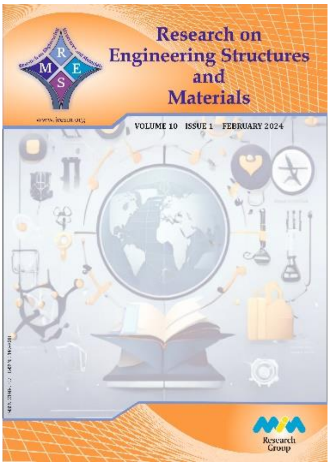
Research on Engineering Structures & Materials
www.jresm.org
Research Group



Investigation of strength and durability performance of concrete with varying crude oil waste ratios

Qosai Sahib Radi Marshdi, Ali Jaafar Dakhil, Zainab Al-Khafaji

Online Publication Date: 30 March 2024
URL: http://www.jresm.org/archive/resm2024.122me1211rs.html
DOI: http://dx.doi.org/10.17515/resm2024.122me1211rs

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article
Marshdi QSR, Dakhil AJ, Al-Khafaji Z. Investigation of strength and durability performance of concrete with varying crude oil waste ratios. *Res. Eng. Struct. Mater.*, 2024; 10(4): 1505-1521.

Research on Engineering Structures & Materials
www.jresm.org
MIM Research Group

Research Article

Investigation of strength and durability performance of concrete with varying crude oil waste ratios

Qosai Sahib Radi Marshdi[1,a], Ali Jaafar Dakhil[2,b], Zainab Al-Khafaji[3,4,c,*]

[1]*Dept. of Water Resources Management Eng., College of Eng., Al-Qasim Green University, Babylon, Iraq*
[2]*Dept. of Roads and Transport Eng., College of Engineering, University of Al-Qadisiyah, Al Diwaniyah, Iraq*
[3]*Imam Ja'afar Al-Sadiq University, Qahira, Baghdad, Iraq*
[4]*Dept. of Civil Eng., Faculty of Eng. and Built Environment, Universiti Kebangsaan Malaysia, Malaysia*

Article Info

Article history:

Received 11 Dec 2023
Accepted 21 Mar 2024

Keywords:

Crude oil (CRO);
Chemical analysis;
Physical properties;
Normal concrete;
Reactive powder concrete;
Pollution

Abstract

The influence of crude oil (CRO) pollution on concrete compressive strength and durability performance is evaluated in this work. Due to CRO contamination on its compositions, concrete exposed to oil-prone areas may lead to considerable changes in its properties. Experimental work has been conducted, and several cubes of concrete with varying ratios of CRO pollution were treated to study the impact of pollution on the mechanical characteristics of the concrete. The current research methodology consists of preparing contaminants by mixing CRO in different ratios with fine aggregates and mixing it with other raw materials to produce polluted concrete. Twelve CRO ratios (0, 1, 2, 2.5, 3, 4, 5, 6, 10, 15, 20, and 25%) were utilized to test typical concrete slump, compressive, and tensile strength. Then, the same concrete procedure and testing were repeated by utilizing 2% CRO in the case of reactive powder concrete. The chemical test was also utilized to identify the changes in concrete composition for the three samples (standard concrete without CRO, standard concrete with 2% CRO, and reactive powder concrete sample). The experimental tests illustrated that a ratio of 2% of CRO in standard concrete improves compressive and tensile strength, while utilizing the same ratio in reactive powder concrete reduces strength. On the other hand, utilizing 2% CRO illustrates that the internal sulfate amount has been increased for both normal and reactive powder concrete compared with normal concrete samples without CRO, which refers to a reduction in concrete durability.

Introduction

Concrete is a combination of cement, aggregate (coarse and fine), and water and is unquestionably the most frequently utilized material in the development of civil engineering projects [1,2]. The slurry (water and cement) binds the aggregate together to form a solid mass; the paste hardens due to a hydration reaction (for example, the chemical reaction of water and cement) [3]. It is a versatile construction and building material utilized for various purposes [4]. Several elements, such as additives and admixtures, may be utilized to modify the characteristics of the concrete to get the desired outcome property, depending on the engineer's specifications or requirements [5,6]. Crude oil (CRO) is among the most significant energy sources influencing any country's economy. Oil leaks throughout oil production and extraction are becoming severe global environmental issues, as seen in Fig. 1. The frequency of oil spills. Other environmental issues contribute to a decline in agricultural production, notably in the fishing industry, as illustrated in Fig. 2 [7], where the loss of the annual revenue from fishing activities has been reduced with

---

*Corresponding author: p123005@siswa.ukm.edu.my
a orcid.org/0000-0002-0532-9812; b orcid.org/0000-0002-3598-261X; c orcid.org/0000-0002-5450-7312
DOI: http://dx.doi.org/10.17515/resm2024.122me1211rs

time due to the spill of large quantities of oil in the water during the last 40 years. For instance, large volumes of oily effluent are generated as part of production processes, contaminating neighboring materials such as sand [8].

Consequently, CRO pollution directly impacts sand erosion, water penetration, and the potential for groundfire [9]. Sand's physio-chemical qualities are also affected by CRO pollution [10]. Sharma and Reddy [11] found that as the density of the fluid filling the gaps rises and the fluid viscosity decreases, the intrinsic permeability (k) of contaminated sand increases. Because the sand's permeability expanded as the CRO's viscosity reduced, the CRO spread quickly, affecting a broader area. Moreover, CRO pollution is more likely to reach subsurface water. According to many investigations, groundwater pollution by CRO and other petroleum-based liquids has become a common concern [12].

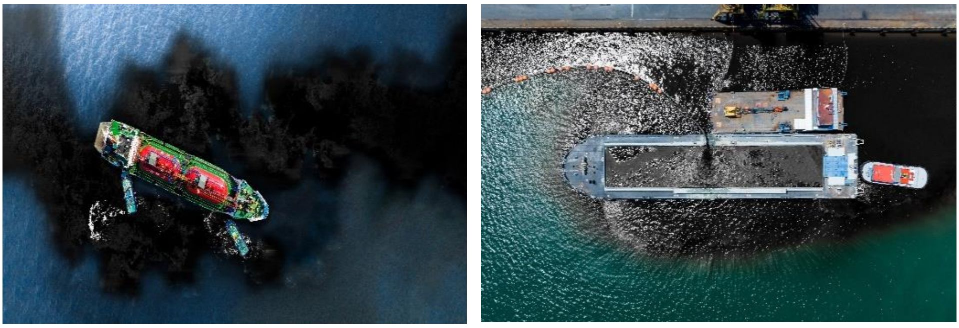


Fig. 1. The CRO spill in water

Some researchers consider utilizing oil-polluted sand in cement and concrete manufacturing as a sustainable, green, and cost-effective solution. With the development, the final product can be employed in various technical applications [13]. Ajagbe et al. [14] studied the impact of CRO on concrete compressive strength, where it was found that 25 %of CRO pollution resulted in a loss of 90 %compressive strength. Another investigation utilized oil solidification utilizing the direct immobilization approach. Some research has been done to see whether utilizing polluted sand in a building is functional.

Moreover, multiple studies [15–17] have investigated the impacts of various light CRO pollution %(0.5, 1, 2, 4, 6, 8, 10, and 20% by weight) on the mechanical microstructure and characteristics of produced concrete. These investigations found that at a contamination level of up to 6%, concrete with minor CRO contamination may preserve most of its compressive and splitting tensile strength. A good connection between the steel concrete and reinforcement may be formed due to this oil pollution.

The impacts of utilized motor oil on concrete characteristics and behavior are investigated by Hamad et al. [18]. The impact of utilized motor oil on hardened and fresh concrete features has been studied. The findings illustrated that utilizing motor oil improved the fluidity and slump of the concrete mixture and the air content of new concrete, acting as an air-entraining agent. The strength qualities of hardened concrete have been affected less by adding oil once a chemical-based air-entraining additive was applied. They discovered that adding used engine oil to concrete mixture materials did not influence the structural behavior of reinforced elements, as the ultimate loading or displacement diagrams were not changed. Ayininuola [19] investigated the impact of gas oil and bitumen on the concrete's compressive strength in which sand was polluted with gas and bitumen at various weight proportions. Oil-subjected concrete exhibits a reduction in compressive strength over time. According to Jassim and Jawad [20], the maximum decrease in the strength magnitudes of high and normal concrete samples subjected to gas and CRO for four months was approximately 25.19 %and 12.86%, respectively.

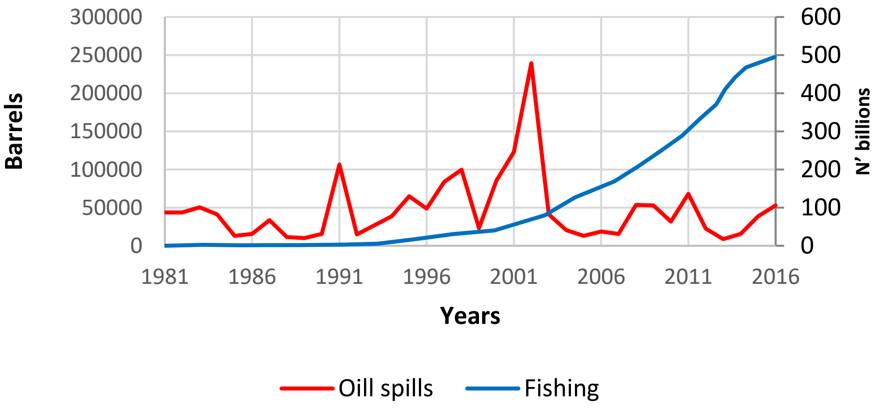


Fig. 2. Relationship between oil spill in water and reduction of fishing activity [7]

Ajagbe et al. [14] evaluated the concrete's compressive strength utilizing fine aggregates polluted with CRO at various percentages of the sand utilized in the combination. As the proportion of contaminants increased, the findings revealed a modest rise in concrete strength and increased loss rate. Abousnina et al. [17] observed that when fine sand concrete was polluted with light CRO, the cohesiveness rose dramatically to 1 %oil pollution and subsequently declined as the percentage of CRO grew. However, the frictional angle fell by 1%. The mortar with 1 %oil pollution had the maximum compressive strength, whereas mortar with 10 % had just an 18 %drop in strength compared to unpolluted specimens. Depending on Osuji and Nwankwo [21], the existence of CRO in concretes prevents the creation of bonds between component minerals, resulting in segregation. Consequently, the existence of CRO in concrete caused differences in workability. The greater the CRO amount in the fine aggregates, the more workable it is. In addition, compared to controlling cubes, polluted concrete cubes had lower compressive strengths, which illustrates that CRO is a compressive strength inhibitor in concrete manufacturing. The lower the compressive strength, the greater the CRO percentage in the fine aggregates. The ideal CRO pollution for normal compressive strength is as low as 0.3 percent [21].

Compared to the controlling concrete's slump, Shafiq et al. [22] observed that adding utilized motor oil raised the concrete slump by 18%to 38%and air amount by 26 to 58 percent. The oxygen permeability and porosity of concretes utilizing motor oil also decreased. In addition, the compressive strength achieved was similar to that of the control sample. Shahrabadi1 and Vafaei [23] investigated the compressive strengths of typical normal-weight concrete utilizing kerosene-contaminated sands. In all exposure settings investigated, they observed that 2 %of kerosene-polluted specimens had a loss in concrete compressive strength of up to 27%.

Because of its exceptional durability and strength characteristics, reactive powder concrete (RPC), a high-performance fiber-reinforced concrete, is receiving increasing attention these days. Recent studies have demonstrated that utilizing steel fibers as reinforcement has effectively overcome concrete fragility [24]. Therefore, high-resistance concrete reinforced with fiber (UHPSFRC) is a good alternative for its favorite features, such as high resistance against pressure and tensility [25].

In an RPC blend mix proportion, the coarse aggregates of traditional concrete are eliminated, requiring that the amounts of silica fume, Portland cement, and fine aggregate be significantly increased to enhance the homogeneity and improve the concrete granular mixture density. After being exposed to CRO products, Tuama et al. [5] looked at the mechanical characteristics of the hardened concrete mixture for reactive powder concrete (RPC) and regular concrete (NSC). After 180 days of exposure, two categories of CRO products (gas oil and kerosene) have been examined. The findings demonstrated that the mechanical properties (modulus of elasticity and modulus of rupture) of the RPC mix, which were reduced by around (3.41-6.32%) compared to the control RPC mix, were not significantly impacted by exposure to each petroleum product. After being exposed to petroleum products for the same amount of time, the NSC mix lost around (13.82-21.95%) of its mechanical properties (modulus of elasticity and modulus of rupture) compared with the control NSC mixture.

Oil spills and leaks constantly happen, especially in facilities that store, transport, or process oil products. Contamination may arise in several ways, but the most crucial consideration when dealing with polluted concrete (apart from environmental concerns) is whether the building is still structurally sound. Furthermore, the concrete underneath these leaks or spills changed. However, more research is needed on the exposure of concrete to CRO products and comparing the behavior of both concrete and reactive powder concrete after exposure to CRO. Therefore, the main goal of the current research is to explore the changes in concrete properties, strength, and durability caused by adding different CRO ratios to the concrete mixture (0, 1, 2, 2.5, 3, 4, 5, 6, 10, 15, 20, and 25%). After that, A 2% CRO ratio was selected to be mixed with reactive powder concrete to investigate the differences between normal and reactive powder concretes. The current research focused on investigating the behavior of fresh and hardened concretes (normal and reactive powder concretes) after exposure to CRO.

2. Experimental Works

2.1 Materials

2.1.1 Cement

Ordinary Portland Cement [26] has been utilized in the research to work as a binder material in the presence of water, and the chemical and physical characteristics of OPC are shown in Tables 1 and 2.

Table 1. Compounds and chemical analysis of cement

Chemical analysis	Percentage by Weight	Limitation 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 $C_3A \leq 5$ 2.8 if $C_3A > 5$
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 Krasta cement features

Physical features	Test findings	Limitation of (EN 197-1:2011)
Specific Surface Area (Blaine Method) m2/kg	314	
Setting times (hr: min)	Initial=122	≥ 45 min
	Final=3:13	≤ 10 hrs
Soundness Utilizing Autoclave Method	0.61	≤ 10 mm
Compressive Strengths		
2 Days (MPa)	21.0	> 20
28 Days (MPa)	45.8	≤ 42.5

2.1.2 Water

For concreting, fresh, drinkable water has been utilized; the water facilitated the cement hydration, resulting in the concrete setting and hardening.

2.1.3 Fine Aggregate

In this work, natural sand was used as fine aggregate. The chemical and mechanical properties of sand are given in Table 3. The fine aggregate used has gradation that lies within the upper and lower limits of the ASTM C33/C33M specification [27] and Iraqi specification (IQ.S 45/1984) zone (2), as shown in Table 4. Fine aggregate has been tested at Al-Mustaqbal University in the Construction Material Laboratories.

Table 3. Chemical and mechanical properties of fine aggregate

Properties	Test results	IQ. S No. 45/1984 zone (2)
Specific gravity	2.6	------
Fineness modulus	3.8	≤ 5 %
Sulfate content $\boldsymbol{SO_3}$	0.22%	≤ 0.5 %
Absorption	2%	------

Table 4. Grading of fine aggregate

Sieve no.	Sieve size (mm)	Passing %		
		Fine aggregate	IQ. S No. 45 Zone (2)	ASTM C 33/C 33M
3/8 in	9.5	100	100	100
NO.4	4.75	91	90 - 100	90 - 100
NO.8	2.36	83	75 - 100	80 - 100
NO.16	1.18	74.8	55 - 90	50 - 85
NO.30	0.60	57.2	35 - 59	25 - 60
NO.50	0.30	24.2	8 - 30	5 - 30
NO.100	0.15	7.2	0 - 10	0 - 10

2.1.4 Coarse Aggregate (Gravel)

This work used coarse aggregate with a maximum aggregate size of 19 mm. The coarse aggregate was cleaned, washed with drinkable water, and dried before use. The mechanical and chemical properties of coarse aggregate are given in Table 5. The sieve analysis of coarse aggregate lies within the lower and upper limits of the Iraqi specification (IQ.S No.45/1984) [28], as shown in Table 6.

Table 5. Mechanical and chemical properties of coarse aggregate

Properties	Test results	IQ. S No. 45/1984
Specific gravity	2.66	------

Sulfate content SO3	0.03%	≤ 0.1 %
Absorption	0.6%	------
Clay content	0.2%	≤ 3%

Table 6. Grading of coarse aggregate

Sieve Size (mm)	Passing %	
	Coarse aggregate	IQ. S No. 45/1984
37.5	100	100
19	100	100 - 95
9.5	43	60 - 30
5.0	3	10 - 0

2.1.5 Crude Oil

Crude oil (CRO) utilized in the current study has been selected from length= 1.3 cm and diameter= 0.02 cm Refinery of Al-Durra and kept in air-tight steel and plastic containers to prevent losses and contamination. Table 7 demonstrates the features of CRO utilized. It has American Petroleum Institute gravity (API gravity) =11.43, specific gravity=0.99, density= 62 lbs/cu ft, and viscosity=4.8 centipoise at 30 ^{0}C.

Table 7. Feature of Al-Dura CRO

Factors	Value
Gravity Degree	< 35
Specific Gravity 15 degrees centigrade	0.812
Sulfur amount (% by weight)	0.30
% by volume	0.40
Wax amount (% by weight)	7.0
Carbon Residue (% by weight)	2.10
Melting point (degree centigrade)	57
Viscosity (21-degree centigrade)	6.81
Acidity (Mg/KOH/g)	0.05

2.2 Preparation of Concrete Mixture

In compliance with the British Standards, a concrete mix design with a water-cement ratio of 0.5 has been selected and batched in weight. The mix design includes specimens of 0 % contaminated cubes cured in freshwater as a control, 0 % contaminated cubes cured in Al-Dura CRO-polluted water as a control, and various levels of artificially contaminated cubes cured in freshwater (1, 2, 2.5, 3, 4, 5, 6, 10, 15, 20, and 25) percent. These three specimens have been compared regarding newly mixed concrete and compressed strength in hardened concrete. The concrete ingredients were mixed in a clean, dry manual tilting drum, yielding 144 cubes. Table 8 illustrates the material mix proportions. After identifying the optimum CRO percentage that causes an increase in the compressive strength of standard concrete, the same CRO proportion (2%) was utilized for reactive powder concretes, as illustrated in Table 9. On the other hand, the reactive powder concrete specimens were tested in two conditions: the first without CRO and the second with the addition of 2% CRO.

Table 8. Standard concrete mix design for 1 m^3 concrete

Mix ID	Cement (kg/m3)	Sand (kg/m3)	Gravel (m3)	Water (kg/m3)	CRO Proportion	CRO (kg/m3)
NM 1	300	650	1200	150	0%	0
NM 2	300	650	1200	150	1%	6.5

NM 3	300	650	1200	150	2%	13
NM 4	300	650	1200	150	2.5%	16.25
NM 5	300	650	1200	150	3%	19.5
NM 6	300	650	1200	150	4%	26
NM 7	300	650	1200	150	5%	32.5
NM 8	300	650	1200	150	6%	39
NM 9	300	650	1200	150	10%	65
NM 10	300	650	1200	150	15%	97.5
NM 11	300	650	1200	150	20%	130
NM 12	300	650	1200	150	25%	162.5

Table 9. Reactive powder concrete mix design

Mix ID	Cement (kg/m3)	Sand (kg/m3)	Silica Fume (kg/m^3)	Water (kg/m^3)	Super Plasticizer3 by Wt. of Cementitious (%)	CRO (kg/m3)
RM	980	10504	245	156.8	7	13

2.3 Workability and Slump Test

A slump mold in the shape of a frustum of a cone 30.5 cm high, 20.3 cm base diameter, with a smaller hole of 10.2 cm diameter at the top - was utilized to produce the slump result. The mold had a smooth surface and was equipped with appropriate fort parts and grips to make lifting easier. The mold was securely held against its base, and three layers of concrete were poured into it. A standard 1.6 cm diameter steel rod has been utilized to tamper with every layer 25 times. The cone was gently inverted and dumped onto a flat plate after filling it. The slump is the reduction in the height of the slumping concrete's center, which was analyzed and evaluated to the closest 0.5 cm, as shown in Fig. 3.

Fig. 3. Slump test

2.4 Physical Tests

2.4.1 Concrete Strength Test

Concrete's great compressibility is one of its most distinguishing features. The compressibility of a concrete cube with dimensions of 150 x 150 x 150mm to produce specific compressive strengths following 28 days has traditionally been referred to as the concrete performance test. Various procedures may determine the concrete's compressive strength, including direct and indirect methods and destructive and nondestructive tests. The destructive technique utilized in this study was the cube compressive test with a size of 15x15x15 cm based on ASTM standard [29], as shown in Fig. 4, and reactive powder concretes were tested at 7, 14, 28, and 56 days.

2.4.2 Splitting Tensile Strength

This test uses six cylinders with a 15 cm diameter and 30 cm height to measure tensile strength based on ASTM [30], as shown in Fig. 4. Every age uses three cylinders, and the reading for that age is determined by averaging the readings from the three cylinders. Splitting Tensile strength tests are performed on specimens of reactive powder concrete and regular concrete at 28 and 56 days.

Fig. 4. Photograph of compressive strength testing and splitting tensile strength

2.5 Chemical Tests

The samples of the two concrete types, standard concrete (NM 1 and NM3) and reactive powder concrete (MR), representing samples exposed to CRO, were the most effective. Fig. 5 illustrates the test device, which gives the concentration of the materials involved in the composition of the samples.

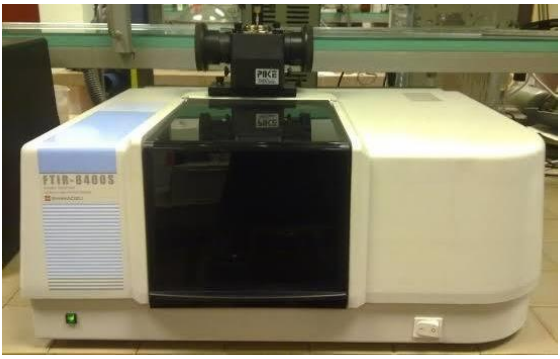


Fig. 5. Chemical testing apparatus

3. Results and Discussion

3.1 Workability and (Slump Test) Results

When the slump values recorded for every polluted specimen are compared to the 20 mm value recorded for the controlling specimen, as demonstrated in Table 10, the polluted specimens exhibit higher slump. This observation is because sand is generally utilized in concrete mixtures with a dry surface, but CRO increases the liquids in the produced mixture. The slump values increase with increasing CRO in the fine aggregate for both standard and reactive powder concrete. With 6 to 25 % CRO pollution, the concrete slump ultimately crumbled. It is also safe to assume that CRO caused the rise in the slump and interfered with the cement-water binding interactions, delaying or inhibiting the complete hydration of the cement particles [31,32]. Increased slump value is compatible with increased workability from very low to high when utilizing 25 % CRO as an additive on regular concrete. However, it caused a slight increase in the workability and slump value for reactive powder concrete due to the presence of a superplasticizer, which already added more workability to the concrete mix.

Table 10. The slump test findings for normal and reactive powder concrete

Sample ID	Slump mm	Workability [33]
NM 1	20	Very low
NM 2	45	Low
NM 3	50	Low
NM 4	55	Medium
NM 5	60	Medium
NM 6	85	Medium
NM 7	105	High
NM 8	120	High
NM 9	165	High
NM 10	178	High
NM 11	180	Very High
NM 12	200	Very High
RM0	80	Medium
RM	85	Medium

3.2 Compressive Strength Test Results

Fig. 6 reveals the compressive strength findings for different CRO ratios at 7, 14, 28, and 56 curing days. Sample NM3 with 2% CRO presents the best compressive strength for all selected ages, while sample NM7 with 25% presents the worst compressive strength due to the prevention of bonds between the cement hydration gel. On the other hand, the reactive powder concrete samples have been tested in two conditions. The loss of moisture and subsequent decrease in water content/moisture might prohibit the concrete cube from absorbing water during curing in water, which could explain the fall in strength. The phenomenon affects the cement hydration reaction of the concrete cubes. A limited strength enhancement of the concrete with CRO might have resulted from the dilatation of the gel and the weakness of the cohesive forces in the paste [14,34]. The negative impact of CRO is due to the contamination of fine aggregate with CRO, a component of the concrete's matrix microstructure.

The strength dropped once the concrete was exposed to CRO [35,36]. Therefore, sand that contains more than 15% CRO by weight findings has less than 42 % strength, as experimentally detected for unpolluted concrete, and should not be utilized for most construction applications (road, bridge, loaded elements) and used just for unloaded elements. The change in the compressive strength can be obtained from Equation 1 and the findings illustrated in Table 11. Nevertheless, efforts might be necessary to enhance the strength of the CRO concrete utilized in low-strength applications with less than 5%contamination. However, a CRO application on reactive powder concrete significantly decreased compressive strength compared with standard concrete with the same CRO ratio, as demonstrated in Fig. 7 and Table 11, which illustrates the highest increase in compressive strength for all selected curing ages.

$$\text{Change in (Fc, Fsp, Fr, Ec)\%} = \left(\frac{\text{(Fc,Fsp, Fr, Ec)}}{\text{(Fc, Fsp, Fr, Ec) (at air)}} \times 100 - 100\right)\% \qquad (1)$$

Based on [37], a single formula, which is presented below, was utilized to establish a connection between the data on strength and the properties of durability:

$$DI = \frac{a}{(f_c')^b} \qquad (2)$$

Whereas DI is the durability index (for example, water penetration depth (mm), chloride permeability (Coulombs), or the coefficient of chloride diffusion, De; f_c' the compressive strength; and a=1400 and b=2.18 are the experiential constants for normal concrete; and (a=1000000 and b=2.78) for reactive powder concrete. A good correlation was noted between compressive strength and durability characteristics, which is expressed in the above expression. However, increasing the compressive strength causes an increase in the concrete's durability due to reducing its permeability. Fig. 8 illustrates that increasing the durability index refers to a reduction in compressive strength; the durability index at 7 curing days is the highest, and increasing the curing days to 14, 28, and 56 reduces the durability index significantly. However, applying crude oil in reactive powder concrete shows a negative impact on the durability index that is shown in Fig. 9.

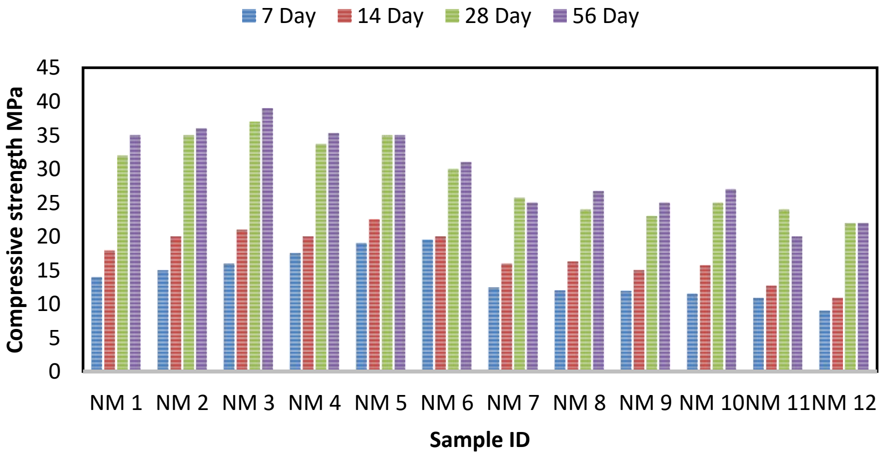


Fig. 6. Compressive strengths of standard concrete with or without CRO contamination

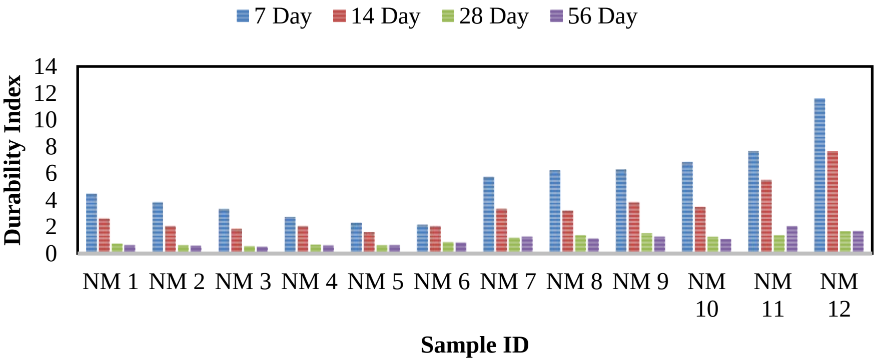


Fig. 7. Durability index for normal concrete samples with different CRO ratios

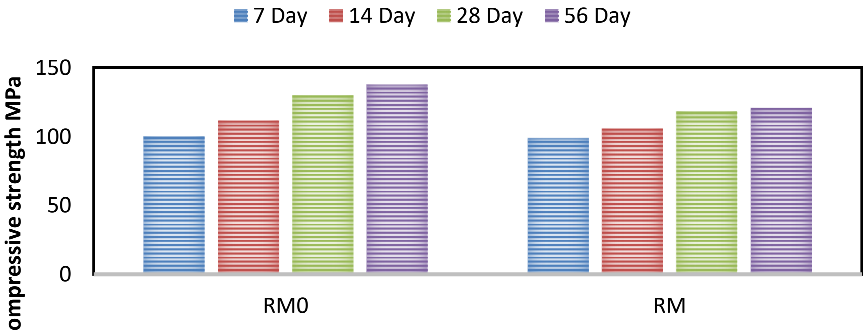


Fig. 8. Compressive strengths of reactive powder concrete with or without CRO contamination

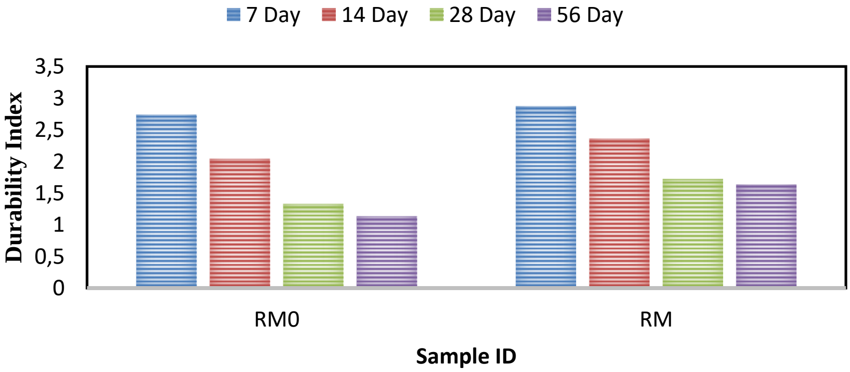


Fig. 9. Durability index for reactive concrete samples with different CRO ratios

Table 11. The change in the compressive strength values.

Sample ID	Improvement percentage %			
	7 Day	14 Day	28 Day	56 Day
NM 1	0.00	0.00	0.00	0.00
NM 2	7.45	11.73	9.38	2.86
NM 3	14.61	17.32	15.63	11.37
NM 4	25.36	11.73	5.31	0.86
NM 5	36.10	25.70	9.38	0.00
NM 6	39.69	11.73	-6.25	-11.43
NM 7	-10.82	-10.89	-19.59	-28.57
NM 8	-14.04	-9.05	-25.00	-23.71
NM 9	-14.54	-16.20	-28.13	-28.57
NM 10	-17.62	-12.29	-21.88	-22.86
NM 11	-21.92	-29.05	-25.00	-42.86
NM 12	-35.53	-39.11	-31.25	-37.14
RM	-1.67	-5.10	-8.92	-12.31

3.3 Tensile Strength Results

The behavior of the standard concrete after exposure to different CRO ratios in both tensile and compressive strength is illustrated in Table 12 and Fig. 10, with enhanced tensile strength after applying less than 4% of CRO. Fig. 10 illustrates the tensile strength in all selected CRO ratios for standard concrete at 28 and 56 curing ages, improving as the concrete ages. However, samples NM2, NM3, NM4, and NM5 illustrate increased tensile strength for two selected periods. Sample NM3, with a 2% CRO ratio, has the highest value, while samples NM6-NM12 illustrate a significant decrease in the tensile strength of standard concrete samples, and sample NM12 records the lowest value. Relying on the works of Bangham [38], Onabolu [39] found that the loss in surface energy brought on by the CRO adsorption onto the surface of C-S-H gel might also have had a role in the material's decreased compressive strength. The control (curing) medium's strength values have always been more significant once compared to the other values. In contrast, the other curing media degrade with time as the curing age rises. Utilizing 2% CRO improves tensile strength in a standard concrete sample. Utilizing the same ratio in reactive power concrete leads to decreased tensile resistance at 28 and 56 curing ages, as demonstrated in Fig. 11 and Table 12.

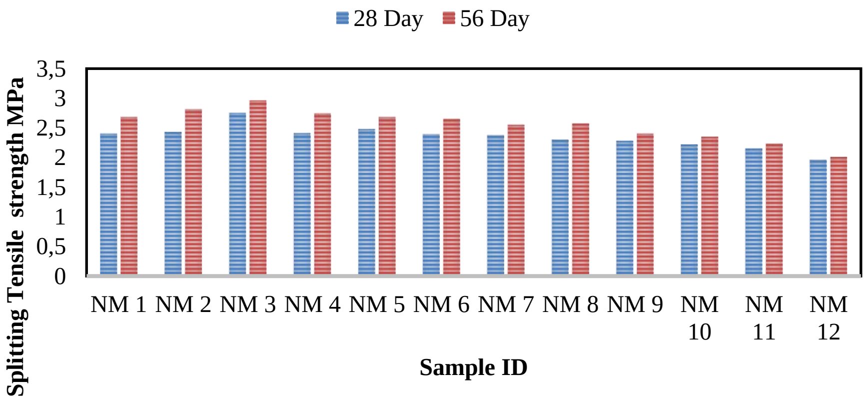


Fig. 10. Tensile strengths of standard concrete with or without CRO contamination

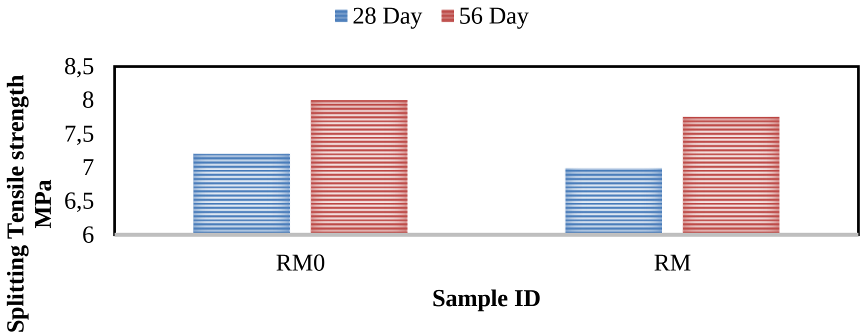


Fig. 11. Tensile Strengths of reactive powder concrete with or without CRO contamination

Table 12. The change in the tensile strength values

Sample ID	Improvement percentage %	
	28 Day	56 Day
NM 1	0.00	0.00
NM 2	1.25	4.85
NM 3	14.58	10.45
NM 4	0.42	2.24
NM 5	3.33	0.00
NM 6	-0.42	-1.12
NM 7	-1.25	-4.85
NM 8	-4.17	-4.10
NM 9	-5.00	-10.45
NM 10	-7.50	-12.31
NM 11	-10.42	-16.79
NM 12	-18.33	-25.00
RM	-3.10	-3.13

3.4 Chemical Observation

By analyzing interactions between the concrete matrix components utilizing the FTIR spectroscopy method [40], it was possible to quantify their chemical compatibility before and after exposure to CRO. The chemical linkages in the composite materials may be examined utilizing FTIR. The findings of the chemical tests demonstrated a significant increase in the concentration of sulfate in normal concrete sample NM1 with the absence of CRO (1424.79 cm-1), as illustrated in Fig. 12, and both samples of normal and reactive powder concrete after exposure to CRO (1900 and 1850.4 cm-1) as illustrated in Fig. 13 and 14, respectively. The concentration of sulfates may harm the concrete, and its reaction with concrete components is accompanied by an increase in volume, which leads to the cracking of the concrete. Sulfate attack is one of the leading contributors to the reduction in durability of concrete. The resistance of concrete materials to sulfate attack may typically be determined by laboratory testing by looking at factors such as the loss of mass, the drop in strength, and the expanding strain of concrete specimens. On the other hand, one cannot utilize these signs to make a quantitative prediction about the carrying capability of actual concrete buildings that are being attacked by sulfate [41] immediately. Based on Figs (13-14), utilizing CRO causes an increase in internal sulfate amount in concrete in comparison with normal concrete without CRO; therefore, utilizing CRO leads to reduced durability due to increased sulfate amounts, and these results are compatible with results obtained by [40].

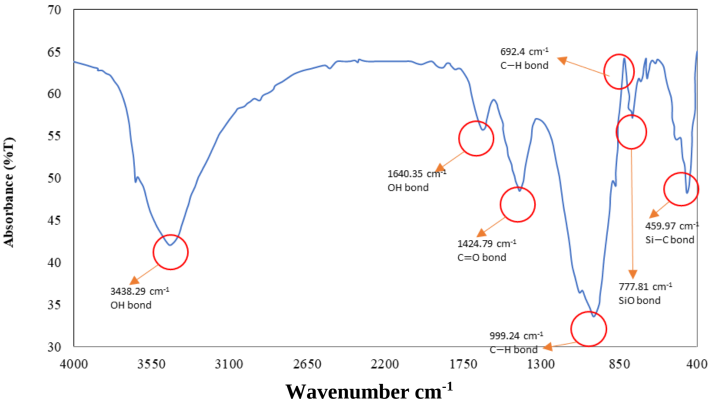


Fig. 12. Chemical analysis for standard concrete without CRO sample (NM1)

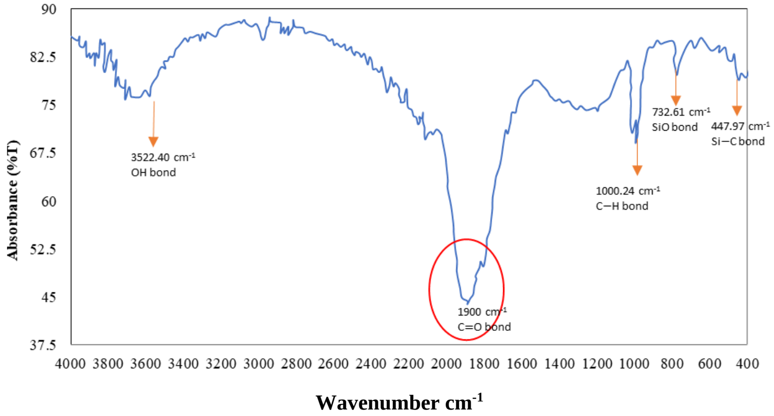


Fig. 13. Chemical analysis for standard concrete with 2% CRO sample (NM3)

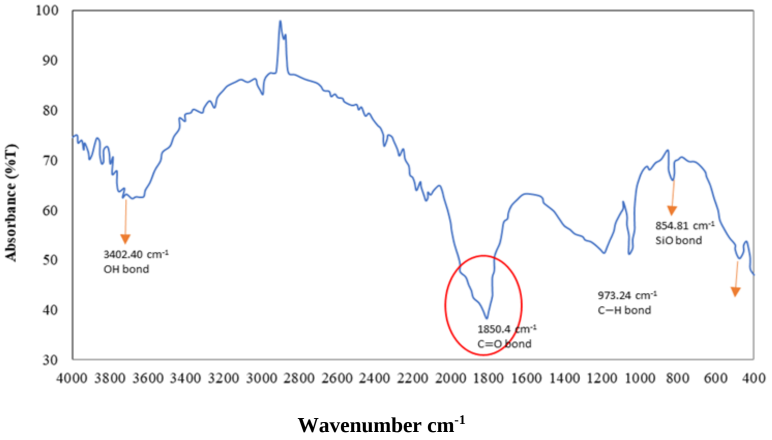


Fig. 14. Chemical analysis for reactive powder concrete with 2% CRO sample (RM)

4. Conclusion

The impact of CRO contamination on concrete compressive strength has been studied, and the following points were concluded from the study:

- CRO was found to influence the concrete's strength depending on the different practical and analytical procedures utilized. Once concrete meets liquids other than potable or fresh water, it is proven harmful to the cement-based material, mainly for OPC. Its low environmental and chemical resistance and low compressive strength due to slow strength development lead to early deterioration.
- The magnitude of the concrete slump rises incompatible with the quantity of polluted CRO ratio for both standard and reactive powder concrete.
- The concrete strength varies depending on the quantity of CRO utilized, and a ratio of 2 % was found to be an enhancement ratio that caused an increase in the compressive strength.
- The compressive strength of reactive powder concrete deteriorated after exposure to 2% of CRO; the lowest compressive strength was obtained after 56 curing days.
- The durability index increased slightly when utilizing 2% CRO based on the durability index, but the internal sulfate amount has increased compared with normal concrete without CRO.

References

[1] Al Zand AW, Hosseinpour E, Badaruzzaman WHW, Ali MM, Yaseen ZM, Hanoon AN. Performance of the novel C-purlin tubular beams filled with recycled-lightweight concrete strengthened with CFRP sheet. Journal of Building Engineering 2021. https://doi.org/10.1016/j.jobe.2021.102532

[2] Nedeljković M, Visser J, Šavija B, Valcke S, Schlangen E. Use of fine recycled concrete aggregates in concrete: A critical review. Journal of Building Engineering 2021. https://doi.org/10.1016/j.jobe.2021.102196

[3] Yaphary YL, Lu J-X, Chengbin X, Shen P, Ali HA, Xuan D, et al. Characteristics and production of semi-dry lightweight concrete with cold bonded aggregates made from recycling concrete slurry waste (CSW) and municipal solid waste incineration bottom ash (MSWIBA). Journal of Building Engineering 2022;45:103434. https://doi.org/10.1016/j.jobe.2021.103434

[4] Ramesh BM, Vongole RM, Nagraj Y, Naganna SR, Sreedhara BM, Mailar G, et al. Valorization of incinerator bottom ash for the production of resource-efficient eco-friendly concrete: Performance and toxicological characterization. Architecture, Structures and Construction 2021. https://doi.org/10.1007/s44150-021-00006-9

[5] Tuama WK, Kadhum MM, Alwash NA, Al-Khafaji ZS, Abdulraheem MS. RPC Effect of Crude Oil Products on the Mechanical Characteristics of Reactive-Powder and Normal-Strength Concrete. Periodica Polytechnica Civil Engineering 2020. https://doi.org/10.3311/PPci.15580

[6] Falah MW, Hafedh AA, Hussein SA, Al-Khafaji ZS, Shubbar AA, Nasr MS. The Combined Effect of CKD and Silica Fume on the Mechanical and Durability Performance of Cement Mortar. Key Engineering Materials, vol. 895, Trans Tech Publ; 2021, p. 59-67. https://doi.org/10.4028/www.scientific.net/KEM.895.59

[7] Bello AT, Amadi J. Oil Pollution and Bio-Diversity Conservation in Nigeria: An Assessment of Legal Framework. Journal of Geoscience and Environment Protection 2019;7:354. https://doi.org/10.4236/gep.2019.78024

[8] Khosravi E, Ghasemzadeh H, Sabour MR, Yazdani H. Geotechnical properties of gas oil-contaminated kaolinite. Engineering Geology 2013;166:11-6. https://doi.org/10.1016/j.enggeo.2013.08.004

[9] Shakesby RA, Wallbrink PJ, Doerr SH, English PM, Chafer CJ, Humphreys GS, et al. Distinctiveness of wildfire effects on soil erosion in south-east Australian eucalypt forests assessed in a global context. Forest Ecology and Management 2007;238:347-64. https://doi.org/10.1016/j.foreco.2006.10.029

[10] Osuji LC, Ezebuiro PE. Hydrocarbon contamination of a typical mangrove floor in Niger Delta, Nigeria. International Journal of Environmental Science & Technology 2006;3:313-20. https://doi.org/10.1007/BF03325939

[11] Sharma HD, Reddy KR. Geoenvironmental engineering: site remediation, waste containment, and emerging waste management technologies. John Wiley & Sons; 2004.

[12] Delin GN. Groundwater contamination by crude oil near Bemidji, Minnesota. US Department of the Interior, US Geological Survey; 1998. https://doi.org/10.3133/fs08498

[13] Abousnina R, Manalo A, Lokuge W, Zhang Z. Effects of light crude oil contamination on the physical and mechanical properties of geopolymer cement mortar. Cement and Concrete Composites 2018; 90: 136-49. https://doi.org/10.1016/j.cemconcomp.2018.04.001

[14] Ajagbe WO, Omokehinde OS, Alade GA, Agbede OA. Effect of crude oil impacted sand on compressive strength of concrete. Construction and Building Materials 2012;26:9-12. https://doi.org/10.1016/j.conbuildmat.2011.06.028

[15] Abousnina R, Manalo A, Lokuge W, Al-Jabri KS. Properties and structural behavior of concrete containing fine sand contaminated with light crude oil. Construction and Building Materials 2018;189:1214-31. https://doi.org/10.1016/j.conbuildmat.2018.09.089

[16] Abousnina R, Manalo A, Ferdous W, Lokuge W, Benabed B, Al-Jabri KS. Characteristics, strength development, and microstructure of cement mortar containing oil-contaminated sand. Construction and Building Materials 2020;252:119155. https://doi.org/10.1016/j.conbuildmat.2020.119155

[17] Abousnina RM, Manalo A, Lokuge W, Shiau J. Oil contaminated sand: an emerging and sustainable construction material. Procedia Engineering 2015;118:1119-26. https://doi.org/10.1016/j.proeng.2015.08.453

[18] Hamad BS, Rteil AA, El-Fadel M. Effect of used engine oil on properties of fresh and hardened concrete. Construction and Building Materials 2003;17:311-8. https://doi.org/10.1016/S0950-0618(03)00002-3

[19] Ayininuola GM. Influence of diesel oil and bitumen on compressive strength of concrete. Journal of Civil Engineering 2009;37:65-71.

[20] A Jawad F, Jasim AT. Effect Of Oil On Strength Of Normal And High Performanc Concrete. Al-Qadisiyah Journal for Engineering Sciences 2010;3:24-32.

[21] Osuji SO, Nwankwo E. Effect of crude oil contamination on the compressive strength of concrete. Nigerian Journal of Technology 2015;34:259-65. https://doi.org/10.4314/njt.v34i2.7

[22] Shafiq N, Nuruddin MF, Beddu S. Properties of concrete containing used engine oil. International Journal of Sustainable Construction Engineering and Technology 2011;2.

[23] Shahrabadi H, Vafaei D. Effect of kerosene impacted sand on compressive strength of concrete in different exposure conditions. J Mater Environ Sci 2015;6:2665-72.

[24] Shubbar HA, Alwash NA. The fire exposure effect on hybrid reinforced reactive powder concrete columns. Civil Engineering Journal (Iran) 2020;6:363-74. https://doi.org/10.28991/cej-2020-03091476

[25] Meng Q, Wu C, Li J, Liu Z, Wu P, Yang Y, et al. Steel/basalt rebar reinforced Ultra-High Performance Concrete components against methane-air explosion loads. Composites Part B: Engineering 2020;198:108215. https://doi.org/10.1016/j.compositesb.2020.108215

[26] Institution BS. Specification for ordinary and rapid-hardening Portland cement. British Standards Institution; 1988.

[27] ASTM C. C 33-86; Standard Specification for Concrete Aggregates, Annual Book of ASTM Standards. ASTM: West Conshohocken, PA, USA 1986.
[28] IQS. No. 45, Aggregate from natural sources for concrete and construction. Iraqi Specif 1984.
[29] ASTM C. 109. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2in or [50-Mm] Cube Specimens)', Annual Book of ASTM Standards, USA 2013.
[30] ASTM C. 496-96. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens 1996.
[31] Pollard SJT, Montgomery DM, Sollars CJ, Perry R. Organic compounds in the cement-based stabilisation/solidification of hazardous mixed wastes-Mechanistic and process considerations. Journal of Hazardous Materials 1991;28:313-27. https://doi.org/10.1016/0304-3894(91)87082-D
[32] Asna MZ. Optimization of solidifications/stabilization for petroleum-based waste using blended cement/Asna Mohd Zain 2013.
[33] Neville AM, Brooks JJ. Concrete Technology (2nd Indian reprint) 2002.
[34] Faiyadh FI. Properties of oil-saturated concrete. 1980.
[35] Ejeh SP, Uche OAU. Effect of crude oil spill on compressive strength of concrete materials. Journal of Applied Sciences Research 2009;5:1756-61.
[36] Abdul Ahad RB, Mohammed AA. Compressive and tensile strength of concrete loaded and soaked in crude oil 2000.
[37] Al-Amoudi OSB, Al-Kutti WA, Ahmad S, Maslehuddin M. Correlation between compressive strength and certain durability indices of plain and blended cement concretes. Cement and Concrete Composites 2009;31:672-6. https://doi.org/10.1016/j.cemconcomp.2009.05.005
[38] Bangham DH. The swelling and shrinkage of porous materials and the role of surface forces in determining technical strength. Symposium Society Chemical Industry, 1946.
[39] Onabolu OA. Effects of hot crude oil on concrete for offshore storage applications 1986.
[40] Horgnies M, Chen JJ, Bouillon C. Overview about the use of Fourier transform infrared spectroscopy to study cementitious materials. WIT Trans Eng Sci 2013;77:251-62. https://doi.org/10.2495/MC130221
[41] Cheng H, Liu T, Zou D, Zhou A. Compressive strength assessment of sulfate-attacked concrete by using sulfate ions distributions. Construction and Building Materials 2021;293:123550. https://doi.org/10.1016/j.conbuildmat.2021.123550