

PAPER • OPEN ACCESS

Properties of self compacting concrete exposed to wetting and drying cycles in oil products

To cite this article: S A Salih *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **579** 012047

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Properties of self compacting concrete exposed to wetting and drying cycles in oil products

S A Salih¹, W I Khalil^{2#} and A A Ali³

^{1,2} Professor in the Building and Construction Engineering Department, University of Technology, Baghdad, Iraq

³An Engineer in Iraqi ministry of oil, Baghdad, Iraq

#Corresponding author's e-mail address: 100108@uotechnology.edu.iq

Abstract. Although the early deterioration of concrete exposed to petroleum products has been observed yet, the behavior of Self Compacting Concrete (SCC) being exposed to oil products is still unknown. In the present investigation, the mechanical and physical properties of hardened SCC cyclically being exposed to oil products (crude oil, gas oil, motor oil and fuel oil) have been tested and discussed. The numbers of exposure cycles are 2, 3, 4, 5 and 6. Each exposure cycle consists of twenty days immersion in water or different oil products followed by air drying at ambient temperature for a period of ten days. The results have been compared to other specimens cured in water or continuously exposed to oil products for the same period. The results show that the effect of continuous exposure to oil products on the mechanical properties is more severe than that of cyclic exposure of SCC specimens. The compressive strength, splitting tensile strength, modulus of rupture, and static modulus of elasticity of SCC specimens have slightly deteriorated until the fifth cycle of exposure for all types of oil products comparing to reference specimens (cured in water). Eventually at the sixth cycle all properties have decreased.

1. Introduction

Oil has become one of the most vital energy resources from the beginning of the previous century for its unique economic and operative characteristics. This has enabled it to exceed the other available power resources, and its importance has increased rapidly with its wide spread use and the discovery of huge oil reservoir in different parts of the world [1]. There are limited information and studies about the behavior of concrete which have been exposed to petroleum products especially the new types of concrete such as self-compacted concrete (SCC). In spite of the advantages of concrete structures such as shock and fire resistant, low cost of maintenance, yet the use of concrete structures as oil storage still limited due to restrictions. The unknown behavior of concrete exposed to oil products, the penetration of oil through concrete or concrete cracks, and the difficulty to modify or repair [2]. Due to the dominant improvements in the properties of concrete containing different types of admixtures, it is very important to study the effect of admixtures on the behavior of concrete exposed to oil products to improve their properties [3]. The behavior of SCC after exposure to oil products is still a foggy area and requires more investigations.



2. Research Significance

The main aim of this research is to investigate the effect of different exposure cycles (wetting and drying) to water or different oil products such as crude oil, gas oil, motor oil, and fuel oil on SCC properties and comparing these properties with those of SCC continuously exposed to water or the same different oil products for corresponding periods of exposure.

3. Experimental Works

3.1 Materials

3.1.1 Cement

Sulphate resistance Portland cement type (V) is used in this research. Its chemical and physical properties conform to ASTM specifications C150-04[4].

3.1.2 Coarse Aggregate

Iraqi natural crashed gravel is used. Its grading conforms to the requirement of ASTM C33-03[5] size No7. The specific gravity, sulfate content and absorption of the coarse aggregate are 2.64, 0.096%, and 0.7% respectively.

3.1.3 Fine Aggregate

Iraqi natural sand is used as fine aggregate. Its gradation was within the requirements of ASTM C33-03[5]. The specific gravity, sulfate content and absorption of the fine aggregate are 2.6, 0.19%, and 0.75% respectively.

3.1.4 Superplasticizer

The Superplasticizer that has been used throughout this study is commercially known as "structure 520" [6]. It is based on a unique carboxylic ether polymer with long lateral chains. It is suitable for the production of SCC. It is free from chlorides and complies with ASTM-C494 type F [7]. Its specific gravity is 1.1 with PH value 6.5 and alkali contents less than 1.5 gm of Na₂O equivalent per liter of admixture.

3.1.5 Water

Potable water is used throughout this experiment for mixing the SCC and curing of the hardened SCC specimens.

3.1.6 Silica Fume

Condensed silica fume is used to produce SCC with reliable fresh concrete properties. Its accelerated pozzolanic strength activity index with Portland cement at 7 days is 106%. The chemical composition and physical requirements shown in Tables (1) and (2) respectively indicate that the silica fume conforms to the chemical and physical requirements of ASTM C1240 specifications [8].

3.1.7 Oil Products

Oil products from Iraqi ministry of oil are used in this investigation. Table (3) shows the chemical analysis of the oil products used in this investigation to expose different SCC specimens for specific period.

3.2 Concrete Mixes

Self-compacted concrete mix has been designed according to European guidelines for testing fresh SCC EFNARC [5] to obtain a minimum cubic compressive strength of 65 MPa at 28 days. The mix proportions are (1:1.72:1.97) by weight with 10% silica fume as addition by weight of cement and a w/c ratio of 0.38. Several trial mixes are carried out in order to select the optimum dosage of Superplasticizer (SP) (2.8 liter per 100 kg of cementitious materials) which is determined by using all workability testes of SCC (slump flow test, V- funnel test, L-Box test, and J-Ring test).

3.3 Preparation of SCC Specimens

3.3.1 Mixing of SCC

SCC has been mixed in a rotary mixer with capacity of 0.1 m³. Fine aggregate has added to the mixer with 1/3 quantity of water and being mixing lasts for 1.5 minutes. Cement and silica fume are added with the end 1/3 of water and mixing continued for 3 minutes. Then half the quantity of coarse aggregate is added with the remaining quantity of water and 1/3 the dosage of superplasticizer (2.8 liter per 100 kg cementitious materials) and mixed for another 1.5 minute. The mixture rest for about 0.5 minute, the remaining quantity of coarse aggregate and superplasticizer added and remixed for 1.5 minutes. After that the fresh properties test were performed to assure the self-compatibility requirements.

3.3.2 Casting and Curing of SCC Specimens

Standard moulds have been prepared for SCC casting. They include 100mm cubes for compressive strength according to BS 1881: part 116 [9], 100*200mm cylinders for splitting tensile strength according to ASTM C496 [10], 150*300mm cylinders for elasticity modulus according to ASTM C469 [11], and 100*100*400 mm prisms for rupture modulus according to ASTM C78 [12]. SCC mixture does not require any compacting procedure, so the mix is poured into the tight steel moulds until completely filled and has leveled easily. The moulds have covered with polyethylene sheet for about 24 hours, and then the specimens are demoulded. To develop the strength of specimens, they are cured in water tanks for 27 days. After 28 days, age the specimens have divided into five groups, according to the goal of the study. These groups are cyclically (six cycles) exposed to the following fluid:-

Group 1: exposed to water.

Group 2: exposed to crude oil.

Group 3: exposed to gas oil.

Group 4: exposed to motor oil.

Group 5: exposed to fuel oil.

Each cycle exposure consist of twenty days of immersion in water or the various oil products followed by air drying at ambient temperature for a period of ten days.

To examine the effect of such condition, the mechanical and physical properties of the SCC specimens have assessed throughout experimental tests as detailed in section 3.3.2.

Table 1. Chemical analysis of silica fume*

Oxide Composition	Oxide content (%)	ASTM C1240-03
SiO ₂	93.94	Min. 85%
Al ₂ O ₃	0.7	<1%
Fe ₂ O ₃	0.45	<2.5%
CaO	0.88	<1%
SO ₃	0.93	< 1%
K ₂ O+Na ₂ O	1.37	< 3%
L.O.I	3.96	Max. 6%
Cl	0.17	< 0.2%
C(free)	3.1	< 4%

* Chemical analysis was conducted by National Center for Construction Laboratories and Researches

Table 2. Physical properties of silica fume*

Property	Result	ASTM C1240-03
Strength activity index	106%	≥ 105
Specific gravity, kg/m ³	2.2	-
Physical form	Powder	-
Color	Grey	-
Size	0.15	0.15 micron
Density	0.5	0.5± 0.1kg/liter (dry bulk)
Moisture	0%	< 2%
Specific surface, m ² /g	16	≥ 15

* Physical properties were conducted by National Center for Construction Laboratories and Researches

Table 3. Properties of different oil products*

Oil inspection data	Fuel oil results	Gas oil results	Motor oil results	Crude oil results	Method
Carbon residue wt%	8.7	0.09	-	-	ASTM-D524
Sulfur content % by weight	4.24	1.2%	-	0.597	ASTM-4294
Sulfur content % by weight	-	-	1.45	-	ASTM-D648
Cetane No.	-	57.8	-	-	IP-218
Specific gravity (gm/cm ³) at 15.6 C° 25.0 C° 30.0 C°	0.9625	0.8383 0.8186 0.8151	0.898	0.8067	ASTM-D1298
Specific gravity at 15.6 °C	-	-	0.898	-	ASTM-D4052
Viscosity (centistokes) at 10 °C 20 °C 30 °C 37.8 °C 40 °C 50 °C 100 °C	- - - - 234 -	- - - 3.4 - -	- 478.7 249.3 - 141.49 86.27 15.24	5.8 3.71 - 2.24 1.6 -	ASTM-D445
Moisture content % by volume	-	-	Nil	-	ASTM-D95
Flash point (pm) °C	90.6	88.6	236 Min	-	ASTM-D93
Pour point	+3	-	-9 Max.	-9 Max	ASTM-D97
Water & sediment % vol.	Trace	-	-	-	ASTM-D1796
Water & sediment % vol.	-	-	-	0.05	IP-75
Diesel index	-	62.1	-	-	IP -21
Ash wt.%	-	Nil	-	-	ASTM-874
Ash wt.%	-	-	0.579	-	ASTM-D482
Sulfate Ash % by weight	-	-	0.7231	-	ASTM-D874
API GRAVITY @15.6 °C	-	-	-	43.9	ASTM-D1298
water content vol %	-	-	-	traces	IP-74
Wax content,%	-	-	-	3.49%	-
Density @15 °C	-	-	-	0.8064	-
Salt content % by weight	-	-	-	0.0006	IP-77
KUOP Characterization Factor	-	-	-	12.1	UOP method 375

All oil products test were carried out by the laboratory of Ministry of Oil

4. Results and Discussion

4.1 Fresh Properties of SCC

Fresh properties of SCC have been tested according to the procedures European guidelines of testing fresh SCC EFNARC [13]. Three characteristics have been achieved by conducting three tests which are, flow ability, passing ability and segregation resistance. After specifying the weight mix proportions of 1:1.72:1.97 (cement: sand: Gravel), several mixtures were carried out as trial to select the optimum dosage of superplasticizer which produce SCC. It is 2.8% liter per 100kg, 10% silica fume as addition by weight of cement is used with w/c ratio 0.38. The ingredients of the mixture to produce SCC with acceptable criteria are shown in Table (4).

Table 4. Mix proportions and fresh properties for the selected SCC mix

Mix proportions for the selected SCC mix		Type of test	Mix Designation	Limits of EFNARC 2005 [13]	
Cement (kg/m ³)	450	Slump Flow D(mm)	750	650 - 800	
Sand (kg/m ³)	778	T50 (sec)	4	2 - 5	
Gravel (kg/m ³)	890	V-Funnel (sec) (Tv)	10	6 - 12	
Silica fume (kg/m ³)	45	T5 min	3	0 - 3	
Water (l/m ³)	188.1	L-box	T20 (sec)	6	-
SP% liter per 100kg	2.8		T40 (sec)	8.5	-
w/cm	0.38		BR% (h2/h1)	0.95	0.8 - 1
Compressive Strength (MPa)		J-ring	TJ500 sec	4.5	-
7 days	28 day		DJ mm	7 [±] 0	-
45	73.9		BJ mm	0	-
			Deviation D-DJ mm	0	0 - 10

4.2 Hardened Properties of SCC

4.2.1 Compressive Strength

The results summarized in Table (5) and Figure (1) represent compressive strength values of SCC exposed to various types of immersion and drying cycles in water or oil products. The compressive strength of SCC specimens increases as the number of wetting and drying cycles in water has increased. This may be due to the continuous hydration process of cement paste which forms new hydration product within the SCC mass. This leads to improve the bonds between cement paste and aggregate [14, 15]. The presence of silica fume in SCC improves the mechanical properties and durability of concrete [16]. Generally, the results indicate that the compressive strength of SCC specimens being exposed to cycles of immersion and drying in oil products (all types) decreases comparing to the reference specimens (exposed to the same number of wetting and drying cycles in water). The reduction of compressive strength may probably be due to the extension of gel pores and spreading solid hydration components caused by oil products penetration into the microstructure of SCC leading to adhesion and cohesion forces in the cement paste matrix reduction. In addition to the effects of oil products on SCC surface interactions which have been confirmed by other investigations [17, 18, 19, 20]. There is a slight decline in compressive strength of SCC specimens exposed to immersion and drying cycles in oil products till the exposure period of 150 days (5 cycles) relative to specimens exposed to same cycles in water. While specimens exposed to six cycles show higher reduction in compressive strength. This could be attributed to the pores of SCC which is still partially filled with water and leads to further hydration that delay the deterioration of SCC [21, 22]. The presence of silica fume leads to a modification of the microstructure

of concrete, especially at later ages that significantly reduces the permeability of concrete. This will delay the deterioration of concrete subjected to oil products [23].

It is observed that specimens exposed to six cycles of immersion in crude and gas oil show higher reduction in compressive strength than those exposed to motor and fuel oil. This is due to the difference in the viscosity of these products which has great effect in concrete properties [24]. The higher the viscosity of the oil, the less dangerous it is on concrete [22]. Table (2) shows that crude and gas oils have less viscosity than motor and fuel oils.

The results of the present study have been compared with the results of a study conducted by [25]. Figure (2) investigates the properties of SCC continuously exposed to oil products. The figure shows that the compressive strength of SCC specimens continuously immersed in water is higher than that exposed to wetting and drying cycles in water for the same of period. This can be attributed to continuous hydration of cement for specimens continuously immersed in water which improves compressive strength. Figure (3) shows the decline of compressive strength of SCC specimens exposed continuously to oil products and specimens immersed in oil products for different cycles relative to reference specimens (exposed to water for the same period). It can be concluded that the continuous exposure to oil products is more severe than the exposure to wetting and drying cycles. This may be due to the deterioration of specimen's surface being exposed continuously to oil product [17]. Moreover the compressive strength of high density concrete depends to a large extent on cement hydration. When coating a concrete surface or un hydrated cement grains in the concrete, the oil film blocks moisture from the coated surfaces and concrete grains, arresting their further hydration. Therefore, increasing concrete strength has slowed down or stopped altogether [26].

4.2.2 *Splitting Tensile Strength*

Splitting tensile strength results of SCC specimens exposed to wetting and drying cycles in water or different oil products are shown in Table (5) and Figure (4). Generally, the test results indicate that, the pattern of behavior of the splitting tensile strength of SCC is similar to that of compressive strength. The test results for SCC specimens have being subjected to wetting and drying cycles in water show continuous increase in splitting tensile strength as the number of cycles have increased.

It is clear that increasing compressive strength will lead to an increase in splitting tensile strength [27]. The results show that the splitting tensile strength of SCC specimens exposed to immersion and drying cycles in different oil products slightly decrease for immersion and drying 2,3,4 and 5 cycles as compared to reference specimen (exposed to water for the same number of cycles). The decrease is only 0.36%, 0.18%, 0.17% and 0.86% for crude oil and 0.36%, 1.4%, 0.34% and 0.86% for gas oil, while the decrease is about 2.14%, 1.58%, 0.52% and 0.17% for motor oil and 2.14%, 1.93%, 0.52% and 0.69% for fuel oil, respectively. The logical explanation to this phenomenon is that the pores in concrete are still partially filled with water, when causes further hydration in cement that increases the strength of concrete. The low penetration of oil products cannot permit to loss the bond due to low permeability of SCC produced in this investigation (containing silica fume) that greatly enhances the durability of concrete subjected to oil products. The splitting tensile strength for SCC specimens exposed to crude oil and gas oil has significantly decreases as the number of immersion and drying cycles in oil products increased to six cycles compared to the reference. The decrease ratio is about 24.1% and 14.85% respectively. Specimens being exposed to motor oil and fuel oil show slight decrease in splitting tensile strength in comparison with the reference (2.56% and 2.39% respectively). This is due to the low viscosity of crude and gas oil. As for compressive strength, splitting tensile strength of SCC specimens continuously immersed in water is higher than that being exposed to wetting and drying cycles in water as shown in Figure (5). The continuous exposure to oil products is more severe than immersion and drying cycles of exposure on splitting tensile strength of SCC, as shown in Figure (6).

Table 5. Properties of SCC specimens exposed to oil products

Exposure Type	Properties	No. of Cycles of Exposure (Age of Specimens, days)					
		1 (28)	2 (60)	3 (90)	4 (120)	5 (150)	6 (180)
Water	Compressive strength (MPa)	73.89	75.2	76.95	82.8	84.4	86.1
	Splitting tensile strength (MPa)	5.5	5.62	5.71	5.82	5.84	5.86
	Modulus of rupture (MPa)	7.28	7.36	7.38	7.48	7.51	7.78
	Static modulus of elasticity (GPa)	54.58	59.78	62.72	63.7	64	64.93
	Total absorption (%)	3.16	3.07	2.7	2.5	2.46	1.93
Crude oil	Compressive strength (MPa)		74.23	76.44	82	80	63.6
	Splitting tensile strength (MPa)		5.6	5.7	5.81	5.79	4.45
	Modulus of rupture (MPa)		7.35	7.37	7.45	7.4	6.6
	Static modulus of elasticity (GPa)		56.27	60	63.5	63	47
	Total absorption (%)		1.39	1.25	1.16	0.84	0.79
Gas oil	Compressive strength (MPa)		74.8	76.72	81	80.4	70
	Splitting tensile strength (MPa)		5.6	5.63	5.8	5.79	4.99
	Modulus of rupture (MPa)		7.35	7.37	7.42	7.41	7.2
	Static modulus of elasticity (GPa)		57.18	61.1	63.4	63.29	52.2
	Total absorption (%)		2.39	1.44	1.51	1.13	1.24
Motor oil	Compressive strength (MPa)		73.95	75.2	80.1	80.9	77.7
	Splitting tensile strength (MPa)		5.5	5.62	5.79	5.83	5.71
	Modulus of rupture (MPa)		7.29	7.36	7.41	7.5	7.39
	Static modulus of elasticity (GPa)		54.92	59.78	63.4	64	62.8
	Total absorption (%)		2.42	2.02	1.21	1.12	0.8
Fuel oil	Compressive strength (MPa)		73.95	74.8	80.1	80.9	77.7
	Splitting tensile strength (MPa)		5.5	5.6	5.79	5.8	5.72
	Modulus of rupture (MPa)		7.29	7.36	7.41	7.5	7.39
	Static modulus of elasticity (GPa)		55.02	57.18	63.9	64.5	62.9
	Total absorption (%)		2.36	1.73	1.57	1.5	0.97

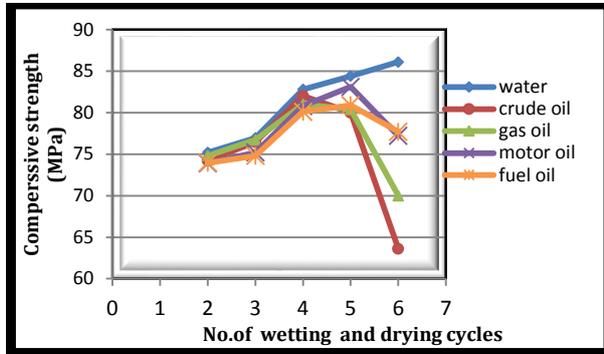


Fig.1. Compressive strength for SCC specimens exposed to wetting and drying cycles in water or

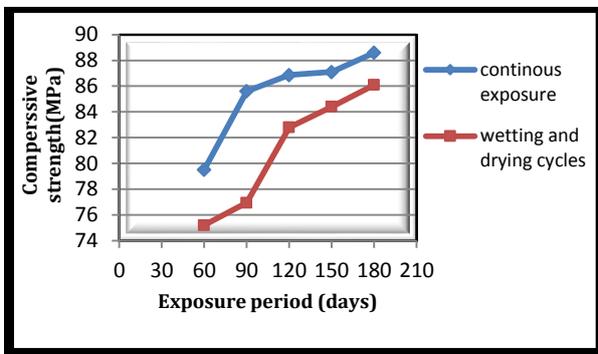
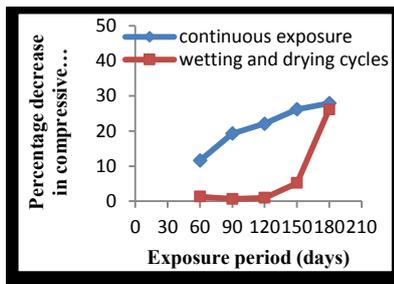
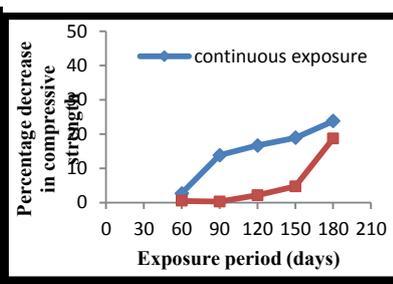


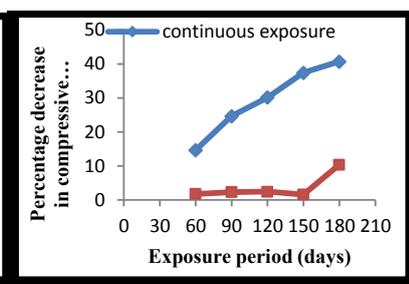
Fig.2. Effect of water exposure type on compressive strength of SCC (The continuous



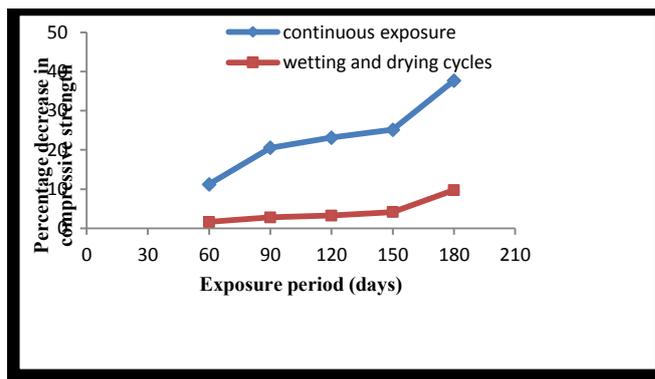
A- Crude



B- Gas oil



C- Motor oil



D - Fuel oil

Fig.3. Effect of type of exposure to oil products on compressive strength of SCC (The continuous exposure results are from reference 15)

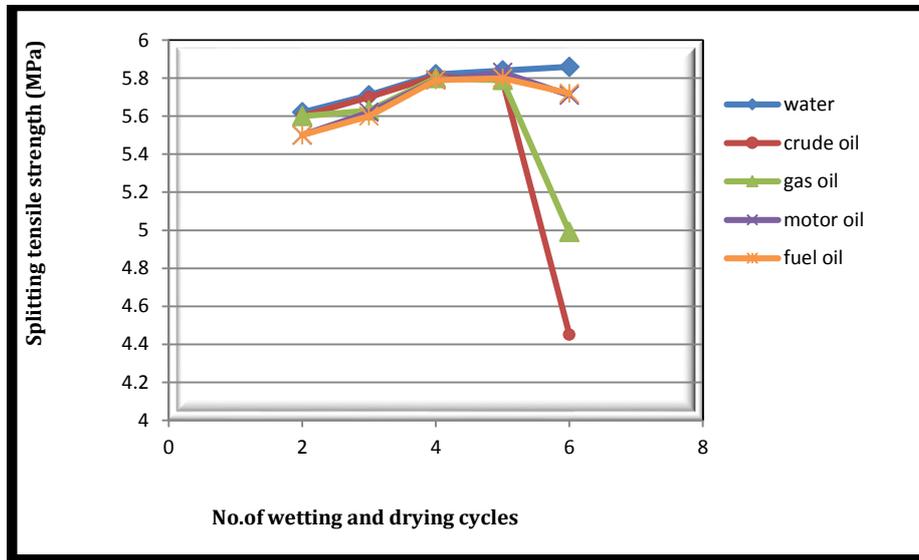


Fig.4. Splitting tensile strength of SCC specimens exposed to wetting and drying cycles in water or different oil products

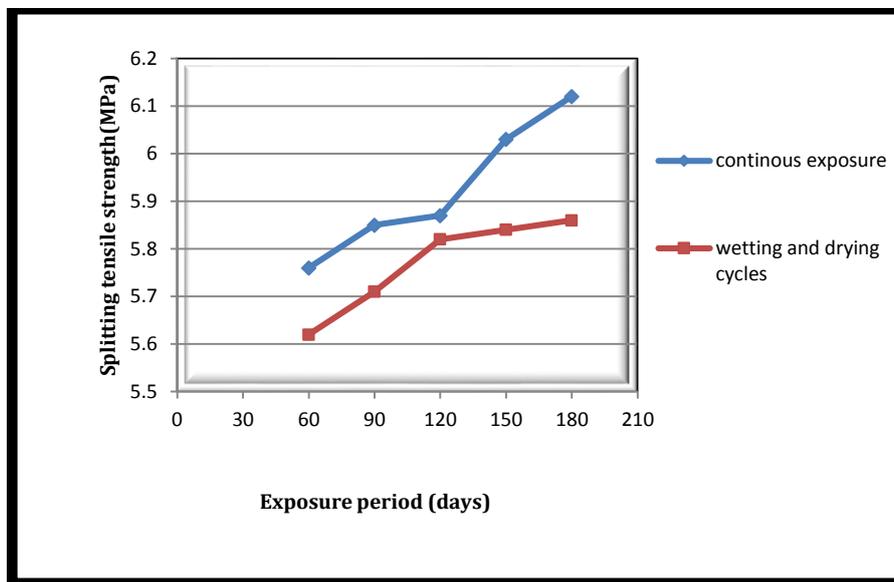


Fig.5. Effect of water exposure type on splitting tensile strength of SCC (The continuous exposure results are from reference 15)

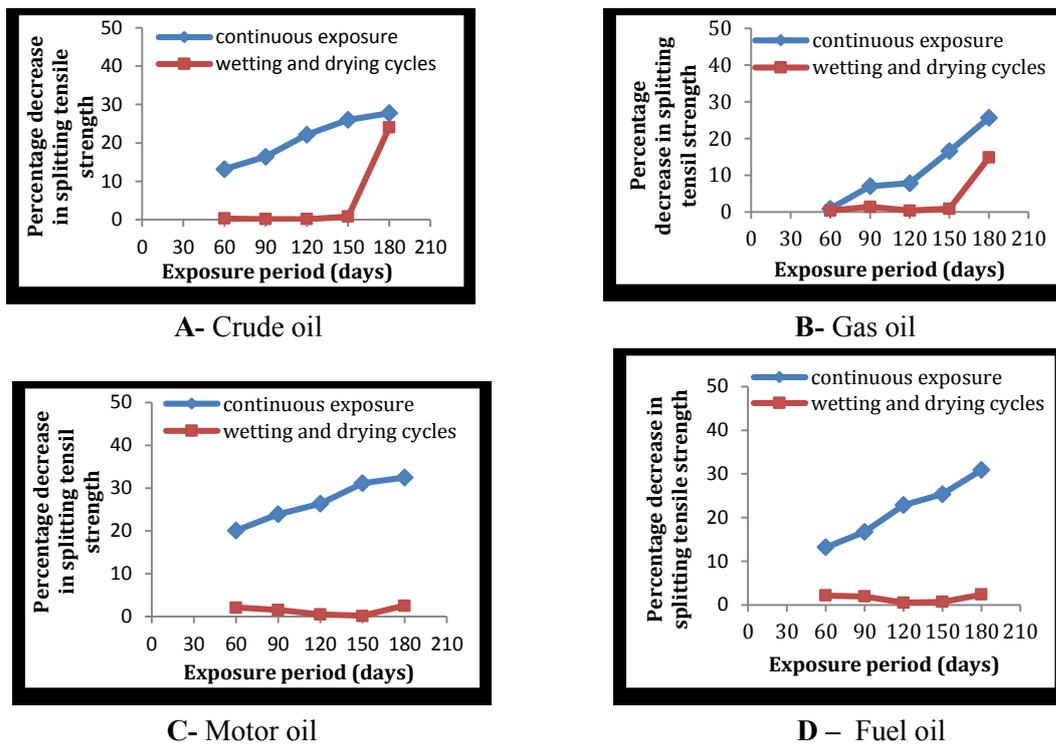


Fig.6. Effect of exposure type to oil products on splitting tensile strength of SCC (The continuous exposure results are from reference 15)

4.2.3 Modulus of Rupture

Modulus of rupture of SCC exposed to wetting and drying cycles in water or different oil products are summarized in Table (5) and Figure (7). The results indicate that there is a continuous increase in modulus of rupture as the number of wetting and drying cycles in water increased. The percentage has increased about 1.09%, 1.37%, 2.74%, 3.15% and 6.86% being exposure in 2, 3, 4, 5 and 6 cycles respectively comparing to the reference (not exposed to wetting and drying cycles). The modulus of rupture of SCC specimens exposed to wetting and drying cycles in different oil products has slightly decreased being exposure in 2, 3, 4 and 5 cycles in comparison with reference specimens (exposed to water for the same number of cycles). This is due to the closing and autogenously healing of crack and flaws in SCC due to possible volume change by effect of products [28]. The modulus of rupture of SCC specimens exposed to different oil products began to decrease as the number of wetting and drying cycles to oil products increased to six cycles relative to the reference. The decrease ratio in modulus of rupture of SCC specimens exposure to six cycles in crude oil, gas oil, motor oil and fuel oil is 15.17%, 7.46%, 5% and 5% respectively relative to the reference. Figure (8) shows that modulus of rupture of SCC specimens immersed in water for a period is more than that which exposed to wetting and drying cycles for all exposure periods. This may be attributed to the continuous hydration of cement due to continuous supply of water which can lead to increase in modulus of rupture. The comparison between the decrease in modulus of rupture of SCC specimens continuously exposed to oil products and specimens exposed to wetting and drying cycles in oil products relative to the reference specimens is shown in Figure (9). It can be concluded that the continuous exposure to oil products is more severe than wetting and drying exposure. This might be attributed to the continuous losses of some oil by evaporation during the drying cycles and hence reduces its negative affect [22]. While for continuous exposure, oil film coated the unhydrated cement grains blocks moisture from the coated surfaces and concrete grains, ceasing further hydration. Therefore, the strength of concrete has slowed or stopped [26].

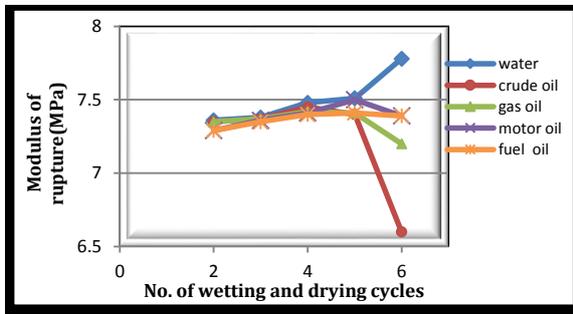


Fig.7. Modulus of rupture of SCC exposed to wetting and drying cycles in water or oil products

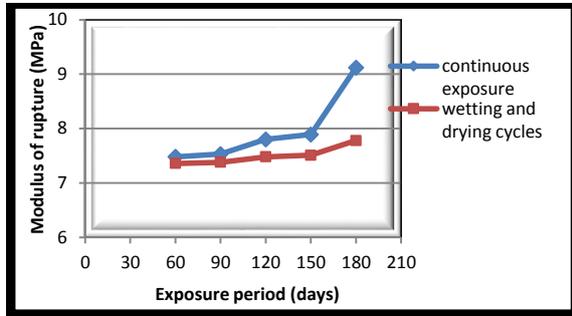
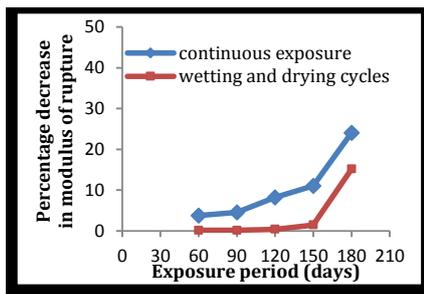
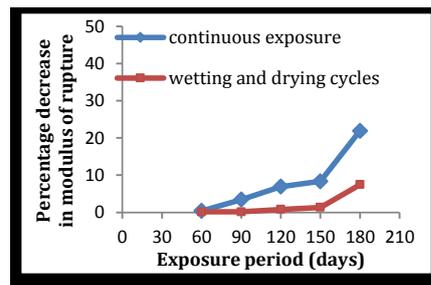


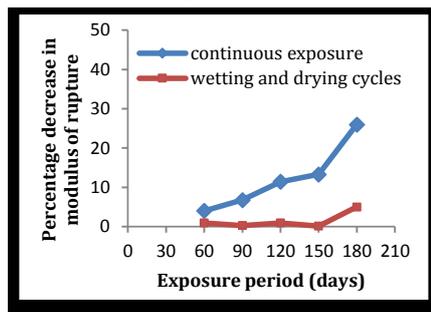
Fig.8. Effect of water exposure type on modulus of rupture of SCC (The continuous exposure results are from reference 15)



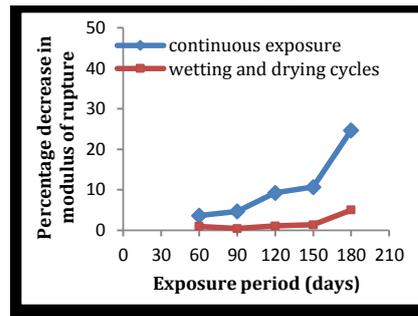
A- Crude oil



B- Gas oil



C- Motor oil



D - Fuel oil

Fig.9. Effect of exposure type to oil products on modulus of rupture of SCC (The continuous exposure results are from reference 15)

4.2. 4 Static Modulus of Elasticity

The results of static modulus of elasticity of SCC specimens exposed to wetting and drying cycles in water and oil products are summarized in Table (5) and Figure (10). The results illustrate that there is a continuous increase in static modulus of elasticity as the number of wetting and drying cycles in water increased. Static modulus of elasticity for SCC specimens exposed to immersion and drying cycles in different oil products slightly decreases for 2, 3, 4 and 5 cycles relative to reference specimens (exposed to water for the same number of cycles). The pattern of decrease in compressive strength leads to a decrease in modulus of elasticity for concrete. SCC specimens exposed to crude oil and gas oil show the higher reduction in static modulus of elasticity when it exposed to six cycles in comparison to the reference. The decrease ratio is about 27.6% and 19.6% respectively. This is because crude and gas oils have lower viscosity than motor and fuel oils, so the aggressivity of crude and gas oils is higher than that of motor and fuel oil. This reduction in modulus of elasticity attributed to:

- a- The presence of the oil might cause a weak effect on the cement paste components due to the dilution of the cement paste and the reduction of the adhesive forces between the gel particles.
- b- The presence of micro cracks at the aggregate-matrix interfaces due to the volume changes during setting and hardening [22].

Figure (11) shows that static modulus of elasticity for SCC specimens continuously immersed in water is more than that exposed to wetting and drying cycles in water for all exposure periods. From Figure (12), it can be concluded that the continuous exposure of SCC to different oil products is more severe than wetting and drying exposure. This may be due to the deterioration of specimen's surface continuously exposed to oil products [17].

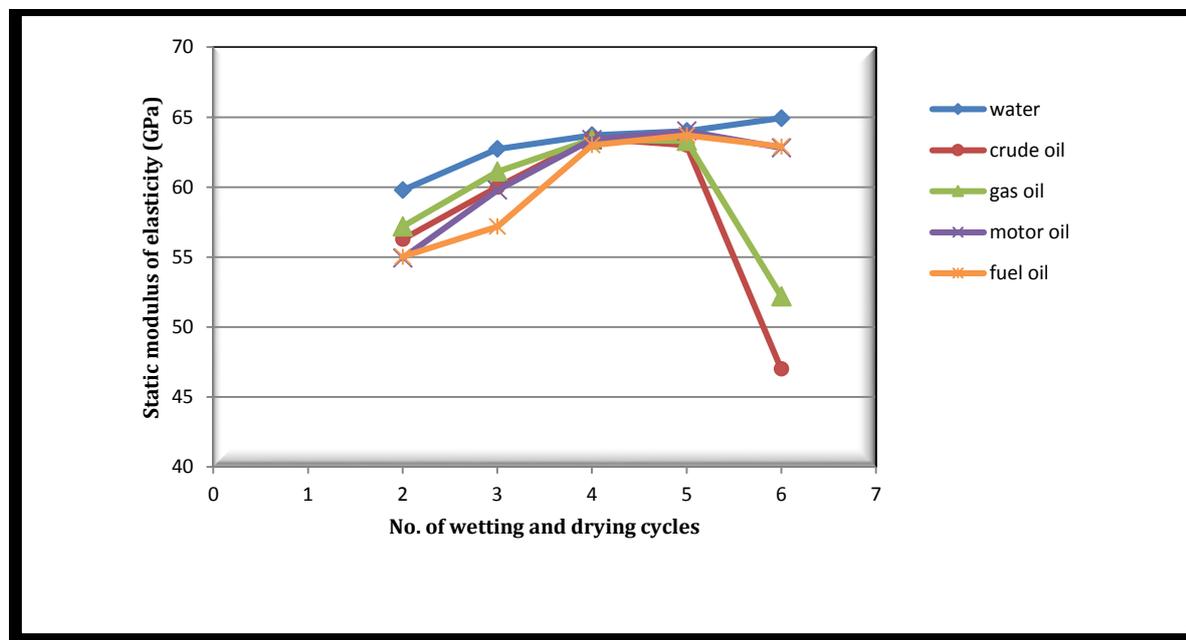


Fig.10. Relationship between static modulus of elasticity for SCC specimens and wetting and drying cycles in water or oil products

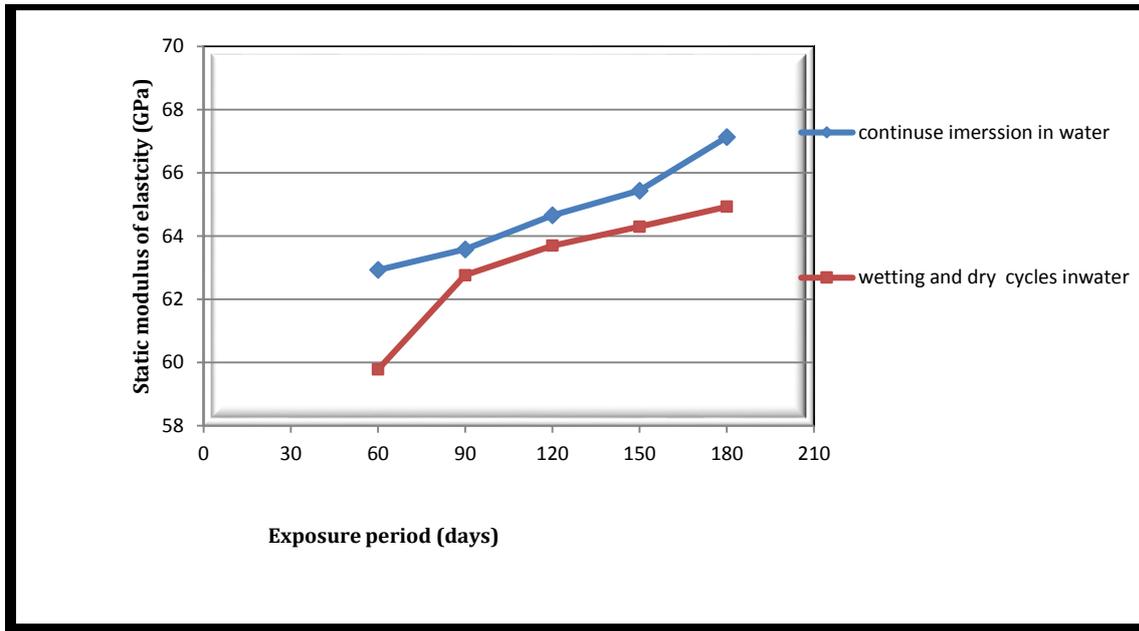


Fig.11. Static modulus of elasticity of SCC specimens exposed to water (continues exposure and wetting and drying cycle exposure)

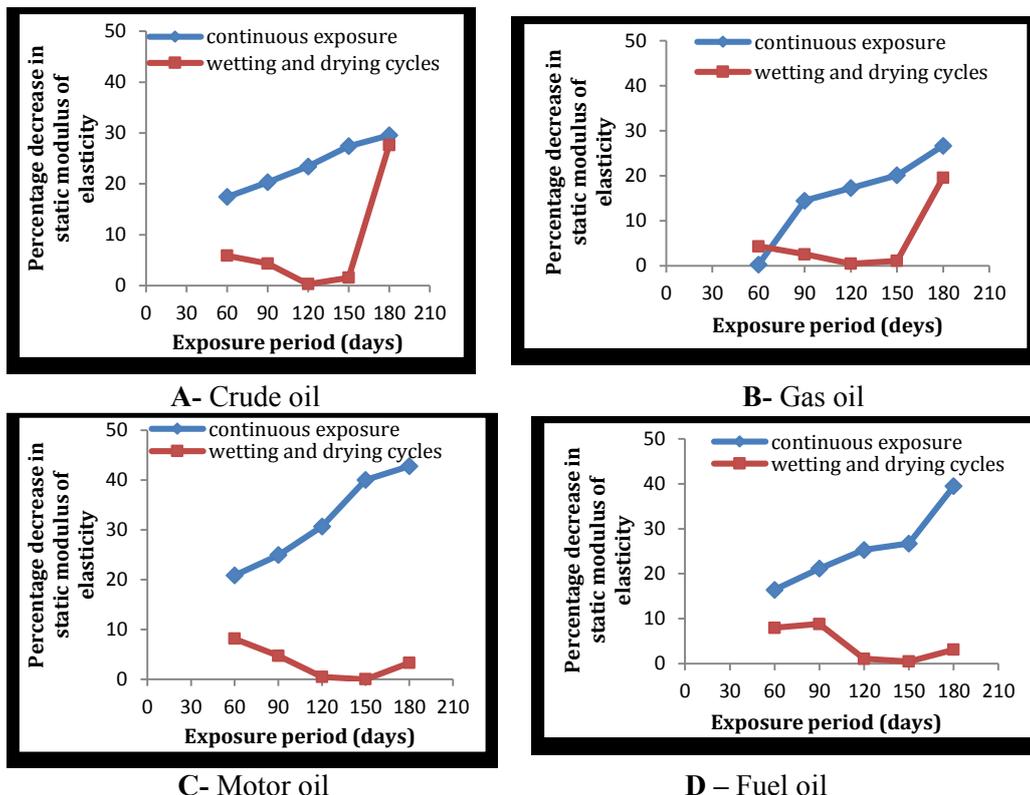


Fig.12. Effect of exposure type to different oil products on static modulus of elasticity for SCC specimens (The continuous exposure results are from reference 15)

4.2.5 Total Absorption

The results show that the total absorption of all SCC specimens exposed to water or different oil products are below 10 % by weight as shown in Table (5). This gives an indication of concrete with low permeability [29]. The total absorption for SCC specimens exposed to wetting and drying cycles in water decreases as the number of wetting and drying cycles increased. This is attributed to the continuous hydration of cement which decreases the absorption of SCC. The use of low water/cement ratio and silica fume which modifies the microstructure of concrete and reduces the capillary porosity leading to better packing and increase the density then reduces the absorption ratio [30]. The results also show that the total absorption of SCC specimens exposed to wetting and dry cycles in crude oil, motor oil and fuel oil products has decreased as the number of cycles increased. Specimens have been exposed to wetting and drying cycles in water show higher total absorption than those exposed to wetting and drying cycles in different oil products for all exposure cycles. This may be related to the large molecular size of oil products and its viscosity compared to water. Also, the SCC which has been produced in this investigation has small pores in its microstructure since silica fume leads to pores size refinement and this will need more time for oil products to penetrate in comparison with water.

Generally, total absorption of SCC exposed to wetting and drying cycles in crude oil is lower than that of SCC exposed to cycles in gas oil, motor oil and fuel oil. This can be attributed to the deposits and the wax that are found in the chemical composition of crude oil as shown in Table (3) which can block some pores.

4.2.6 Density

The results of density of SCC specimens exposed to wetting and drying cycles in water and oil products are shown in Figure (13). The results indicate that there is a slight increase in the density as the number of wetting and drying cycles in water have increased. This can be attribute to the continuous hydration process of cement paste which forms a new hydration product within the SCC mass, then increases the bond between cement paste and aggregate [29, 14].

From the results, it can be concluded that there is no significant effect on the density of SCC exposed to 2, 3, 4 and 5 wetting and drying cycles in different oil products, but as the exposure cycles increased to six cycles, the density slightly decreases relatively to reference the specimen (exposed to water for the same number of cycles). The results of SCC specimens which have been exposed to six wetting and drying cycles in crude oil and gas oil show the higher reduction in density (1.42% and 1.1%) compared to the reference. This may be due to the slight deterioration of specimen's surface exposed to oil product [17].

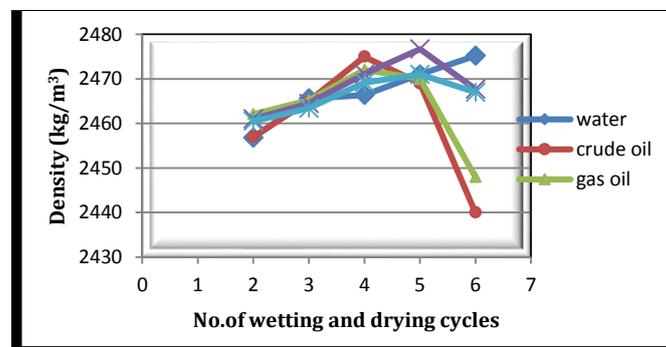


Fig.13. Relationship between density of SCC and number of wetting and drying cycles in water or oil products

5. Conclusions

This research presents an experimental study of the properties of SCC exposed oil products for different cycles. The following conclusions are drawn from the test results:

1. The compressive strength, splitting tensile strength, modulus of rupture, and static modulus of elasticity, of SCC specimens exposed to wetting and drying cycles in water have increased as the number of cycles increased. The percentage of increase is between 1.77-16.52 % for compressive strength, 2.18-6.54% for splitting tensile strength 1.09 -6.86% for modulus of rupture, and 9.50 - 18.96% for static modulus of elasticity for 2-6 cycles respectively.
2. The compressive strength, splitting tensile strength, modulus of rupture, and static modulus of elasticity of SCC specimens exposed to wetting and drying cycles in all oil products generally have decreased in comparison with the reference specimen (exposed to water for the same number of cycles). Specimens exposed to crude oil and gas oil show a significant decrease as the number of wetting and drying cycles has increased to six cycles. The decrease ratio is about 26.13%, 18.7% for compressive strength, 24%, 14.85% for splitting tensile strength, 15.2%, 7.46% for modulus of rupture, and 27.6%, 19.6% for static modulus of elasticity respectively relative to the reference (exposed to water for the same number of cycles).
3. Continuous exposure to oil product is more severe than wetting and drying exposure cycles on compressive strength, splitting tensile strength, modulus of rupture, and static modulus of elasticity of SCC specimens.
4. Total absorption for SCC specimens exposed to wetting and drying cycles in water decreases as the number of cycles increased. Water absorption is about 3.1%, 2.7%, 2.5%, 2.46% and 1.9% for wetting and drying cycles of 2,3,4,5 and 6 respectively. While the total absorption for SCC specimens exposed to wetting and drying cycles in oil products is lower than that exposed to wetting and drying cycles in water.
5. The density of SCC is slight increase as the number of wetting and drying cycles in water increased, while there is no significant effect on the density of SCC exposed to 2, 3, 4 and 5 wetting and drying cycles in different oil products, but the density slightly decreases as the exposure cycles increased to six cycles relatively to SCC exposed to water for the same number of cycles.

References

- [1] Ra'ed KHA *Behavior of High Performance Concrete in Direct Contact with an Oil Products* MSc Thesis University of Technology Baghdad (2002)
- [2] Rashed L *Behavior of Fiber Reinforced Concrete Exposed to Oil* MSc Thesis University of Technology Baghdad (1998)
- [3] Al hamadani ZK *Improvement of the Performance of Concrete Against Oil Products* MSc Thesis University of Technology Baghdad (1997)
- [4] ASTM C150 2015 *Portland Cement Annual Book of Standards American Society for Testing and Materials 04.01*
- [5] ASTM C33 2015 *Concrete Aggregate Annual Book of Standards American Society for Testing and Materials 04.02*
- [6] Fosroc constructive solution *Structuro 520* fosam company limited FO SA/STRUCTURO 520/07/09
- [7] ASTM C494 2015 *Standard Specification for Chemical Admixtures for Concrete, Annual Book of Standards, American Society for Testing and Materials 0402*
- [8] ASTM C1240 2015 *Standard Specification for the use of Silica Fume as a Mineral Admixture in Hydraulic Cement Concrete, Mortar, and Grout, Annual Book of Standards, American Society for Testing and Materials 04.02*

- [9] BS 1881 part 116 1989 *Method of Determination of Compressive Strength of Concrete Cubes*, British Standards Institution
- [10] ASTM C496 2015 *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*, Annual Book of Standards, American Society for Testing and Materials **0402**
- [11] ASTM C469 2015 *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*, Annual Book of Standards, American Society for Testing and Materials **04.02**
- [12] ASTM C78 2015 *Standard Test Method for Flexural Strength of Cement*, Annual Book of Standards, American Society for Testing and Materials **04.02**
- [13] EFNARC *The European Guidelines for Self-Compacting Concrete Specification, Production and Use* (May 2005)
- [14] Shetty M S 2000 *Concrete Technology India*
- [15] Neville AM and Brooks JJ **2010** *Properties of Concrete* (Second Edition Prentic Hall England)
- [16] Siddique R 2011 Utilization of Silica Fume in Concrete: Review of Hardened Properties, *Resources, Conservation and Recycling* **55** 923-932
- [17] Onabolu OA 1989 Some Properties of Crude Oil Soaked Concrete Exposure at Ambient Temperatures *ACI Material Journal* **26** 2 150-158
- [18] Onabolu OA 1989 Some Properties of Crude Oil Soaked Concrete Exposure at Elevated Temperatures *ACI Material Journal* **86** 3 205-213
- [19] Ejeh SP and Uche OAU 2009 Effect of Crude Oil Spill on Compressive Strength of Concrete Materials *Journal of Applied Sciences Research* **5** 10 1756-1761
- [20] Ogbonna AC, Okoro EE and Daraha T 2013 Laboratory Investigation of the Effect of Crude Oil Spill on Engineering Properties of Concrete *IOSR Journal of Mechanical and Civil Engineering* **10** 2 11-17
- [21] AL- Harby MG 1989 Effect of Oil Products on Structures *Nationalist Center of Constructional Laboratories Baghdad*
- [22] Abdul- Moghni HSM 1999 *Durability of High Performance Concrete Exposed to Oil Products* PhD Thesis University of Technology Baghdad Iraq
- [23] Mehta KP and Monteiro PJM 2006 *Concrete Microstructure, Properties and Material* Third Edition Mc Graw-Hill, London
- [24] Biczok I 1967 *Concrete Corrosion and Concrete Protection* Publishing House of the Hungarian Academy of Science Budapest
- [25] Al Mashhadany SA, Khalil WI and Ali AA 2014 Properties of Self Compacting Concret Continuously Exposed to Oil Products *Engineering and Technology Journal* **32** Part (A) 8
- [26] Diab H 2012 Compressive Performance of Low- and High- Strength Concrete Soaked in Mineral Oil *Construction and Building Materials* **33** 25-31
- [27] Khaleel O R 2007 *The Effect of Coarse Aggregate Properties on the Behavior of Self-Compacting Concrete* MSc Thesis University of Technology
- [28] Matti M 1976 *Some Properties and Permeability of Concrete in Direct Contact with Crude Oil* PhD Thesis University of Sheffield
- [29] Neville AM 2005 *Properties of Concrete* Pearson Education Limited Fourth and Final Edition
- [30] *Guide for the Use of Silica Fume in Concrete* ACI 234R (2006)