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Effect of Crude Oil Products on the Mechanical Characteristics of Reactive-Powder and Normal-Strength Concrete

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Abstract

This study includes detailed information on the mechanical characteristics of the hardened concrete mix for normal concrete (NSC) and reactive powder concrete (RPC) after exposure to crude oil products. Two types of crude oil products (kerosene and gas oil) were investigated after exposure for a period of 180 days. The experimental program consisted of three sets of NSC and RPC specimens; after curing all concrete specimens for 28 days and 2 days to dry in the air, the first set of specimens was immersed in kerosene for 180 days and the second set was immersed in gas oil for the same age, while the third set was left in the air as a reference set (cured normally for 28 days and tested at the age of 180 days). The results showed that the mechanical characteristics of the RPC mix were not highly affected after exposure to each type of crude oil products, where it lost about (3.41–6.32 %) compared with reference RPC mix. While the NSC mix lost about (13.82–21.95 %) of its mechanical characteristics compared with reference NSC mix after exposure to crude oil products for the same period.

Keywords

crude oil, crude oil storage tanks, normal concrete (NSC), Reactive Powder Concrete RPC, durability, permeability

1 Introduction

The concrete durability in various environments is catching more attention recently as the consumption of concrete has increased significantly around the world. Designers try to design concrete structures with long term performance and good serviceability. Nevertheless, up to the current day just rather limited investigations about the performance of concrete in the physicochemical environments with organic active polar molecules such as crude oil.

Crude oil is a combination of hydrocarbons produced by animals and plants, which existed thousands of years ago. Crude oil seems to be a fossil fuel that occurs in liquid shape in deep reservoirs or pools, in small areas in sedimentary rocks, and also in tar (or oil) sands near the surface. It was sent to a refinery already when crude oil is lifted from either the ground, in which various parts of crude oil are split up into functional products of petroleum. Other products of petroleum involve asphalt, lubricating oils, waxes, petrochemical feedstock, jet fuel, distillate oil, diesel fuel, and coal [1].

On the other hand, the activity of oil on concrete is as yet fuzzy and the ongoing huge development of raw oil exploration from the Middle East nations and the seaward fields (North Sea), together with the issues emerging edge transportation and capacity require a quantitative investigation of the features of concrete in contact with oil. Recent experimental works have revealed that the impact of petroleum products on concrete is categorized either as non-destructive or only slightly destructive. Nevertheless, there is an indication that these products can cause a serious deterioration in concrete structures in contact with it [1, 2].

Oiling of structural elements is an issue that appeared in industrial buildings. Recently, damages were found in concrete oil storage containers. Heavily oiled concrete floors show great damage that mostly impairs the exploitation of buildings [3]. This damage depends on the concrete quality and its density [4]. Most authors have considered the permeability of concrete as a direct measure of its

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durability against harmful liquids [5–8]. The permeability of concrete is strongly affected by the pore structure and the presence of cracks and micro-cracks in the microstructure of concrete [9].

In general, normal strength concrete is well known as having inherent features of low tensile strength and a tendency to crack under different external tensile stresses. In most cases, long term loading extends the magnitude of cracks in both plain and reinforced concrete [1, 10]. Thus the serviceability of reinforced concrete storage containers necessitates controlling of cracking and impermeability and finding a better material with nearly impermeable characteristics to construct oil containers.

Reactive powder concrete (RPC) is described as a fiber-reinforced, super-plasticized, impermeable material, which contains elevated dosages of cement and silicate fumes, a low water/binding ratio, and quartz sand with very fine particles (0.15–0.60 mm) rather than a regular aggregate. To advance the impermeability and microstructure of the RPC, coarse aggregate is eliminated to decrease heterogeneity between the aggregate and the cement matrix. Nevertheless, as a result of the elimination of coarse aggregate and the utilizing of sand with very fine particles, the cementitious materials utilized in RPC are as high as (900–1200 kg/m^3) [2].

Adding silica-fume to the concrete mixture enhances compressive strength and abrasion resistance of hardened concrete, decreases permeability and improves corrosion resistance to steel reinforcement. It fills the remaining voids as a micro-filler between fine aggregates and cement. Improving the transition zones of interfacial between fibers and binders also between aggregates and binder which is another important impact of silica fume. It also produces extra calcium-silicate-hydrate by the pozzolanic reaction between calcium hydroxide extracted from the process of Portland cement hydration and silica fume which therefore enhances the bond between aggregates and cement paste, thus enhancing the final strength [11]. RPC as an ultra-high-performance fiber reinforced concrete (UHPFRC) is catching more attention nowadays due to its durability and extraordinary strength characteristics [1, 12, 13]. Lately, many researchers have illustrated that the utilizing of steel fibers as reinforcement has brought good results to overcome the fragility of concrete [12, 14–17]. Thus, UHPFRC is a good alternative option to construct oil containers for its excellent properties including high-pressure resistance and tensile resistance in addition to its impermeable characteristics [1, 18–21].

Ajagbe et al. [22] examined the influence of impacted sand by crude oil (COIS) on the concrete compressive strength. Concrete mixing, 1:1.8:2.7 has been designed with 0.5 w/c for all specimens. Crude oil (2.5, 5, 10, 15, 20 and 25 %) by sand's weight has been utilized to contaminate the sand for the COIS concrete preparation. 147 specimens of 100 mm cubes of concrete were investigated (21 controls and 126 contaminated specimens). The cubes were tested at the ages of 3, 7, 14, 28, 56, 84, and 168 days to determine the compressive strengths. COIS concrete specimens demonstrated a slow increase in strength and a decrease in the final strength value in comparison with control specimens.

Faiyadh [23] studied the mechanical characteristics of oil-saturated concrete. The test results indicated that the mechanical properties of the hardened concrete, mortar, and cement paste have been adversely affected by oil saturating. The modulus of elasticity and the compressive-strength have been decreased by amounts depending on the absorbed oil amount. In addition, the tensile-strength has been decreased but the reduction was less than the compressive strength and elastic modulus.

Though many studies have been conducted on RPC [12, 13, 24–27], the impact of crude oil products on RPC remains unclear as there is a lack of information about the reaction between these products and concrete. The aim of our work is to further the knowledge about the impact of crude oil products on the mechanical characteristics of RPC.

2 Experimental work

2.1 Materials

2.1.1 Cement

The cement utilized in this project is Ordinary Portland cement Type I (CEM 11/A-L 42.4R), which produced in the north of Iraq and known commercially as Karasta. This cement complies with the requirement of (EN 197-1:2011) [28], the chemical and physical test results are demonstrated in Tables 1 and 2 respectively. Test results were conducted in University of Babylon, Civil Engineering Department Laboratories.

2.1.2 Fine aggregate

The sand utilized in this work was natural sand from Al-Ekhaidhir region, Iraq. The grading of the fine aggregate utilized is illustrated in Table 3. The results illustrate that the grading of fine aggregate after omitting the large size of the particle (>600 μm) was within the Iraqi Specification

Table 1 Composition and compounds chemically for Karasta cement

Chemical Composition	Percentage by Weight	Limit of (EN 197-1:2011)
Lime (CaO)	62.79	-
Silica (SiO_2)	20.58	-
Alumina (Al_2O_3)	5.6	-
Iron Oxide (Fe_2O_3)	3.28	-
Magnesia (MgO)	2.79	5% max
Sulfate (SO_3)	2.35	2.5 if C3A ≤ 5 2.8 if C3A > 5
Chloride content	0.02	≤ 0.10 %
Loss on Ignition (L.O.I.)	1.94	5% max
Insoluble Residue (I.R.)	1.00	-
Lime Saturation Factor (L.S.F.)	0.9	-
Main Compounds (Bogue's Equation)		
Tricalcium Silicate (C_3S)	50.12	-
Dicalcium Silicate (C_2S)	21.26	-
Tricalcium Aluminate (C_3A)	9.29	-
Tetracalcium Aluminoferrite (C_4AF)	9.98	-

Table 2 Physical Karasta cement characteristics

Physical Properties	Test Result	Limit of (EN 197-1:2011)
Specific Surface Area (Blaine Method) m^2/kg	314	
Initial Setting, (hr : min)	122	≥ 45 min
Final setting, (hr : min)	3:13	≤ 10 hrs
Soundness Using Autoclave Method	0.61	≤ 10 mm
Compressive Strength at:		
2 Days (MPa)	21.0	> 20
28 Days (MPa)	45.8	≤ 42.5

requirements (IQS No.45/1984) [29]. The physical tests of fine aggregate that involve specific gravity, absorption, fineness modulus, sulfate content and content of fine materials are given in Table 4. These results are according to the Iraqi Specification requirements (IQS No.45/1984) [29].

2.1.3 Silica fume

The silica fume utilized in this study is produced by the chemical company (CONMIX), commercially called Mega Add MS (D). It is a gray-colored powder with a particle size that varies from 0.1 µm to 1 µm. The average particle size is (100) times lower than that of portland cement in terms of particle diameter size. The silica fume is manufactured in accordance with the requirements of (ASTM C1240-15) [30]. The silica fume is utilized for space-filling, rheology enhancement, and secondary hydrate production. This is due to the enhancement in the densification of the cement matrix and also to the enhancement of the bonding between the aggregates and the cement paste in the interfacial area.

Tables 5 and 6 show the characteristics, analyzing the chemical composition and physical requirements respectively of the silica fume utilized in this project with a comparison with (ASTM C1240-15) requirements [30].

Table 3 Fine sand grading results associated with requirements of (IQS no.45/1984) [29]

Size of the Sieve (mm)	Cumulative Passing	Limits of IQS No.45/1984 as in (Zone 4)
10	100	100
4.75	100	95–100
2.36	100	95–100
1.18	100	90–100
0.60	100	80–100
0.30	40	15–50
0.15	11	0–15

Table 4 Chemical and Physical characteristics for utilized sand

Physical features		
Features	Test Results	Iraqi Specification Vo.45/1984
Specific Gravity	2.65	-
Absorption	0.94 %	-
Fine Material Passing from (75 µm) Sieve	3 %	Max ≤ 5.0 %
Fineness Modulus	2.6	-
Chemical Properties		
Sulfate Content	0.344 %	Max ≤ 0.5 %

Table 5 Chemical analysis of the utilized silica fume

Oxide Composition	Oxide Content %	ASTM C1240-15 Limitations
SiO_2	89.41	Min. 85 %
Al_2O_3	0.63	-
Fe_2O_3	0.45	-
CaO	0.82	<1
So_3	0.87	<2
K_2O+Na_2O	1.35	-
L.O.I	4.10	Max. 6 %
CI	0.18	-
CaO (free)	2.15	-

Table 6 Physical properties of silica fume used

Physical Properties	Result	ASTM C1240- 15
Strength activity index	130 %	≥ 105
Percent retained on 45 µm (No.325) sieve, max, %	1.7	≤ 10
Specific Surface, Min, (m^2/g)	23	≥ 15

2.1.4 Water
Tap water was used for producing and curing of concrete specimens in the experimental work of this research. The temperature (25±2 °C) of water was maintained.

2.2 Concrete mix design
The quantities of constituents of NSC and RPC mixtures were selected after several preliminary mixtures were made. The quantities were as illustrated in Table 7. The ordinary Portland cement type 1 was utilized in both mixtures. In RPC mix, the sand was utilized with a maximum size of 0.6 mm, silica fume utilized was according to ASTM C1240-15 [30] and the fibers length was 13 mm and diameter 0.2 mm, the plasticizer polycarboxylic polymers was also utilized in this examination as high range water reducing admixture (superplasticizer) which conforms to the ASTM C494/C494M-17 [31].

2.3 Exposure to crude oil products
Two types of oil products were utilized in the present investigation (kerosene, and gas oil). They were obtained from (Al-Durra Refinery), produced locally in Iraq, and stored in an airtight steel and plastic containers to avoid losses and contamination. Table 8 illustrates the characteristics of the oil products utilized.

Table 7 NSC and RPC mix design for 1 m^3 concrete

Constitutive Type	Mix Proportion	
	(RPC)	(NSC)
Cement (kg/m^3)	980	456
Sand (kg/m^3)	10504	776
Gravel (kg/mv)	-	825
Silica Fume (kg/m^3)	245	-
Steel Fiber (kg/m^3) (2 %)	157	-
W/cm	0.16	0.5
Super Plasticizer by Wt. of Cementitious (%)	3.5	-

Table 8 Features of utilized crude oil products

Oil Inspection Data	Kerosene Results	Gas oil Results
humidity content % by size	0 %	0 %
Sulfur content % by weight	0.2 %	1 %
pH	7.6	6.3
Specific gravity (g/cm^3) at:	0.801	0.85
Viscosity (centipoises) at 25C°	1.092	3.960
Flash point (min)	38	54
Char value mg/kg (max)	20	-
Diesel index (min)	-	55

After the period of curing (28 days) is finished, the specimens were left in the air to dry for two days. The first set of specimens was then immersed in kerosene for 180 days and the second set immersed in the gas oil for the same period, while the third set was left in the air as a reference set (for comparison).

2.4 Tests
2.4.1 Compressive strength
Cubes specimens are utilized to test the compressive strength. Three cubes of (50 × 50 × 50 mm for RPC and 150 × 150 × 150 mm for NSC) are utilized for each test results and the average of these three cubes is taken as the reading for a single age. Compressive strength is tested at the age of 7, 28 and 180 days according to ASTM C109/C109M-16 [32].

2.4.2 Splitting tensile strength
For this test, cylinders of 150 mm in diameter and 300 mm in height are used for both RPC and NSC to test the tensile strength. Three cylinders are used in each age and the average of these three cylinders is taken as the reading for that particular age. Tensile strength is tested at the age of 7, 28 and 180 days according to ASTM C496-17 [33].

2.4.3 Flexural test
This test is utilized to identify material flexural-strength or flexural-modulus. This test is more reasonable compared with a tensile-test. The major benefit of a three-point flexural test is the ease of specimens testing and preparing. Three prisms of (50 × 50 × 300 mm for RPC and 100 × 100 × 400 mm for NSC) were tested for each outcome according to ASTM C 348-19 [34] at 7, 28 and 180 days.

2.4.4 Modulus of elasticity
The static modulus of elasticity was conducting on (100 × 200 mm) cylindrical specimens and according to ASTM C469-14 [35]. For each specimen, the top surface was well finished and smoothed by using an electric grinding machine to prevent any loss of strength. The specimens were tested at ages (3, 7, 28 and 60 days) and the average of three specimens was taken for each test result.

3 Results and discussion
The most important visual implication during the testing process of concrete specimens was the discoloration of the concrete core after exposure to crude oil products for 180 days. The appearance of the NSC and RPC specimens

after exposure to crude oil products is illustrated in Figs. 1 and 2. In addition, Fig. 3 illustrates the analysis of color change which was performed on the surfaces of the RPC specimens before and after exposure to crude oil products. The images obtained in Fig. 3, were taken after magnification with a macro lens (25–58 mm). It can be seen from this figure that after exposure to kerosene the specimen turned to a darkish grey color, while after exposure to gas oil, the discoloration progressed more notably as the concrete surface became darker and close to the black color. The mechanical characteristics of the hardened concrete conducted in this study consist of compressive resistance, splitting tensile resistance, flexural resistance, and modulus of elasticity. Those characteristics are investigated in order to estimate the resistance of RPC and NSC to crude oil products. RPC and NSC specimens were cured for 28 days and then left in the air to dry for two days. After that, the tested specimens were grouped

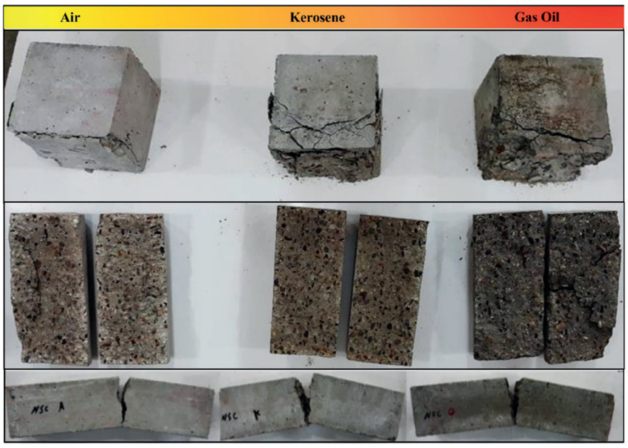


Fig. 1 the appearance of tested NSC specimens before and after exposure to crude oil products

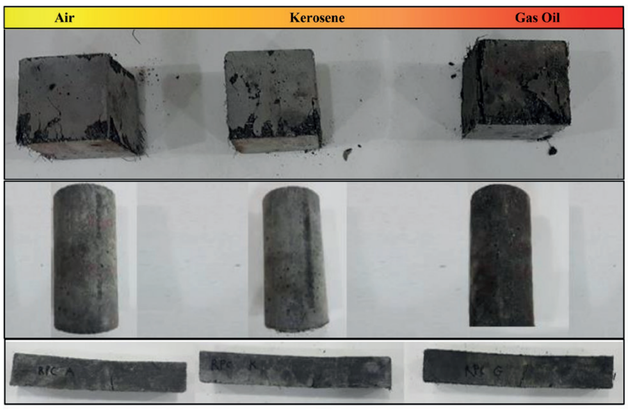


Fig. 2 the appearance of tested RPC specimens before and after exposure to crude oil products

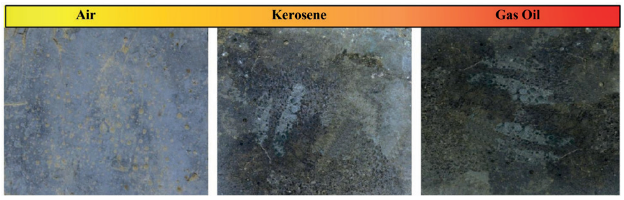
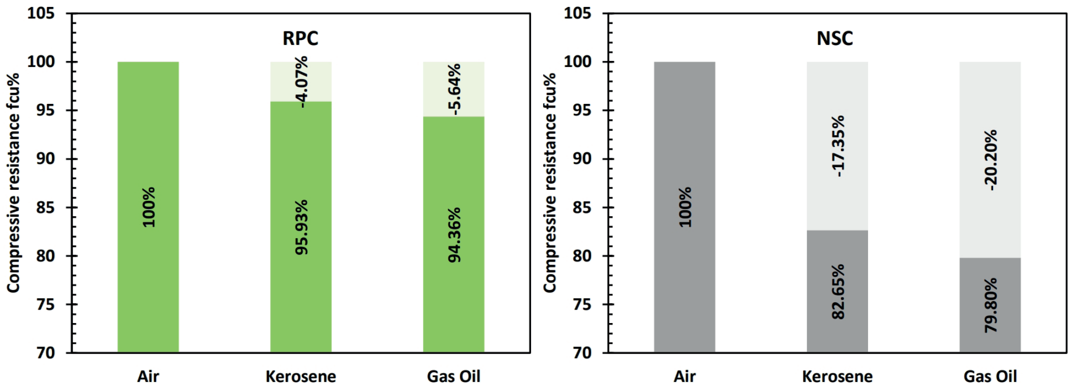
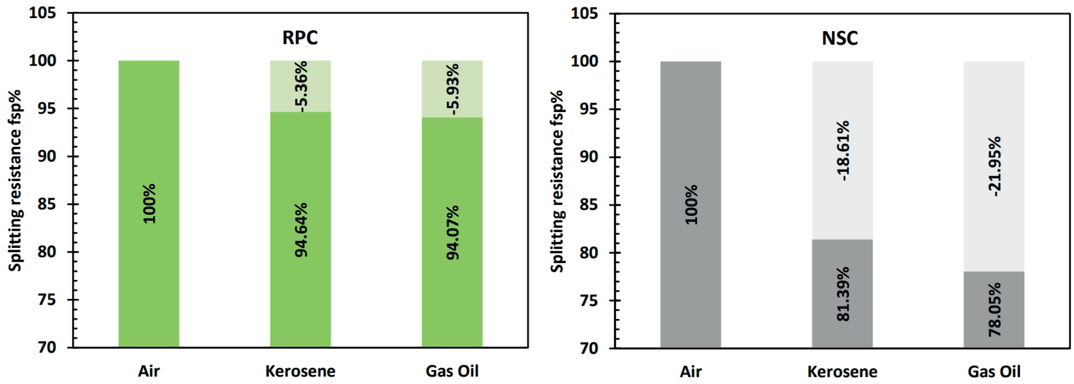


Fig. 3 discoloration analysis of tested RPC specimens before and after exposure to crude oil products

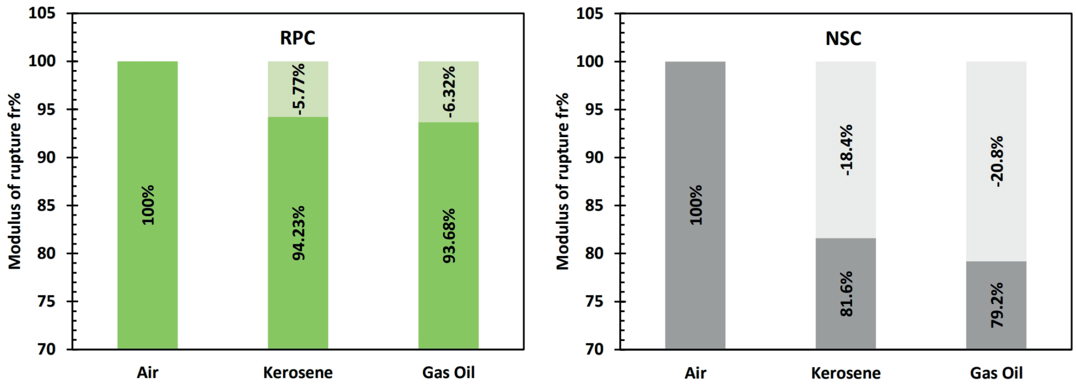
into three categories. The first one was cured in kerosene, meanwhile, the second one was cured with gas oil and the third one was left in air for 180 days. The overall measurement results of the mechanical characteristics for both RPC and NSC mixes are summarized in Table 9. Fig. 4 (a–d) displays the percentages of reduction and residual mechanical characteristics results of all investigated mixes for various exposure conditions. Each value in Fig. 4 reflects the average value of three specimens so as to reduce the error. This figure illustrates the values of the mechanical characteristics of the mixtures at the age of 180 days and comparisons between NSC and RPC mixtures in term of resistance to crude oil products. It can be seen from Fig. 4 that the reduction in the mechanical characteristics of RPC after exposure to crude oil products for 180 days was nearly negligible with the highest reduction of 6.32 % compared with reference RPC mix. On the other hand, it can be seen from Table 9 and Fig. 4 that the mechanical characteristics of NSC specimens deteriorated significantly after exposure to crude oil products for the same period. NSC lost about (13.82–21.95 %) of its mechanical characteristics compared with reference NSC mix after exposure to crude oil products for the same period, see Fig. 4. It also can be seen from this figure that the reduction in the mechanical characteristics of the RPC and NSC specimens exposed to gas oil was slightly higher than that of kerosene. The most likely explanation is that in term of permeability, concrete acts as a "molecular sieve" in which the penetration depth of various liquids depends on the molecule size of it and permeability of concrete, which means that the water can penetrate deeper into the concrete pore system as compared with the larger molecule size crude oil products. Nevertheless, because RPC contains silica fume, which in turn increases the resistance of the concrete by forming the secondary gel and increasing the density of the concrete by reducing the pores, in addition to using a very small w/c percentage, oil products cannot penetrate into the concrete core deeply as in NSC.



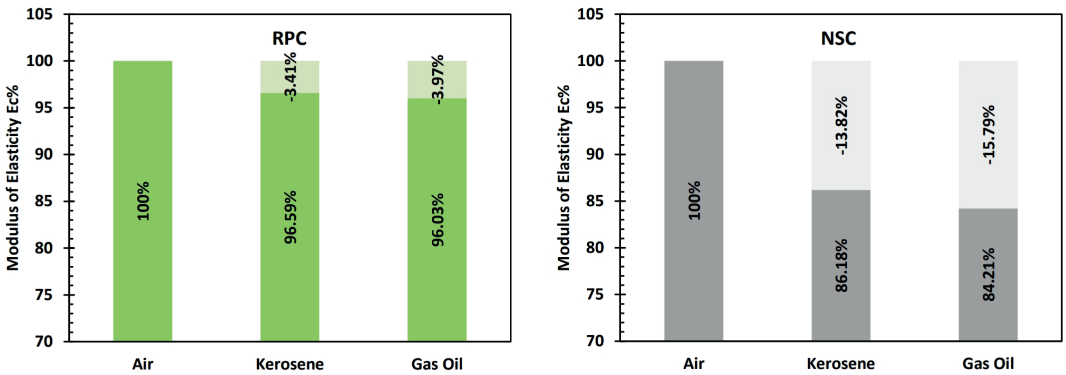
a) Compressive strength of RPC and NSC at the age of 210 days after exposure to crude oil products for 180 days



b) Tensile splitting strength at the age of 210 days after exposure to crude oil products for 180 days



c) Modulus of rupture at the age of 210 days after exposure to crude oil products for 180 days



d) Modulus of elasticity at the age of 210 days after exposure to crude oil products for 180 days

Fig. 4 Percentages of reduction and residual mechanical characteristics of RPC and NSC specimens after exposure to crude oil products

Table 9 Summary of the overall mechanical characteristics results for RPC and NSC specimens

Type of Concrete	RPC					NSC				
Age (days)	7	28	180			7	28	180		
			Air	Kerosene	Gas Oil			Air	Kerosene	Gas Oil
Compressive strength (MPa)	106.7	129.3	140.2	134.5	132.3	30.9	44	49	40.5	39.1
Splitting strength (MPa)	8.2	11.75	14	13.25	13.17	2	2.9	3.6	2.93	2.81
Modulus of rupture (MPa)	15.25	23.5	31.2	29.4	29.23	4.1	4.5	5	4.08	3.96
Modulus of Elasticity (GPa)	42.3	45.7	47.32	45.71	45.44	25.13	29.2	30.9	26.63	26.02

4 Conclusions

The impact of crude oil products on the mechanical characteristics of reactive-powder and normal-strength concrete was investigated. The experimental program consisted of three sets of NSC and RPC specimens; the first set of specimens was immersed in kerosene for 180 days and the second set was immersed in gas oil for the same age, while the third set was left in the air as a reference set. Depending on the aforementioned experimental investigation, the conclusions can be drawn as the following:

- The reduction in the mechanical characteristics of RPC after exposure to crude oil products for 180 days was insignificant, while NSC specimens deteriorated significantly after exposure to crude oil products for the same period, in which NSC lost about (13.82–21.95 %) of its mechanical characteristics compared with reference NSC specimens.
- The reduction in the mechanical characteristics of RPC and NSC specimens exposed to gas oil was slightly higher than that of kerosene after exposure for 180 days.
- Taken together, these findings implicate that RPC performs better as compared with NSC in term of external attacks of harmful liquids as RPC is nearly impermeable material.
- Future research on the topic using a scanning electron microscope (SEM) of RPC and NSC specimens which might extend the explanations of the concrete microstructure deterioration and the depth of the penetration of crude oil products.

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