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A COMPARATIVE STUDY ON PHYSICAL/MECHANICAL PROPERTIES OF POLYMER CONCRETE AND PORTLAND CEMENT CONCRETE

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ABSTRACT

Polymer concretes (PC) were introduced to building and construction industry more than 50 years ago. Gradually, they became a suitable substitute for concrete structures; however, their application was shortly diminished due to the higher costs.

In this research a homemade cost-quality effective resin (unsaturated polyester) is used as binder in the polymer concrete production. Laboratory specimens made and evaluated for physical/mechanical tests. A comparative study was performed on the polymer concrete specimens, the ordinary Portland cement concrete (normal concrete) and the durable concrete specimens. It was found that the PC materials show much better physical/mechanical properties than the durable concretes.

Keywords: Polymer concrete; isophthalic polyester resin; concrete; mechanical; chemical properties

1. INTRODUCTION

Polymer concrete (PC) is a composite material in which resin is used as binder for aggregates instead of Portland cement [1-2].

Polymer concrete materials were originally developed as a substitute for decorative stones. They become particularly popular in construction industry during the early 1950s [3-4]. Superior characteristic of these materials led to their increased utilization during 1980s when they were used to repair damaged Portland cement concrete structures [5-6].

Polymer concrete offers higher strength and ductility, and faster curing than the ordinary Portland cement (OPC) concrete. Some of these properties include more rapid curing, higher mechanical strength, better adhesion to substrate, higher resistance to chemicals, lower water impermeability and etc. [3,7].

Various resins such as epoxies, Polyesters and acrylics have been used as binder in polymer concrete production. However, recently vinyl ester, furan and polyurethane resins are also incorporated for special-purpose polymer concretes [1,3, 8].

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Unlike other resins, application of polyester resins as binder leads to a weaker polymer concrete. Nonetheless, they are the more commonly used resins in PC [9] due to their lower cost and reasonable performance.

In this study, authors reviewed characteristics of a polymer concrete composite made by using unsaturated isophthalic resin.

In order to illustrate characteristics of this type of PC a durable concrete was prepared and examined. As a result, the researchers came up with suggestions and appropriate applications to produce a cost-effective and durable PC.

2. EXPERIMENTAL

2.1 Materials Aggregates

Crushed gravel and sand were used as coarse and fine aggregate respectively. The properties of aggregates are shown in Table 1.

Figures 1 and 2 show distribution of particle size in the aggregates.

Table 1: Aggregate properties

Type of aggregate	Specific gravity	Absorption (%)	Fineness modulus
Sand	2.53	2.6	2.7
Coarse	2.56	1.46	6.5

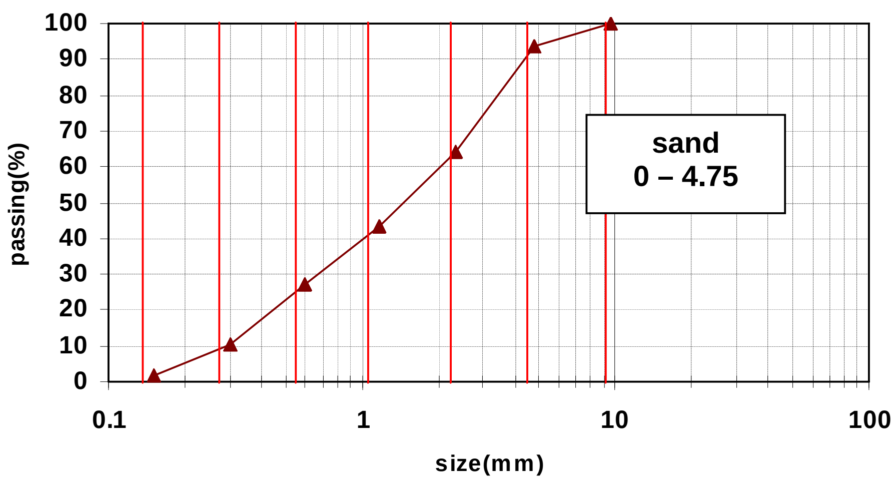

Figure 1. Curve of grading of the sand

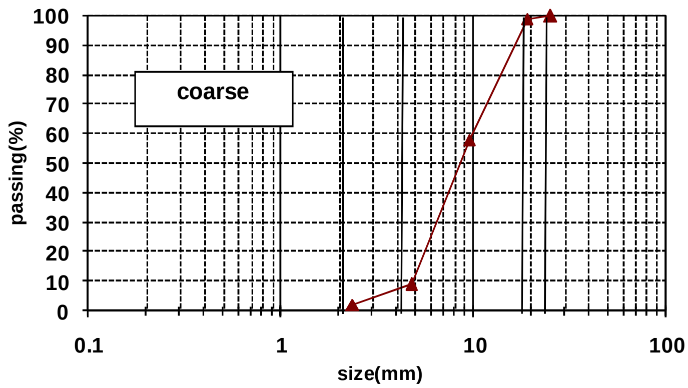

Figure 2. Curve of grading of coarse

Cement

ASTM type II Portland cement was used in this experiment. Chemical composition and physical properties of the cement are shown in Table 2.

Table 2: Chemical compositions of Portland cement (Type II)

Components	**Type II**
SiO_2	20.96
Al_2O_3	4.2
Fe_2O_3	4.6
MgO	3.4
CaO	61.88
SO_3	1.79
Na_2O+0.658 K_2O	1.47
C_3S	52.74
C_2S	20.31
C_3A	7.35

Polymer

An isophthalic polyester resin was used in PC compound preparation.

2.2 Tests

Specimens were tested for the followings:

a- Compressive strength

Compressive strength, measured based on EN 12390-3.

b- Flexural strength

Flexural strength, determined based on DIN 1048-5.

c- Tensile splitting strength

Tensile splitting strength, measured based on DIN 1048-5

d- Static modulus of elasticity

Static modulus of elasticity, determined based on DIN 1048-5.

e- Depth of water penetration

Depth of water penetration, determined based on EN 12390-8.

f- Rapid chloride permeability

Rapid chloride permeability, measured based on ASTM 1202.

2.3 Concrete mixtures

Mixture proportions of polymer concrete samples are summarized in Table 3. To illustrate improvements in the polymer concrete performance durable (DC) and normal (NC) concretes were made, simultaneously.

Table 3: Mixture proportions and fresh concrete properties

Mixture	**w/c**	**Water (kg/m^3)**	**Cement (kg/m^3)**	**Polymer (kg/m^3)**	**Sand (kg/m^3)**	**Coarse (kg/m^3)**	**Density (kg/m^3)**
PC	-	-	-	438	912	842	2192
NC	0.6	225	375	-	912	842	2215
DC	0.4	150	375	-	912	842	2215

The polymer concrete mixture was designed based on a suitable aggregate grading and desired slump. In order to achieve the designed mixture, the amount of polymer used was equivalent to 25% of the aggregate weight.

2.4 Tests on fresh concrete

a) Determination of density

Density of fresh concrete was evaluated based on EN 12350-6. Results are shown in Table 4.

b) Determination of workability

Workability of fresh concrete was determined by slump test based on EN 12350-2. Results are shown in Table 4.

2.5 Curing of specimens

After mixing the concrete, it was cast into the moulds. Control specimens were remained in the moulds under laboratory conditions for a day. Then they were removed and transferred to the curing basin. They were then tested after 7, 28 and 90 days of curing.

Polymer concrete specimens were cured after 2 hours at ambient temperature. They were tested at the same curing times as for the control samples.

2.6 Tests on hardened concrete

Hardened specimens were used to evaluate physical and mechanical properties of the samples. The tests included determination of compressive, flexural and tensile splitting strength, static modulus of elasticity, depth of water penetration, rapid chloride ion permeability and resistance to sulfuric acid.

3. RESULTS AND DISCUSSIONS

3.1 FTIR analysis of Resin

The used resin for PC compound preparation was characteristically studied using FTIR analysis. Results are shown in Figure 3.

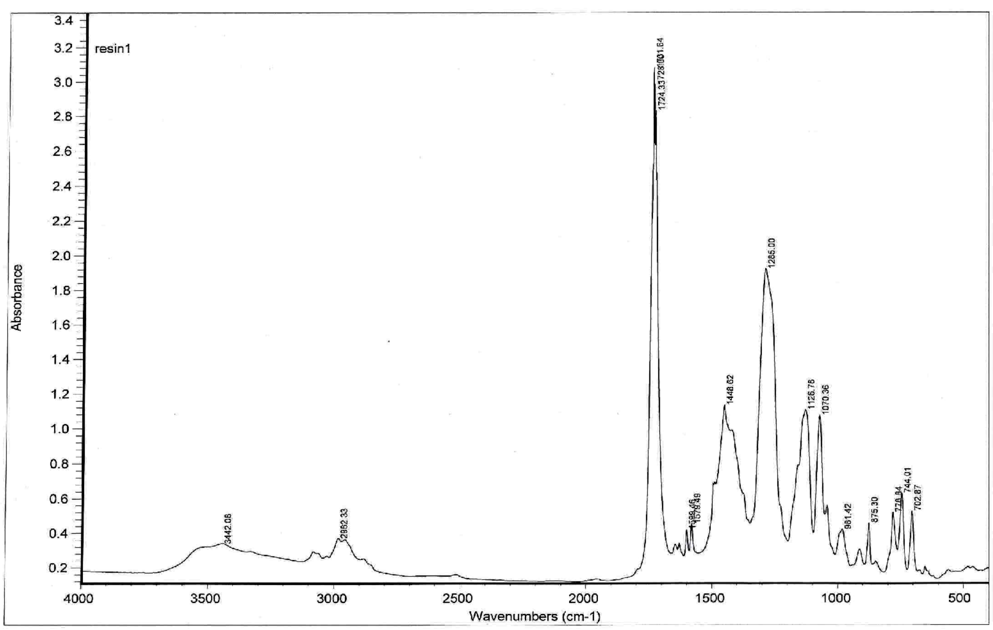

Figure 3. FTIR analysis of resin used in polymer concretes

In this figure adsorption of resin bonds are plotted against the wavelength. At the wavelength of 3440cm^{-1} there is a broad and weak peak which is ascribed to the hydroxyl (-OH) groups. Keeping in mind the fact that adsorption of hydroxyl group is usually very strong and evident peak in this region; we can conclude the following characteristics for this resin:

1. More hydroxyl groups of the resin have been blocked (i.e. reacted with the functional groups of other resin or admixtures) therefore this weak peak is related to some non-reacted hydroxyl groups or,
2. It is also probable that the resin has long chains in structure (i.e. it is a high molecular weight resin) therefore its hydroxyl groups are few in comparison to the length of the chains.

Further, the second adsorption peak at 1070 cm^{-1} conform the presence of primary hydroxyl group in the resin too.

Another adsorption peaks at 2980cm^{-1} and 1100 cm^{-1} belongs to the C-H bonds. Also, the peak of 1400 cm^{-1} is related to the adsorption of Methylene (CH_2 and CH_3) groups.

The strong peak at 1700 cm^{-1} is related to keton (C=O) bonds. Another strong peak in the figure is located on 1280 cm^{-1} which belongs to ether(C-O) bonds adsorption. This is an indicator of the fact that the resin has many ester (-CO-O-) groups and is called a polyester resin.

The weak double bonds adsorption at 1500 and 1600cm^{-1} are attributed to the aromatic groups (benzene) of the compound. This could suggest using adsorptions at the regions of 700 to 800 cm^{-1}. However these peaks are related to the two substitutes benzene groups in meta situation and are attributes of the aromatic groups of isophthalic polyester resins.

This is also evident of the presence of unsaturated C=C bonds in the resin in the form of alkenes. This could be confirmed by using the weak adsorption peak at 3100 cm^{-1} and the second peak at 980cm^{-1}.

Even though the resin used for PC preparation was introduced as an isophthalic polyester brand, it clearly is not a pure resin but chemically modified.

Modification of the resins is a traditional method to improve chemical and mechanical properties of the low cost materials in the industry. Isophthalic polyester resin is the most economical with reasonable properties amongst resins used for PC production.

Modification of polyester resin promotes adhesion and improves mechanical and chemical properties of the resin. As a result, this has turned the resin into an excellent choice for preparation of polymer concrete repairing materials to protect old concrete structures exposed to sever environmental conditions (offshore or onshore systems). In addition, using thin sheets of PC is recommended due to the high costs of the PC in comparison to similar competitive materials.

3.2 Compressive strength

150mm concrete cubes were used to determine compressive strength. Specimens were tested in different ages of 7, 28 and 90 days. Results are shown in Figure 4.

The compressive strength of polymer concrete mixture was very high immediately after short time of curing (even after one day of curing). It is noted that the compressive strength of polymer concrete mixture is about 100 MPa at the day 7, however nearly constant at different ages of curing. Referring to standards of DIN 54815-2, minimum requirement for compressive strength of polymer concrete materials used in jacking pipes should be 80 MPa. Therefore we can conclude that this type of resin is suitable in production of sewer pipes.

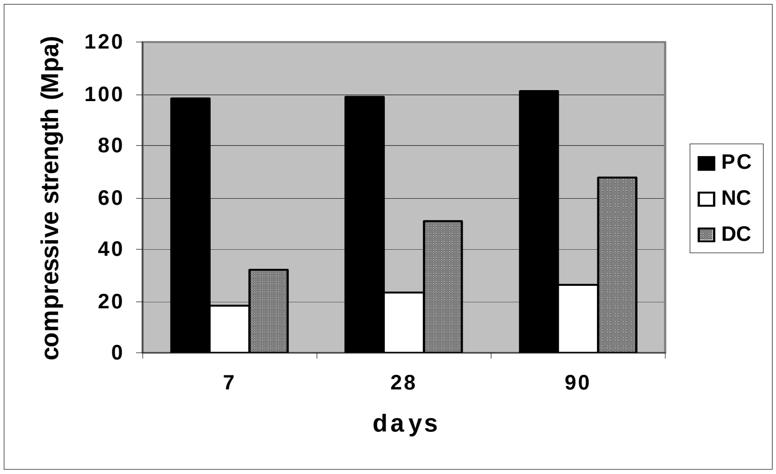

Figure 4. Compressive strength of concrete versus age

Normal concrete specimens (NC) had a much lower compressive strength than the dorable concrete specimens (DC).

Although DC specimens had a suitable increasing rate of compressive strength at different ages, they were much lower in strength compared to the polymer concrete ones. For example, at day 28 of curing their compressive strength was measured at 50% of that for the polymer concrete.

Based on these findings, we could suggest that the polymer concrete mixtures are a good choice in building structures requiring high primary strength or structures constructed under severe environmental conditions. It is well known that even durable concrete does not perform well under such conditions.

3.3 Flexural strength

Flexural strengths were measured using 100×100×500 mm concrete specimens. Results are shown in Figure 5.

The flexural strength of NC specimens was shown to be much lower than all other specimens. This process was repeated in the following tests as well.

The flexural strength of polymer concrete is significantly different than that of the durable type at the early stages. However, throughout the time of the experiment it stays approximately constant similar to its compressive strength. The flexural strength of durable concrete increases during time too although it is much lower than that for the polymer concrete. For example, it was about 45% of that for the polymer concrete specimen in this experiment.

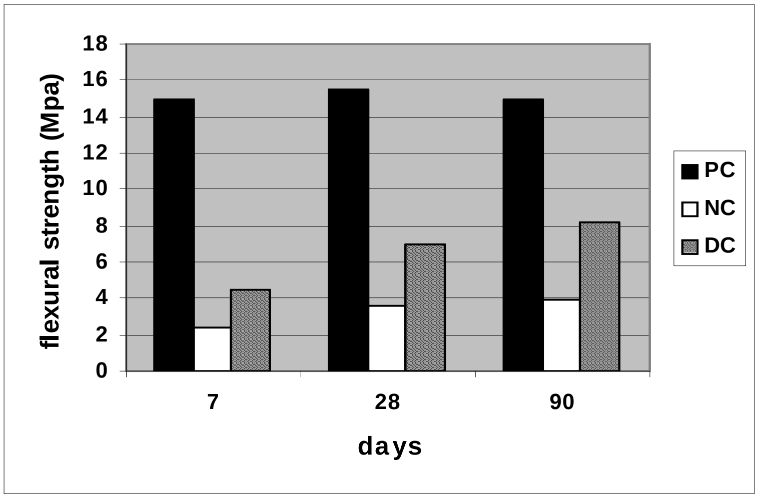

Figure 5. Flexural strength of concrete versus age

As noted earlier, the polymer concrete mixtures are clearly a more suitable choice for building structures bearing highly compressive and bending loads at early ages of moulding (such as !pier!of bridges, offshore concrete structures, strategic onshore structures).

3.4 Tensile splitting strength

Specimens used to determine the tensile splitting strength were cylindrical, 150 mm in diameter and 300 mm in height. Results are shown in Figure 6.

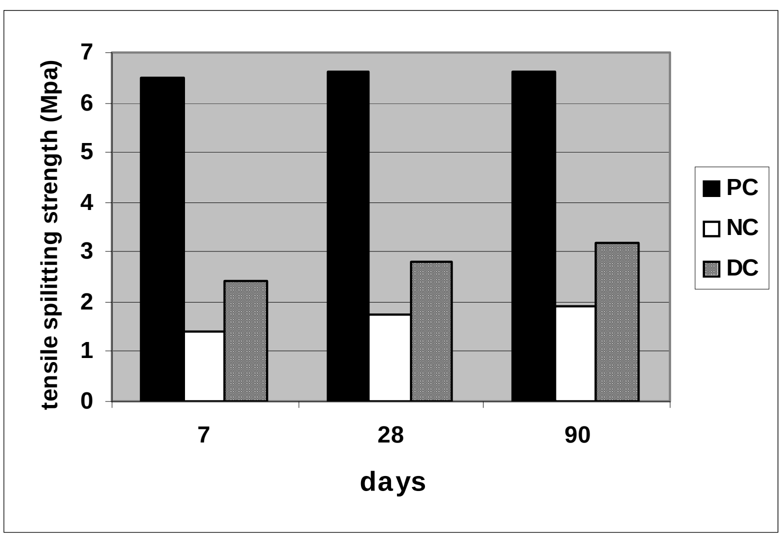

Figure 6. Tensile splitting strength of concrete versus age

The tensile splitting strength of polymer concrete was 3 times as high as that for the durable concrete but it was constant during different curing time. Whereas, the splitting strength of the durable concrete specimens increased by curing time.

3.5 Static modulus of elasticity

Specimens used to determine the static modulus of elasticity were cylindrical, 150 mm in diameter and 300 mm in height. Results are shown in Figure 7.

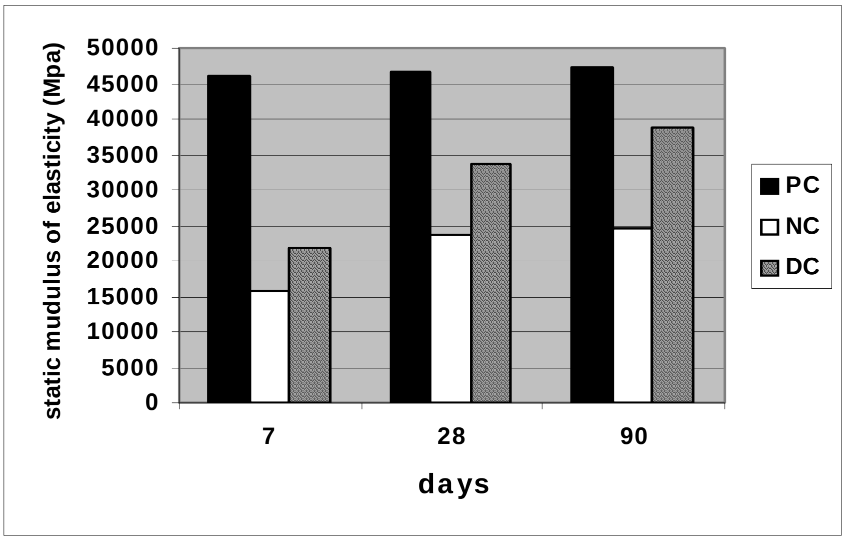

Figure 7. Static modulus of elasticity of concrete versus age

Higher modulus of elasticity was expected for polymer concrete specimens than those for the durable concrete due to their higher compressive strength. The results of Figure 7 demonstrate this feature too. However, the difference in modulus of elasticity between the two is lower than it is in their compressive strength, at the age of 90 days in particular.

3.6 Rapid chloride permeability test

This test was performed based on the ASTM 1202 method, at the age of 28 and 90 days. Tests results are given in Figure 8.

The total passed charge was zero for polymer concrete specimens and negligible for the durable concrete. Keeping in mind the fact that the passed charge for normal concrete is usually significantly high**,** this result shows that the polymer concrete is a resistant and suitable protective material for chloride attack (e.g. corrosion by seawater).

3.7 Depth of water penetration test

This test was performed based on EN 12390-8 method at the age of 28 and 90 days. Results are given in Figure 9.

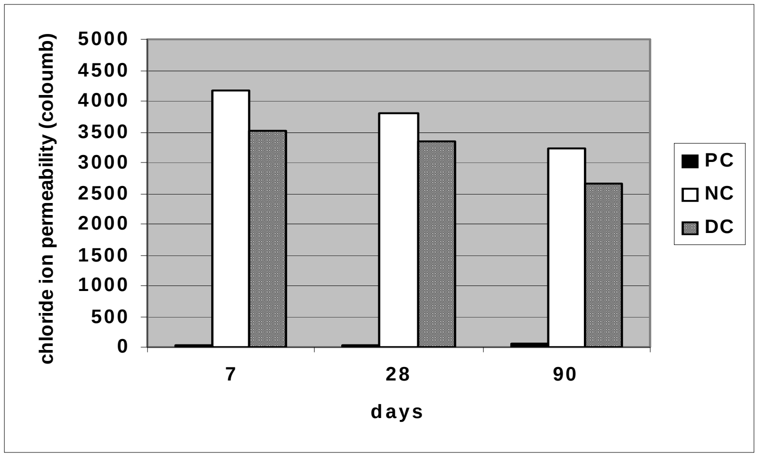

Figure 8. Rapid chloride permeability test of concrete versus age

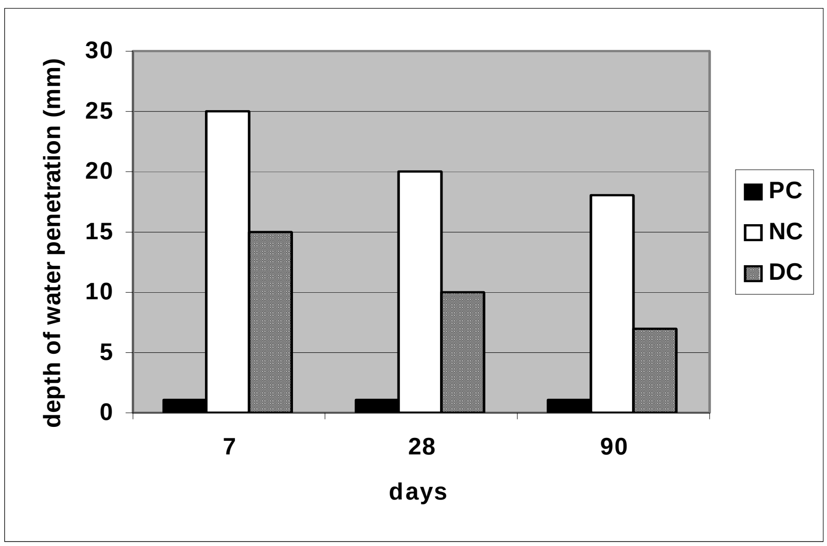

Figure 9. Depth of water penetration of concrete versus age

Water penetration into polymer concrete specimens was negligible at different ages. Moreover, the depth of penetration for durable concrete was low especially in comparison to normal concretes.

Although formulating high performance concretes (HPC) for special-purpose structures (low permeable) is a possibility, polymer concrete mixtures with simple mixing design have clearly very low permeability for water and chloride ion and therefore are most practical for protection of concrete and armature metallic substrates exposed to corrosive condition.

3.8 Resistance to sulfuric acid

The prepared specimens of PC, NC and DC after 28 days of curing were immersed in one normal sulfuric acid for 180 days. Thereafter, they removed from acid solution and tested for compressive strength. Results are shown in Figure 10.

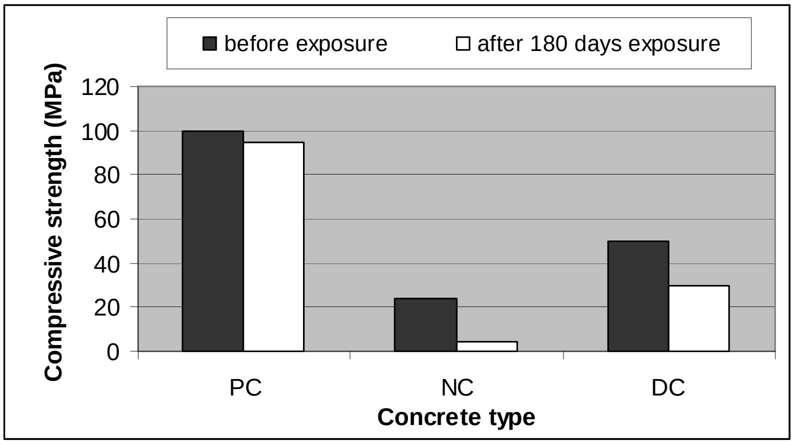

Figure 10. Compressive strength after 180 days of exposure to sulfuric acid

It is evident that the polymer concrete specimens had about 5% decrease in compressive strength after 180 days of exposure, while the normal concrete specimens actually degraded after 70 days and showed more than 80% decrease in compressive strength after 180 days of acid exposure. Although, the DC specimens showed better resistance than NC specimens but they also showed about 40% decrease in compressive strength in acid solution after 180 days of exposure.

The concretes made by Portland cement showed week performance in this test because of decomposition of cement hydration products (CH and CSH) in sulfuric acid solution. Albeit, the normal concrete specimens degrade from surface and depth due to high water penetration rate, but durable concrete degrade from surface at first.

4. CONCLUSIONS

Plastic resins such as polyesters, acrylics and epoxies are used as binder for aggregates in the polymer concrete (PC) materials. Essentially the PC materials have higher compressive, tensile and flexural strength in comparison to the cement base materials.

The isophthalic polyester resins are one of the most popular resins in the PC production due to their reasonable cost-quality balance.

In this research, properties of the polymer concrete specimens, made using a unsaturated polyester resins, were compared to those of the durable and the normal concrete specimens.

On the basis of the results it was found that the polymer concretes made by home made Orthophtalic polyester resin show much more mechanical properties than the normal and even the durable concrete.

The results of long term acid resistance test showed that the compressive strength of PC, NC and DC specimens after 180 days of exposure to sulfuric acid decrease about 5, 85 and 40%, respectively.

Due to the excellent performance of the polymer concrete specimens in depth of water penetration and chemical resistance tests, it was postulated that they should perform well in corrosive and aggressive environments. Although, due to the high costs of the polymer concrete materials these are not good choices for mass concrete production, but they are very good materials for thin sheet repair of old concrete structures and factory made pre-cast products.

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