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Studying the Effect of Hydrocarbon Solutions on the Properties of Epoxy Polymer Concrete

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***Abstract*—**The destruction effect of hydrocarbon solutions on concrete besides its high permeability have led researchers to try to improve the performance of concrete exposed to these solutions, hence improving the durability and usability of oil concrete structures. Recently, polymer concrete is considered one of the most important types of concrete, and its behavior after exposure to oil products is still unknown. In the present work, an experimental study has been carried out, in which the prepared epoxy polymer concrete immersed in different types of hydrocarbon exposure solutions (gasoline, kerosene, and gas oil) for 120 days and compared with the reference concrete left in the air. The results for outdoor specimens indicate that the mechanical properties are increased after 120 days, but the specimens that were immersed in gasoline, kerosene, and gas oil for the same period show a reduction in compressive strength by -21%, -27% and -23%, whereas in splitting tensile strength by -19%, -24% and -20%, respectively. The reductions in ultrasonic pulse velocity for cubic specimens are -17%, -22% and -19% and in cylindrical specimens are -20%, -25% and -22%, respectively.

***Keywords*—**Epoxy resin, hydrocarbon solutions, mechanical properties, polymer concrete, ultrasonic pulse velocity.

I. Introduction

OIL has gained a special importance in various aspects of life because it is considered as a basic source of energy all over the world. For this reason, countries, whether importing or exporting oils, try to store crude oil and its products for the time of necessity. Usually oil has been stored or transported successfully by steel structures but as a result of the critical shortage and problems of serviceability, safety and high maintenance costs, large concrete structures are used for oil production, transportation and storage due to low cost of repair, maintenance, and construction. In addition, concrete offers considerable resistance to fire and explosive during war times [1].

In spite of the many advantages of concrete, the use of oil storage concrete structures is still limited due to some restrictions such as the leakage of oil through concrete leads to decrease its strength and the bond strength between cement and aggregate or between reinforcement and concrete. The ingress of oil to the concrete may cause deterioration in the reinforced concrete tanks, leading to cracking and spalling in it.

Oil products will not cause corrosion directly, but they may cause deterioration or reduce the bond between steel and concrete. For that reason, the permeability of concrete becomes a priority interest to designers of industrial and liquid storage concrete tanks [2].

Polymer concrete (PC) is a particulate composite where thermoset resin binds inorganic aggregates instead of the water and cement binder typically used in Portland cement concrete (PCC). Polymer concrete composites have generally good resistance to attack by chemicals and other corrosive agents, have very low water sorption properties, good resistance to abrasion, and marked freeze-thaw stability. Also, greater strength of polymer concrete in comparison to that of Portland cement concrete permits the use of up to 50% less material. This puts polymer concrete on a competitive basis with cement concrete in certain special applications. The chemical resistance and physical properties are generally determined by the nature of the polymer binder to a greater extent than by the type and the amount of filler. In turn, the properties of the matrix polymer are highly dependent on time and the temperature to which it is exposed.

Because of the use of a polymer instead of Portland cement represents a substantial increase in cost, polymers should be used only in applications in which the higher cost can be justified by superior properties, low labor cost or low energy requirements during processing and handling. Therefore, it is important that you should have some knowledge of the capabilities and limitations of PC materials in order to select the most appropriate and economical product for a specific application [3].

Several studies have been carried out to evaluate the performance of polymer concrete with various resins and mix proportions of aggregates.

Varughese and Chaturvedi have used fly ash as fine aggregate in polyester based polymer concrete. Mechanical strength and resistance to water absorption with addition of fly ash as filler were improved up to 75% [4].

Gorninski et al. have assessed and compared polymer concrete with Portland cement concrete. The modulus of elasticity of polymer concrete compounds has been measured. Based on reported data, there was an increase in axial compressive strength as concentrations of fly ash increased. Furthermore, high modulus of elasticity values was obtained and the peak value was 29 GPa [5].

Golestaneh et al. evaluated the mechanical properties of epoxy polymer concrete reinforced with silica powder. The results showed that the compressive strength of polymer concrete reinforced with silica powder in comparison with cement concrete was enhanced by four folds [6].

Reis studied the fracture mechanics (toughness and energy), at early ages, of polymer concrete made with unsaturated

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polyester resin as a binder. The results indicated that the fracture parameters (toughness and energy) decrease and the brittleness increases with the age of the polymer concrete [7].

Abdul Hadi and Omar studied the effect of oil products on the mechanical properties of polyester resin concrete. The results showed that the compressive strength of specimens immersed 90 days in gas oil, kerosene and gasoline was decreased by 26.31%, 44.73% and 13.15%, respectively [8].

The purpose of this study was to compare the compressive strength, splitting tensile strengths, and ultrasonic pulse velocity (UPV) of epoxy polymer concrete immersed in gasoline, kerosene, and gas oil for 120 days with the reference specimens left in air. The goal of the experimental study was to obtain PC specimens with superior characteristics and high mechanical strength.

II. Experimental Work

A. Specimens Preparation

For preparing the PC specimens, AL- Ekhaider sand (4.75 mm maximum size), coarse aggregate crushed to 37.5 mm maximum size, and a commercial epoxy resin were used. A dry mixing had been done for both fine and coarse aggregate for 3 minutes in a dry plastic container and then the epoxy resin was added to the mix after mixing with the hardener in 0.01% of its weight and then poured into the molds. After 24 hours, the molds were removed and the specimens were cured in air for a period of 28 days.

B. Mixing and Proportion

Two mixes design were used in this work: (1: 1: 2) 100 mm *100 mm *100 mm cubic specimens and (1: 2: 4) 100 mm * 200 mm cylindrical specimens were used for compressive strength, splitting tensile strength, and UPV tests. It had no percent of cement and water. Tables I and II show the details of used mixture.

TABLE I
DETAILS OF CUBIC SPECIMENS MIXTURE USED THROUGHOUT THIS STUDY

Epoxy kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3
529	529	1058

TABLE II
DETAILS OF CYLINDRICAL SPECIMENS MIXTURE USED THROUGHOUT THIS STUDY

Epoxy kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3
426	852	1704

C. Test Procedure

1. Compressive Strength

The compressive strength test was determined according to B.S.1881, part 116 specification [9]. This test was made on 100 mm * 100 mm * 100 mm cubes using an electrical testing machine with a capacity of 2000 kN. The test was conducted at ages of 30, 60, 90, and 120 days of exposure to oil products at room temperature after 28 days air curing. The compressive strength of the specimen was calculated by dividing the maximum load applied on the specimen during the test by the average cross-sectional area of the specimen.

$$Compressive\ strength = \frac{force}{area} \quad (1)$$

where compressive strength in (MPa), force in (N), and area in (mm^2).

2. Splitting Tensile Strength

A concrete cylinder is placed with its horizontal axis between platens of a testing machine; the splitting tensile strength test was done according to ASTM C496-86 specification [10]. Cylinders of 100 mm * 200 mm were used and load was applied continuously up to failure using a standard testing machine of 2000 kN capacity. The test was conducted at ages of 30, 60, 90, and 120 days of exposure to oil products after 28 days air curing.

$$Splitting\ tensile\ strength = \frac{2P}{\pi\, D\, L} \quad (2)$$

where splitting tensile strength in (MPa), (P) maximum applied load in (N), (D) diameter of specimens in (mm), and (L) length of the specimens in (mm).

3. *UPV*

The test was carried out according to ASTM C597-02 [11]. Cubic and cylindrical specimen with dimension of (100 mm * 100 mm * 100 mm) and (100 mm * 200 mm) were used in this test. The accuracy of the dial measurement was checked against a calibration circuit. The faces of the transducers were pressed against the sides of the test specimens after establishing contact through coupling medium. Wetting the test specimen with grease was made to exclude entrapped air between the contact surfaces of the transducer and the surface of the test specimen. By moving the transducers, the average time interval was conducted. The test was conducted at ages of 30, 60, 90, and 120 days of exposure to oil products after 28 days air curing. Finally, the velocity of ultrasonic waves passing through the concrete is calculated by:

$$Ultrasonic\ pulse\ velocity = \frac{L}{T} \quad (3)$$

where UPV in (km/s), L length of specimen in (mm), and (T) effective transient time (μ s).

After that the compressive strength is obtained by using:

$$\sigma = 2.8\, Exp\, [0.53 * V] \quad (4)$$

where (σ) compressive strength in (N/mm^2) and (V) velocity of ultrasonic waves in (km/s) [12].

III. Results and Discussion

A. Compressive Strength

Compressive strength is the most important property of concrete since the first consideration in structural design is that the structural elements must be capable of carrying the imposed loads. Fig. 1 summarizes the results of compressive strength values for epoxy resin concrete at various periods of immersion in oil products relative to reference concrete left in air. The compressive strength results for epoxy concrete specimens show an increase due to high density, less porosity, and good dispersion of polymer particles within the pore volume thereby eliminate the large pores. Whereas the results for concrete specimens immersed in oil products show a continuous decreasing in compressive strength with immersion time increasing. This behavior occurs because of that the oil products decrease the compatibility and bond strength between the resin polymer with aggregate due to the penetration of oil products into the microstructure of concrete leading to weak adhesion and cohesion forces, agreed with Ali [13].

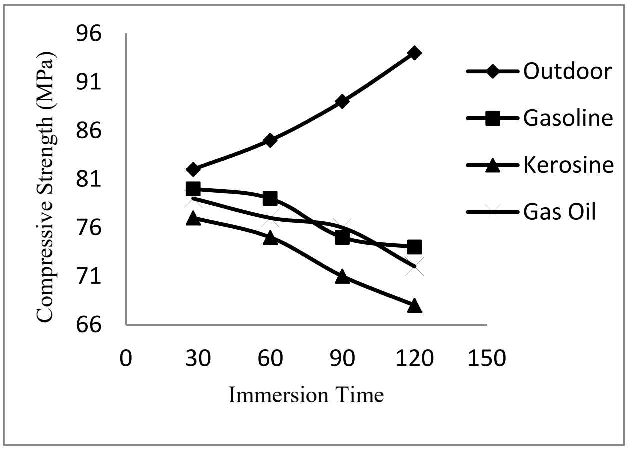

Fig. 1 Compressive strength results for epoxy concrete specimens at various ages of immersion in oil products and outdoor concrete

B. Splitting Tensile Strength

Splitting tensile strength is an important property, since cracking in concrete is mostly occurred due to the tensile stresses that occur under load, the failure of concrete in tension is governed by microcracking, associated particularly with the interfacial transition zone (ITZ) [15]. Fig. 2 summarizes the results of splitting tensile strength values for epoxy resin concrete at various periods of immersion in oil products relative to reference concrete which left in air. Results demonstrate that the splitting tensile strength shows a considerable increase at all testing periods for specimens cured in air and this increasing may be because of the formulation of three-dimensional networks of polymer molecules through the concrete which increases the binder system due to good bond characteristics of the polymer [16]. On the other hand, when the specimens were immersed in oil products, they show decrease in splitting tensile strength values during 120 days of immersion that due to the deterioration of concrete exposed to oil products and the effect of bond between aggregate and epoxy resin due to increase in micro cracks in the microstructure of concrete specimens, agreed with Faiyadth [17].

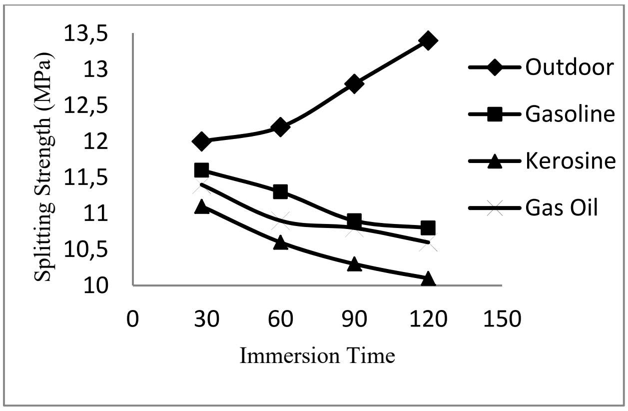

Fig. 2 Splitting tensile strength results for epoxy concrete specimens at various ages of immersion in oil products and outdoor concrete

C. UPV

Ultrasonic measurements are used in structural engineering to determine material characteristics, detect defects, and assessment of deterioration. An indicated property value, such as UPV, is determined using laboratory specimens. Field measurements are compared with the indicated property value to estimate the condition of the material. The ratio of field UPVs to the indicated UPV clarifies the level of material deterioration [14]. Fig. 3 and Fig. 4 indicate the results of estimated compressive strength by UPV for epoxy resin concrete at various periods of immersion in oil products relative to reference concrete left in air for cubes and cylinders, respectively.

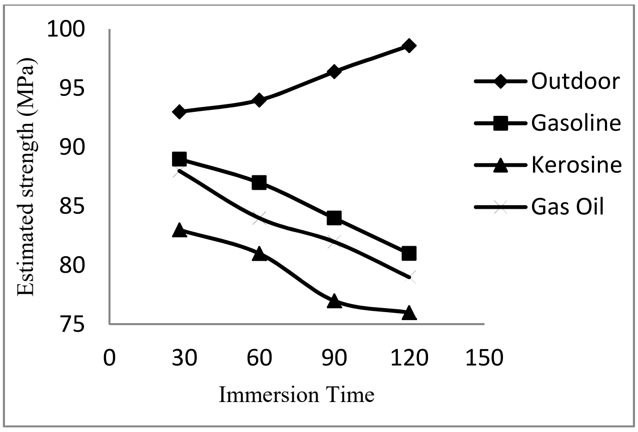

Fig. 3 Estimated compressive strength results by UPV for epoxy concrete cubes at different periods of immersion in oil products and reference concrete

As in compressive strength results the UPV for specimens exposed to oil products decreases as the exposures periods increases. The air curing specimens show an increasing in UPV values due to the high compatibility of the polymer resin with aggregate, which agreed with Hassan [18].

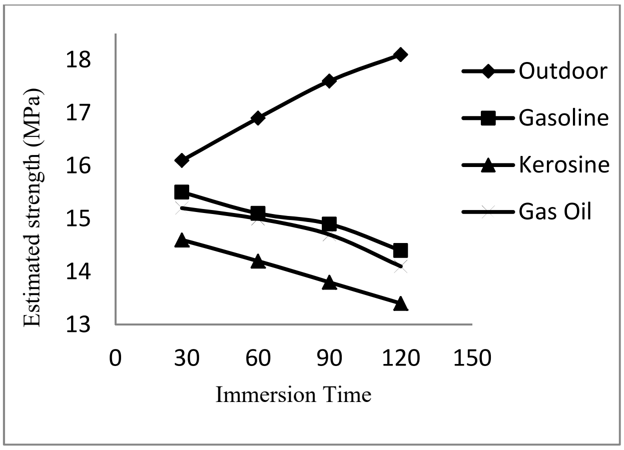

Fig. 4 Estimated compressive strength results by UPV for epoxy concrete cylinders at different periods of immersion in oil products and reference concrete

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