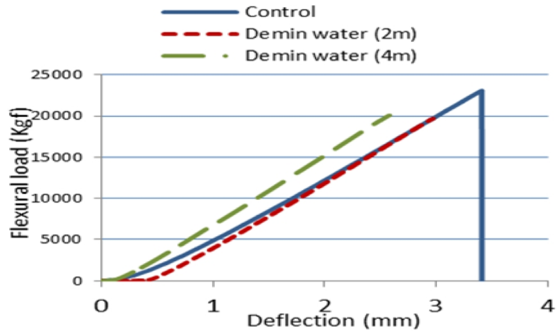

Figure 9. Flexural strength of the PC specimens against Demineralized water after 2 & 4 months of exposures

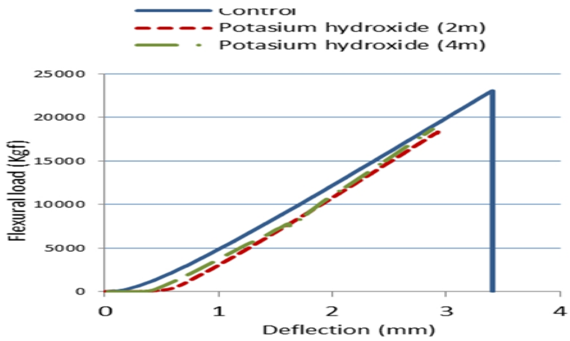

Figure 10. Flexural strength of the PC specimens against Potassium hydroxide after 2 & 4 months of exposures

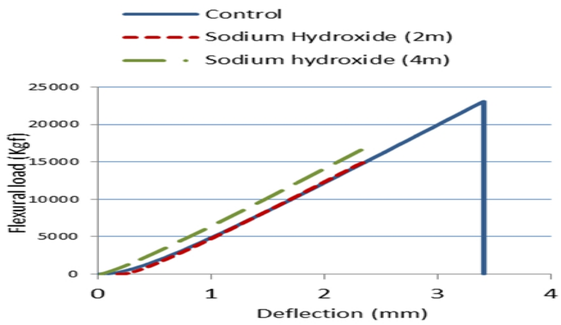

Figure 11. Flexural strength of the PC specimens against Sodium Hydroxide after 2 & 4 months of exposures

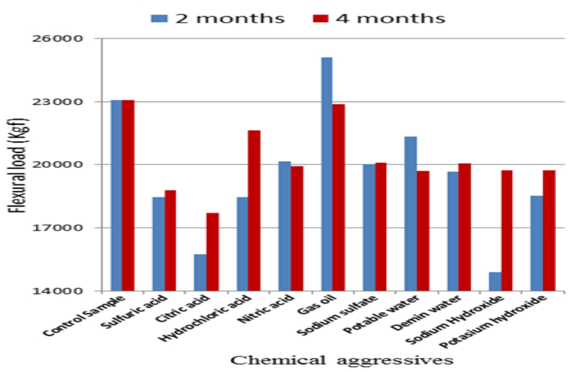

Figure 12. Flexural strength of the PC specimens against different chemicals after 2 & 4 months of exposures

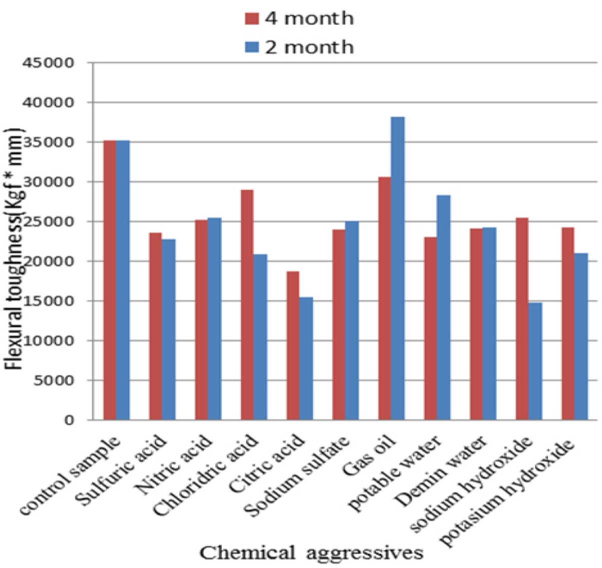

Figure 13. Flexural toughness of the PC specimens against different chemicals after 2 & 4 months of exposures

The results indicate decrease in the flexural strength of polymer concrete specimens when exposed to the most of the solutions. Results reveal higher decrease of the flexural strength in the alkali solutions in comparison to acid solutions. This was attributed to the hydrolysis of the resins at ester groups of the polymer chain in alkali environments.

Test results demonstrate considerable decrease of the flexural strength in the potable and demin water (especially in the latter one).

Figure 12 shows good retention of sustained flexural load for the specimens immersed in sulfuric acid, nitric acid, sodium sulfate and potable water between the two steps of the testing.

Also the results indicate that NaOH had the most destructive effect on the PC specimens after 2 months. This trend was changed to increasing of the flexural load after four months of exposure. It was attributed to the filling effect of reaction products in the pores.

After 4 months of exposure, citric acid had the highest effect on flexural strength. The specimens exposed to gas oil, nitric acid then sodium sulfate showed the lowest decrease in the strength in comparison to other chemicals. It was not seen a significant reduction in sustained flexural load of the specimens exposed to gas oil.

The area under the curve of Flexural force versus deflection that is called flexural toughness, calculated which results are shown in Figure 13. Results indicate a reduction in the flexural toughness of polymer concrete when exposed to degradation agents (except in the case of gas oil). The most aggressive conditions for PC was determined sodium hydroxide solution and citric acid.

5. CONCLUSIONS

The present study aimed to investigate the degradation of polymer concrete when submitted to different aggressive agents. Polymer concrete made with unsaturated polyester resin was tested at the ages 2 and 4 months immersion in ten chemical solutions.

- The higher average loss of flexural strength was 35.54% for sodium hydroxide after two months of exposure.
- Citric acid as an organic acid despite of higher pH comparing to other inorganic strong acids had higher impact on flexural strength. It was attributed to capability of swelling of the PC samples by this organic acid.
- The lower average loss of flexural strength was 0.87% which was attributed to specimens which exposed to gas oil. The PC specimens immersed in gas oil showed an unexpected increase of 8.7% after 2 months which this was attributed to swelling and absorbsion effects of gas oil on polyester resin.
- The flexural toughness of the specimens exposed to hydrochloric acid and sodium hydroxide was decreased dramatically in comparison to the other samples.
- Flexural toughness of the PC specimens after four months of exposuring to gas oil increase which this was attributed to the leaching and swelling effects of this solvent on the polyester resin.

It was found that the different chemical solutions have different effects on flexural strengths & flexural toughness of the PC specimens and this effect may changes by increasing the exposuring time.

7. REFERENCES

1. Gorninski, J.P., Dal Molin, D.C. and Kazmierczak, C.S., "Study of the modulus of elasticity of polymer concrete compounds and comparative assessment of polymer concrete and portland cement concrete", ***Cement and Concrete Research***, Vol. 34, No. 11, (2004), 2091-2095.
2. Jamshidi, M. and Pourkhorshidi, A., "A comparative study on physical/mechanical properties of polymer concrete and portland cement concrete", ***Asian Journal of Civil Engineering (Building and Housing)***, Vol. 11, No. 4, (2010), 421-432.
3. Kim, K. and Milstein, F., "Relation between hardness and compressive strength of polymer concrete", ***Construction and Building Materials***, Vol. 1, No. 4, (1987), 209-214.
4. Jamshidi, M. and Pourkhorshidi, A.R., "Modified polyester resins as an effective binder for polymer concretes", ***Materials and Structures***, Vol. 45, No. 4, (2012), 521-527.
5. Lokuge, W. and Aravinthan, T., "Effect of fly ash on the behaviour of polymer concrete with different types of resin", ***Materials & Design***, Vol. 51, No., (2013), 175-181.
6. Haddad, H. and Al Kobaisi, M., "Optimization of the polymer concrete used for manufacturing bases for precision tool machines", ***Composites Part B: Engineering***, Vol. 43, No. 8, (2012), 3061-3068.

7. Reis, J., "Effect of aging on the fracture mechanics of unsaturated polyester based on recycled pet polymer concrete", ***Materials Science and Engineering: A***, Vol. 528, No. 6, (2011), 3007-3009.
8. Elalaoui, O., Ghorbel, E., Mignot, V. and Ouezdou, M.B., "Mechanical and physical properties of epoxy polymer concrete after exposure to temperatures up to 250 c", ***Construction and Building Materials***, Vol. 27, No. 1, (2012), 415-424.
9. Reis, J., Moreira, D., Nunes, L. and Sphaier, L., "Experimental investigation of the mechanical properties of polymer mortars with nanoparticles", ***Materials Science and Engineering: A***, Vol. 528, No. 18, (2011), 6083-6085.
10. Reis, J. and Ferreira, A., "The effects of atmospheric exposure on the fracture properties of polymer concrete", ***Building and Environment***, Vol. 41, No. 3, (2006), 262-267.
11. Reis, J., "Mechanical characterization of polymer mortars exposed to degradation solutions", ***Construction and Building Materials***, Vol. 23, No. 11, (2009), 3328-3331.
12. Committee, R.T., "Method of making polymer concrete and mortar specimens", in Symposium on properties and test methods for concrete–polymer composites; proceedings, Oostende-Belgium, TC-113. (1995), 129-132.
13. CPT PCM-8. Method of test for flexural strength and deflection of polymer modified mortar. TC 113, RILEM, UK", (1995), 182-184.

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چکیده

بتن پلیمری یک ماده‌ی کامپوزیتی است که با ترکیب رزین و سنگدانه ساخته میشود. از مزیت های بتن پلیمری میتوان به پخت سریع در دمای محیط ، مقاومت فشاری و خمشی بالا، مقاومت شیمیایی مناسب و نفوذ پذیری کم اشاره کرد. در این پژوهش مطالعه‌ای مقایسه‌ای از تخریب بتن پلیمری ساخته شده از رزین پلی استر در محلول های شیمیایی مختلف صورت گرفته است. نمونه های بتن پلیمری پس از دو و چهار ماه قرار گیری در محیط های شیمیایی (مانند اسید سولفوریک، سدیم هیدروکسید، سدیم سولفات، اسید نیتریک، اسید هیدروکلریک، اسید سیتریک، آب مقطر، آب آشامیدنی، پتاسیم هیدروکسید و گازوئیل) به لحاظ مقاومت و چقرمگی خمشی ارزیابی شدند. نتایج نشان داد که بیشترین افت در مقاومت خمشی در آزمونه های بتن پلیمری قرار گرفته به مدت دو ماه در محلول سدیم هیدروکسید رخ داده است (معادل ٣٦٪). در مقایسه‌ی اثر اسیدها، مشخص شد که اسید آلی (یعنی سیتریک اسید)، علیرغم قدرت اسیدی کمتر نسبت به اسیدهای معدنی اثر تخریبی بیشتری را بر مقاومت خمشی بتن پلیمری داشته است. مقاومت خمشی و چقرمگی در تمامی محلول‌ها (به جز گازوئیل) طی دو و چهار ماه غوطه‌وری افت داشته است، با این حال افت محسوسی بین نتایج دو و چهار ماهه مشاهده نشد که حاکی از شروع واکنش‌های تخریبی طی دو ماه‌ی آغازین آزمون بوده است.

***doi**: 10.5829/idosi.ije.2015.28.07a.03*