Properties of High Performance Self Compacting Concrete Continuously Exposed in Oil Products

Dr. Shaker.A.Al-Mashhadany
Building and Construction Engineering Department, University of Technology/Baghdad.
Dr. Wasan Ismail Khalil
Building and Construction Engineering Department, University of Technology/Baghdad.
Email: wasan1959@yahoo.com
Ali Adel Ali
Al-Daura Refinery/Baghdad.

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ABCETRACT

Self compacted concrete (SCC) is a new generation of concrete. Its behavior after exposure to oil products is still unknown. This investigation includes producing SCC and investigate its properties after different exposure periods (28,60,90,120,150 and 180 days) to water or different oil products (crude oil, gas oil , motor oil and fuel oil). The mechanical properties (compressive strength, splitting tensile strength, modulus of rupture and static modulus of elasticity) and dynamic properties (Ultrasonic pulse velocity and dynamic modulus of elasticity), length change, total absorption and density of SCC were studied. The results show that compressive strength, splitting tensile strength, modulus of rupture and static modulus of elasticity, ultrasonic pulse velocity, dynamic modulus of elasticity and density for SCC specimens continuously exposed to water are increase as the exposure period increased. Generally the results indicate a reduction in all these properties as the exposure period to oil products increased.

Keywords: self compacting concrete, oil products, exposure period.

خواص الخرسانة عالية الاداء والذاتية الرص المعرضة للمشتقات النفطية

الخلاصة :

تعتبر الخرسانة ذاتية الرص جيل جديد من الخرسانة ومازال سلوكها بعد التعرض للمشتقات النفطية غير معروف. يتضمن البحث إنتاج خرسانة ذاتية الرص و التحري عن خواصها بعد تعرضها لفترات مختلفة (180,150,120,90,60,28 يوم) الى الماء او المشتقات النفطية المختلفة (نفط خام, دهن سيارات, نفط اسود وكاز). الخواص التي درست هي, الخواص الميكانيكية, (مقاومة الانضغاط ، ومقاومة الشد، مقاومه الانثناء، ومعامل المرونة الاستاتيكي) الخواص الديناميكية (الموجات فوق الصوتية , ومعامل المرونة الديناميكي), التغير بالطول و الامتصاص الكلي والكثافة للخرسانة ذاتية الرص بعد التعرض للمشتقات النفطية بشكل مستمر. اظهرت النتائج ان مقاومة الانضغاط ، ومقاومة الشد، مقاومة الانثناء، ومعامل المرونة

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

الاستاتيكي, الموجات فوق الصوتية, ومعامل المرونة الديناميكي و الكثافة لنماذج الخرسانة ذاتية الرص المغمورة بشكل مستمر في الماء ازدادت بزيادة فترة الغمر. بشكل عام اظهرت النتائج انخفاضا في خواص الخرسانة ذاتية الرص بزيادة فترة التعرض للمشتقات النفطية.

INTRODUCTION

In spite of the advantages of concrete structures such as shock and fire resistant, low cost of maintenance and they could be built to large dimensions compared with steel structures, the use of oil storage concrete structures is still limited due to some restrictions such as the unknown behavior of concrete exposed to oil products, the penetration of oil through concrete or concrete cracks, and the difficulties for any modifications or repair [(1)]. For several years, the problem of the durability of concrete structures has been a major problem posed to engineers. The creation of durable concrete structures requires adequate compaction by vibrating. Over vibration can easily cause segregation. In conventional concrete it is difficult to ensure uniform material quality and good density in heavily reinforced locations. If steel is not properly surrounded by concrete it leads to durability problems. One solution for the achievement of durable concrete structures is the employment of self-compacting concrete [(2)]. The behavior of SCC after exposure to oil products is still unknown. Many local and foreign researches were carried out to investigate the properties of concrete after exposure to oil products. Al-Ameer [(3)] studied the influence of oil products (kerosene and diesel oil) on the mechanical properties of steel fiber reinforced concrete. High tensile crimped steel fiber with aspect ratio 100 and different volume fractions (0.5, 0.75 and 1%) was used. The results show that the compressive strength for plain and fiber reinforced concrete exposed to kerosene and diesel oil for 60 days was higher than that cured in water, while at exposure period 120 days the compressive strength reduced. Modulus of rupture strength results was improved for fiber reinforced concrete with different fiber content and for all periods of exposure. The maximum increase in modulus of rupture was 36% and 37% after 120 days exposure to diesel oil and kerosene respectively. There are no local and foreign researches on properties of SCC after exposure to oil products, so the present research tries to fulfill this shortage of knowledge by studying properties of SCC after different continuous exposure to different oil products.

EXPERIMENTAL PROGRAM

Materials

Cement

Tasloga sulfate resistance cement (ALGSER) type (V) was used in this research. Tables (1) and (2) show the chemical composition and physical properties of the cement used respectively. Test results indicated that the adopted cement satisfies the requirements of the Iraqi specification No.5/1984.

Coarse Aggregate

Natural crashed aggregate from Al-Niba'ee region was used. Tables (3,and 4) show the grading, physical and chemical properties of the aggregate. The results show that the coarse aggregate used conforms to the requirement of Iraqi specification No.45/1980.

Fine Aggregate

Al-Ukhaider Natural sand was used as fine aggregate. Tables (5) and (6) show, the physical and chemical properties and grading of fine aggregate which lies in zone (2) respectively. The results show that sand gradation and sulfate content were within the requirements of Iraqi specifications No.45/1984.

Superplasticizer

Superplasticizer used throughout this study is commercially known as "structure 520" [(4)]. It is based on a unique carboxylic ether polymer with long lateral chains. It is suitable for the production of SCC. Also, it is free from chlorides and complies with ASTMC494 type F. Specific gravity is 1.1 with PH value 6.5 and alkali content of less than 1.5 gm of Na_2O equivalent per liter of admixture. Table (7) shows the technical descriptions of the superplasticizer used.

Water

Potable water was used throughout this investigation for mixing and curing.

Silica Fume

Condensed silica fume was used to produce SCC with reliable fresh concrete properties. Table (8) and (9) show Chemical analysis and Physical properties of silica fume.

Oil Products

Oil products from Al-Daura Refinery were used in this investigation. Tables (10)-(13) show the chemical analysis of different oil products used in this investigation.

Concrete Mixes

Self compacted concrete (SCC) mix was designed according to the European guidelines for SCC specifications, EFNARC, [(5)] to obtain minimum compressive strength of 65 MPa at 28 days. After many trials the mix proportions are (1:1.72:1.97) (cement: sand: aggregate) by weight with 10% silica fume as addition by weight of cement and w/c ratio 0.38. Several trail mixes were carried out in order to select the optimum dosage of Superplasticizer (sp) that was determined by using all workability testes of SCC.

Preparation of SCC Specimens

Mixing of SCC

Mixing of SCC was carried out in a rotary mixer with capacity of 0.1 m^3. Fine aggregate was added to the mixer with 1/3 quantity of water and mixed for 1.5 minutes. Cement and silica fume were added and then another 1/3 the quantity of water was added and mixed for 3 minutes. Half the quantity of coarse aggregate was added with the last 1/3 the quantity of water and 1/3 the dosage of superplasticizer and mixed for 1.5 minute. The mixture was left for about 0.5 minute to rest and then the remaining quantity of coarse aggregate and superplasticizer was added and mixed for 1.5 minutes.

Casting and Curing of SCC Specimens

Standard moulds were prepared for casting SCC. They include 100mm cubes for compressive strength 100*200mm cylinder for splitting tensile strength, 150*300mm cylinder for modulus of elasticity, 100*100*400 mm prisms for modulus of rupture, 100*100*285 mm prisms for drying shrinkage and 100 mm cubes for ultrasonic pulse velocity test of concrete. SCC mix not required compacting, so the mix was poured into the tight steel molds until it was fully filled without any compaction. The moulds were covered with polyethylene sheet for about 24 hours, and then the specimens were demoulded. Concrete specimens were completed immersed in water storage tank for 28 days then stored in laboratory environments. After 28 days curing in water these specimens were taken out from water and then oven dried at a temperature of 105^{o}C until they reach a constant weight or until the weight loss is about 1 gm/day, this normally take about 4 days. Some of SCC specimens continuously soaked in water for different periods (28,60,90,120,150 and 180 days) ,while the others divided to four groups, each group continuously soaked in either crude oil, gas oil, motor oil and fuel oil for different exposure periods (28,60,90,120,150 and 180 days).

Result and Discussion

Fresh Properties of SCC

Fresh properties of SCC were tested according to the procedures of European guidelines [5] for testing fresh SCC. Three characteristics were achieved by conducting three tests which were, flow ability, passing ability and segregation resistance. After mix design for selection mix proportions, several trial mixes were carried out in order to select the optimum dosage of superplasticizer using all workability testes of SCC. Table (14) shows the mix proportions for the selected SCC mix. Table (15) summarized the fresh properties for the selected SCC mix. The workability test results indicate that the results are within the acceptable criteria for SCC and also indicate excellent deformability of SCC mix without blocking.

Hardened Properties of SCC

Compressive Strength

Table (16) and Fig.(1), summarize the results of compressive strength values for SCC at various periods of immersion in water or oil products. The compressive strength of SCC specimens immersion in water increases as the period of immersion in water increased. This is due to the continuous hydration process of

cement paste and the delay pozzolanic reaction of silica fume which forms a new hydration products within the microstructure of concrete and increases the bond between aggregate and cement paste [(6), (7)].
Generally the results indicate that there is a slight increase in compressive strength of SCC after exposure to oil products for 28 days relative to reference (exposed to water at same exposure period). This may be due to the presence of water in partially filled pores which leads to further hydration that delays the deterioration of SCC. The compressive strength for SCC decreases as the period of exposure to oil products increased. The percentage decrease after 180 days exposure to crude oil, motor oil, fuel oil and gas oil was about 27.93%, 40.74%, 37.69% and 23.81% respectively. From a microstructure viewpoint, the reduction in strength of concrete specimen caused by absorption has been related to the surface energy. On saturation with fluids, the surface energy decreases and reduces the strength, and the mount of reduction can be related to the molecular size of the fluid absorbed [(8)].
The aggressivity of the oil products depended on their viscosity, the higher the viscosity of oil products, the less dangerous it is on concrete [(8), (9)].

Splitting Tensile Strength

The results of splitting tensile strength for SCC at various periods of immersion in water or oil products are shown in Table (17) and Fig. (2). The test results for SCC specimens continuously exposed to water show a continuous increase in splitting tensile strength as the period of exposed increased. Splitting tensile strength for SCC specimens exposed to oil products for 28 days slightly increases in comparison with reference specimen (exposed to water at same exposure period). After exposure period of 28 days, the splitting tensile strength decreases as the period of exposure to oil products increased in comparison with the reference. The percentage decrease after 180 days exposure to crude oil, motor oil, fuel oil and gas oil was about 27.77%, 32.51%, 30.88% and 25.65% respectively. This reduction is due to the effect of oil products on the bond between aggregate and cement paste which cause microcrack in the interfacial transition zone and will increase the permeability of concrete [(10)].

Modulus of Rupture

Modulus of rupture results for SCC after various periods of immersion in water or oil products are summarized in Table (18) and Fig. (3). The test results for SCC specimens continuously immersed in water show a continuous increase in modulus of rupture as the period of immersion increased.
Generally, the results indicate that the modulus of rupture of SCC specimens exposed to oil products for 28 days slightly increases in comparison with reference specimens (exposed to water at same exposure period). Modulus of rupture for SCC specimens began to decrease as the time of exposure to oil products increased.

The percentage decrease after 180 days exposure to crude oil, motor oil, fuel oil and gas oil was about 24.01%, 25.98%24.67% and 21.92% respectively.

Modulus of Elasticity

The results in Table (19) and Fig. (4) indicat that the modulus of elasticity of SCC specimens continuously immersed in water show a continuous increase in static modulus of elasticity as the period of immersion increased. Specimens exposed to oil products for 28 days show a slight increase in comparison with reference specimens (exposed to water at same time of exposure). This is because of the pores inside the SCC are still filled with water, which lead to further hydration of cement [11]. Then modulus of elasticity for SCC specimens decreases as the time of exposure to oil products increased. The percentage decrease after 180 days exposure to crude oil, gasoil, motor oil and fuel oil was about 29.53%, 42.33%, 39.45% and 26.7 respectively.

Ultrasonic Pulse Velocity (UPV)

From the results in Fig.(5), it can be observed that SCC specimens show continuous increase in UPV as the period of immersion in water increased. This is due to continuous hydration of cement paste and silica fume with age, therefore the compressive strength and density of these specimens increased. As in compressive strength, the UPV for specimens exposed to different oil products decreases as the exposure periods increased. This may be due to the deterioration of concrete exposed to oil products and the formation of cracks in the microstructure of concrete specimens.

Dynamic Modulus of Elasticity

The results of dynamic modulus of elasticity for SCC specimens continuously exposed to water or different oil products are shown in Fig. (6). The results show a continuous increase in dynamic elastic modulus as the period of exposure to water increased. Dynamic modulus of elasticity for SCC specimens exposed to oil products for 28 days slightly increases, and then it decreases as the exposure period increased in comparison with reference specimens (exposed to water at same exposure period). It can be concluded that SCC exposed to oil products shows reduction in dynamic modulus of elasticity for all exposure periods relative to that exposed to water.

Length Change

Self compacting concrete specimens continuously exposed to water or oil products for 28 days show a slight shrinkage, then expansion occurs for other exposure periods as shown in Table (20) the expansion increases as the exposure periods increase. This increase can be attributed to a considerable increase in the volume of pores due to C-S-H interlayer space and small capillaries during hydration. On the other hand, it may be due to the relaxation in gel due to the presence of water by moist curing. This is in agreement with what was stated by other researchers [12].

Total Absorption

The results show that the total absorption for all SCC specimens exposed to water or different oil products are below 10 percent by weight as shown in Table (21). This gives an indication that SCC has low permeability[13]. Total absorption for SCC specimens continuously immersed in water decreased as the period of immersion increased. The results also indicate that total absorption for SCC continuously exposed to different oil products increases as the period of exposure to those product increased. This is due to the harmful effects of oil products on microstructure of the concrete and the bond between aggregate and cement past which leads to increase the porosity and then the absorption of concrete [14], [15].
Generally SCC specimens continuously immersed in water have higher total absorption till exposure period 90 days in comparison to those exposed to different oil product. This behavior may be related to the large molecular size of oil products particles and its viscosity relative to water. On the other hand SCC produced in this investigation has small pores in it′s microstructure, since silica fume leads to pore size refinement and this will need more time for oil products to be penetrated in comparison with water. Also the results show that SCC specimens continuously exposed to crude oil have total absorption less than that for specimens continuously exposed to gas oil, motor oil and fuel oil. This may be attributed to the wax deposits that are found in the chemical composition of crude oil as shown in Table (10) which may decrease the permeability of concrete by blocking some cement paste pores [14].

Density

The test results for SCC specimens continuously immersed in water show a continuous increase in density as the period of immersion increased as shown in Fig. (7). Generally the results indicate that the density of SCC specimen exposed to oil products for 28 days slightly increases in comparison with reference specimen (exposed to water at same exposure period). As the time of exposure to oil products increases the density slightly decreases. This is due to the harmful effect of oil products on hydrated cement past and bond between aggregate and cement paste which cause microcracks, so this lead to increase porosity and decrease the strength and density [14], [15] .

Scanning Electron Microscopy for SCC Specimen Continuously Exposed to Water or oil Products

Scanning electron microscopy (SEM) has been developed to imaging the complex microstructure of concrete and to provide images with sub-micrometer definition. The application of SEM enhances our ability to characterize cement and concrete microstructure, and will aid in evaluating the influence of supplementary cementitious material, evaluation of concrete durability problems, and in the prediction of service life [16]. Specimen preparation is important in any microscopically technique with proper preparation methods facilitating examination and interpretation of micro structural features. Improper preparation methods may be misinterpreted. SEM requires a highly polished surface for optimum imaging. Rough-textured surfaces, such as those produced using only saw- cutting diminish the image quality by reducing contrast and loss of feature definition [17] .

A slice from tested specimens to be examined is cut to a suitable thickness of 5mm from 1cm and 2.5 cm depth from the surface of the cube specimens. The slices are oriented in any required manner to make polished section to be examined by this technique. It is clearly seen that an abundance of hydrated phases and pores, as well as cores such as $Ca\ (OH)_2$ crystals (marker "CH") and intermixed with calcium silicate hydration marked (C-S-H) exists in SCC.

The use of silica fume in SCC produced in this investigation causes a modification of the microstructure of concrete. The pozzolanic reaction of silica fume with calcium hydroxide produces additional calcium silicate hydrate that causes pore size refinements which improves the pore structure of concrete. Also the fine particles of silica fume can act as a filler to enhance the density of concrete, this fact reduces the porosity of concrete significantly [18]. The SEM for SCC immersed in water for 180 days reveals a compact formation of hydration products and a reduced content of $Ca\ (OH)_2$ crystals with a few air pores. This can be attributed to the low water/cement ratio, the continuous hydration of cement and the pozzolanic effect of silica fume. The main hydration products is a homogeneous morphology of C-S-H gel and very low crystals of $Ca\ (OH)_{2,}$ no ettringite products can be seen. Form Fig. (8b), the SEM shows different microstructure for SCC specimen at 25 mm depth from the surface of the cube specimen in comparison with that in Fig.(8a) at 10mm depth from the surface of the same cube specimen continuously immersed in water for 180 days. SEM in Fig. (9a) shows more granular structure of SCC. Figure (9 to 12) show the SEM micrographs for SCC continuously exposed to crude oil gas oil, motor oil and fuel oil respectively after exposure period 180 days. It is clearly that the microstructure of SCC exposed to different oil products shows deterioration of concrete due to high volume of pores and different microstructure in comparison with microstructure of SCC continuously immersed in water.

CONCLUSIONS

1. The compressive strength, splitting tensile strength, modulus of rupture, static modulus of elasticity, ultrasonic pulse velocity and dynamic modulus of elasticity for SCC specimens continuously exposed to water increase as the exposure period increased.

2- The compressive strength for SCC decreases as the exposure period to oil products increased. The reduction is between 11.59 -27.93%, 14.62 -40.74% , 11.24 -37.69%, 2.66-23.81% for SCC continuously immersed in crude oil, motor oil, fuel oil and gas oil respectively at exposure period from 60-180 days.
3- The reduction in splitting tensile strength for SCC after 180 days exposure to crude oil, gas oil, motor oil and fuel oil is 27.77%, 25.65%, 32.51% and 30.88% respectively.
4- The reduction in modulus of rupture is in the range 3.74 -24.01%, 0.4 -21.92%, 4-25.98% and 3.6 -24.67% after exposure to crude oil, gas oil, motor oil and fuel oil respectively at exposure period 60- 180 days.
5- The reduction in static modulus of elasticity is between 17.43 -29.53%, for specimens immersion in crude oil, 0.27 -26.7% for specimens immersion in gas oil, 8.73 -29.07% for specimens immersion in motor oil and 16.41 -39.45% for specimens immersion in fuel oil at exposure period from 60- 180 days respectively.
6- The reduction in dynamic modulus of elasticity is between 8.25 -23.63% for specimens immersed in crude oil and 0.75 -22.1% for specimens immersed in gas oil 12.4 -26.9% for specimens immersed in motor oil and 10.77 -24.55% for specimens immersed in fuel oil at exposure period from 60- 180 days respectively.
7- The total absorption for SCC specimens continuously exposed to different oil products increases as the period of exposure increased. The percentage increase for exposure period 180 days is 1.9% ,2.64%,2.91%and 3.06% for SCC continuously exposed to crude oil, gas oil, motor oil and fuel oil respectively.

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Table(1) Chemical composition and main compounds of cement*

Oxide Composition	% by weight	Limit of Iraqi specification No.5/1984
SiO_2	21.5	-
CaO	62.4	-
MgO	3.3	5.0 (max)
Fe_2O_3	5.04	-
Al_2O_3	3.7	-
SO_3	2.14	2.5 (max)
Loss on ignition	1.07	4.0 (max)
Insoluble residue	0.37	1.5 (max)
Time saturation factor	0.83	0.66 -1.02
Main compounds (Bogue's equation)		
Tricalcium silicate (C_3S)	58.522	-
Dicalcium Silicate (C_2S)	17.5	-
Tricalcium Aluminate (C_3A)	1.29	≤ 3.5
Tetracalcium Aluminoferrite (C_4AF)	15.33	-

Table (2) Physical properties of cement*

Physical properties	Test results	Limit of Iraqi specification No.5/1984
Specific surface area (Blaine Method), m^2/kg	270	230 (min)
Setting time (vicate's method) Initial setting, hrs: min Final setting, hrs: min	 1:55 3:35	 00:45 (min) 10:00 (max)
Compressive strength, MPa 3 days 7 days	 23.76 24.99	 15.00 (min) 23.00 (min)
Autoclave expansion, %	0.24	0.8 (max)

*Chemical and physical analysis of cement was conducted by central organization of standardization and quality control in Baghdad.

Table (3) Grading of coarse aggregate*

Table (4) Properties of coarse

property	Test result	Limit of Iraqi specification No.5/1984
Specific gravity	2.60	-
Sulfate	0.19	specification

aggregate*

Sieve Size (mm)	%Passing by weight	Limits of the Iraqi specification No.45/1984
20	100	100
14	94.5	90-100
10	61.6	50-85
4.75	0	0-10
2.36	0	-

content		requirements ≤ 0.5% (max)
Absorption	0.75%	-

*Chemical and physical analysis of aggregate was conducted by central organization of standardization and quality control in Baghdad.

Table (5) Properties of fine aggregate*

Property	Test Results	Limits of the Iraqi specification No.45/1984
Specific gravity (S.G)	2.64	-
Fineness modulus	3	-
Absorption %	0.7	
Sulfate content (SO_3)%	0.096	≤ 0.1
Clay %	0%	≤ 1.0

Table (6) Grading of fine aggregate*

Sieve Size (mm)	%Passing by weight	Limits of the Iraqi specification No.45/1984 zone (2)
4.75	90	90-100
2.36	87	75-100
1.18	70.2	55-90
0.60	60.8	35-59
0.30	25.4	8-30
0.15	3.8	0-10

*Chemical and physical analysis of fine sand was conducted by central organization of standardization and quality control in Baghdad.

Table (7) Technical description of superplasticizers*

Form	Viscous liquid
Color	Light brown
Specific gravity	1.1

pH	**6.5**
Transport	**Not classified as dangerous**
Labeling	**No hazard label required**
Alkali content	**Typically less than 1.5 gm Na_2o equivalent per liter of admixture**
Chloride content	**Nil**

* According to the manufacturer

Table (8) Chemical analysis of silica fume *

Oxide Compositi on	Oxide content %	ASTM C1240-03
SiO_2	93.94	Min. 85%
Al_2O_3	0.7	<1%
Fe_2O_3	0.45	< 2.5%
CaO	0.88	<1%
SO_3	0.93	<1%
K_2O + Na_20	1.37	<3%
L.O.I	3.96	Max. 6%
Cl	0.17	< 0.2%
C (free)	3.1	<4%

Table (9) Physical properties of silica fume*

Property	Result	ASTM C1240-03
Strength activity index	106%	≥ 105
Specific gravity, kg/m³	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

*Chemical and physical analysis was conducted by National Center for Construction Laboratories and Researches in Baghdad.

Table (10) Fuel oil properties*

Oil inspection data	Fuel oil results	Method
Carbon residue wt%	8.7	ASTM-D524

Sulfur content % by weight	**4.24**	**ASTM-4294**
Specific gravity at 15.6 °C	**0.9625**	**ASTM-D1298**
Viscosity (centistokes) at 50 °C	**234**	**ASTM-D445**
Flash point (pm) °C	**90.6**	**ASTM-D93**
Pour point	**+3**	**ASTM-D97**
Water &sediment % vol.	**Trace**	**ASTM-D1796**

Table (11) Gas oil properties*

Oil inspection data	Gas oil results	Method
Carbon residue (rams) bottom (on10% res.)	**0.09**	**ASTM-D524**
Sulfur content % by weight	**1.2%**	**ASTM-4294**
Cetane No.	**57.8**	**IP-218**
Specific gravity (gm/cm^3) at **15.6 C°** **25.0 C°** **30.0 C°**	 **0.8383** **0.8186** **0.8151**	**ASTM-D1298**
Viscosity (centistokes) at 40 °C	**3.4**	**ASTM-D445**
Diesel index	**62.1**	**IP -21**
Flash point (pm) °C	**88.6**	**ASTM-D93**
Ash wt.%	**Nil**	**ASTM-874**
Pour point °C	**-15**	**ASTM-D97**

Table (12) Motor oil properties *

Oil inspection data	Motor oil results	Method
Moisture content % by volume	**Nil**	**ASTM-D95**
	1.45	**ASTM-D648**
Specific gravity at15.6 °C	**0.898**	**ASTM-D4052**
Viscosity centistokes (Cst). at 20 °C	**478.7**	**ASTM-D445**

Viscosity centistokes (Cst). at 30 ^{o}C	**249.3**	**ASTM-D445**
Viscosity centistokes (Cst). at 40 ^{o}C	**141.49**	**ASTM-D445**
Viscosity centistokes (Cst). at 50 ^{o}C	**86.27**	**ASTM-D445**
Viscosity centistokes (Cst). at 100 ^{o}C	**15.24**	**ASTM-D445**
Flash point	**236 Min**	**ASTM-D93**
Pour point ^{o}C (max)	**-9 Max**	**ASTM-D97**
Ash wt.%	**0.579**	**ASTM-D482**
Sulfate Ash %by weight	**0.7231**	**ASTM-D874**
Neutralization number Mgkoh/gm oil		**ASTM-D974**

Table (13) Crude oil properties *

Oil inspection data	Crude oil results	Method
API GRAVITY @15.6 ^{o}C	**43.9**	**ASTM-D1298**
water content vol%	**traces**	**IP-74**
Sulfur content % by weight	**0.597**	**ASTM-4294**
Wax content,%	**3.49%**	**-**
Density @15 ^{o}C	**0.8064**	**-**
Specific gravity at 15.6 ^{o}C	**0.8067**	**ASTM-(Table3) petroleum measurement table**
Salt content %by weight	**0.0006**	**IP-77**
Asphaltene by weight		**IP-143**
Ash content %by weight		**ASTM-D482**

Rams bottom Carbon residue ,%by weight	0.87	ASTM-D524
Pour point ^oC	-9	ASTM-D97
Acidity ,mg KOH/g	Not detected	
Kinematic viscosity Cst. 10 ^oC 21. ^oC 37.8 ^oC 50 ^oC	 5.8 3.71 2.24 1.6	ASTM-D445
Water &sediment % vol	0.05	IP-75
KUOP Characterization Factor	12.1	UOP method 375

Table (14) Mix proportion for the selected SCC mix.

Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Silica fume kg/m^3	Water l/m^3	SP% liter per 100kg	w/cm	Compressive Strength (MPa)	
							7 days	28 days
450	778	890	45	188.1	2.8	0.38	45	73.89

Table (15) Fresh properties for the selected SCC mix.

Type of test		Mix Designation	Limits of EFNARC,2005
Slump Flow D(mm)		750	650 - 800
T50 (sec)		4	2 - 5
V-Funnel (sec)(Tv)		10	6 - 12
T5 min		3	0 - 3
L-box	T20 (sec)	6	
	T40 (sec)	8.5	
	BR% (h2/h1)	0.95	0.8 - 1
J-ring	TJ500 sec	4.5	
	DJ mm	750	
	BJ mm	0	
	Deviation D-DJ mm	0	0 - 10

Table (16) Compressive strength results for SCC specimens after various exposure periods to water or oil products .

Type of exposure / Exposure Period (days)	Compressive strength of SCC after different exposure periods (MPa)					
	28	60	90	120	150	180
Water	73.89	79.52	85.6	86.87	87.1	88.6
Crude oil	74.1	70.3	69.1	67.67	64.3	63.85
Gas oil	75.95	77.4	73.74	72.39	70.62	67.5
Motor oil	74	67.89	64.5	60.69	54.5	52.5
Fuel oil	75.6	70.58	68.01	66.75	65.2	55.2

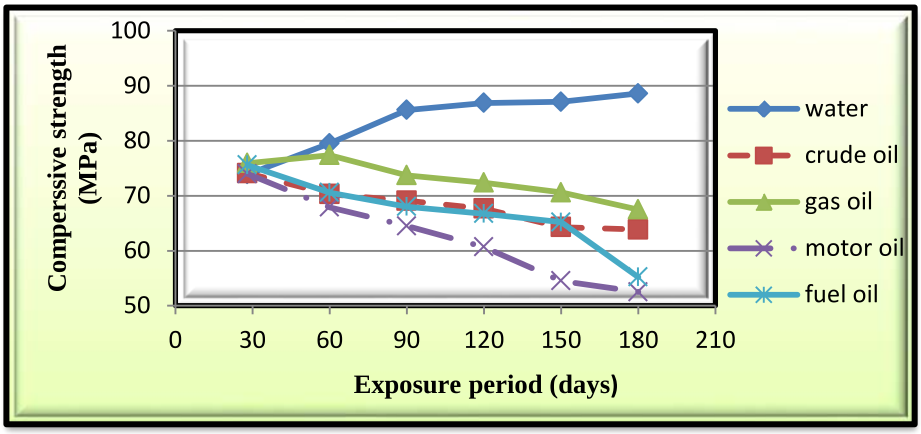


Figure. (1) Relationship between compressive strength of SCC specimens and various exposure periods to water or oil products.

Table (17) Splitting tensile strength for SCC specimens after various exposure periods to water or oil products.

Type of exposure / Exposure Period (days)	Splitting tensile strength of SCC at different exposure periods (MPa)					
	28	60	90	120	150	180
Water	5.5	5.76	5.85	5.87	6.03	6.12
Crude oil	5.6	5	4.89	4.57	4.46	4.42
Gas oil	5.63	5.71	5.44	5.41	5.03	4.55
Motor oil	5.59	4.6	4.45	4.32	4.15	4.13
Fuel oil	5.61	5	4.87	4.53	4.5	4.23

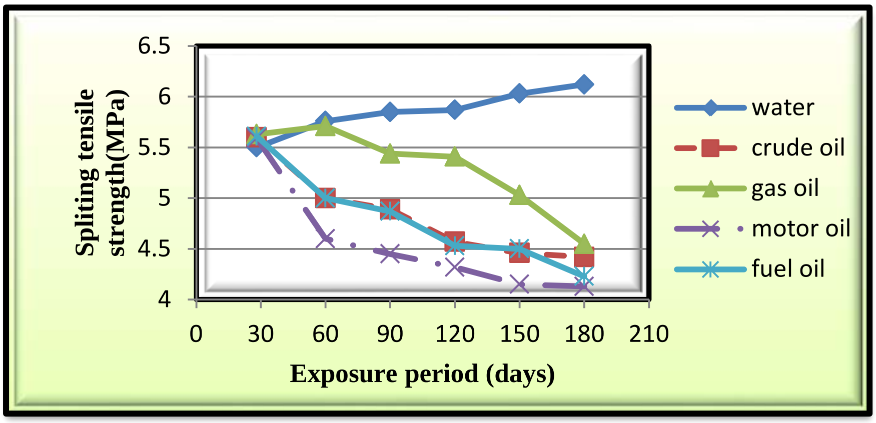


Figure.(2) Relationship between splitting tensile strength for SCC specimens and periods of exposure to water or oil products

Table (18) Modulus of rupture for SCC specimens at various periods of immersion in water or oil products.

Type of exposure / Exposure Period (days)	Modulus of rupture for SCC at different exposure periods (MPa)					
	28	60	90	120	150	180
Water	7.28	7.48	7.53	7.8	7.89	9.12
Crude oil	7.37	7.2	7.19	7.16	7.02	6.93
Gas oil	7.4	7.45	7.27	7.26	7.23	7.12
Motor oil	7.35	7.18	7.02	6.91	6.84	6.75
Fuel oil	7.39	7.21	7.18	7.08	7.05	6.87

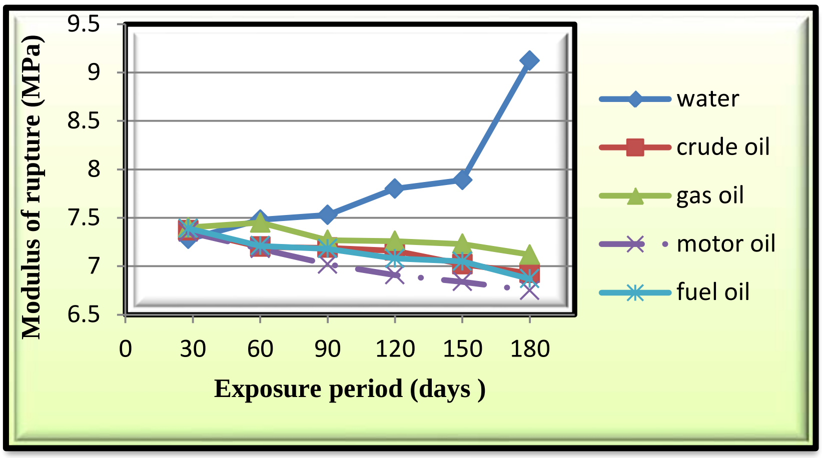


Figure.(3) Relationship between modulus of rupture for SCC specimens and periods of exposure to water or oil products.

Table (19) Static modulus of elasticity for SCC specimens at various periods of immersion in water or oil products.

Type of exposure / Exposure Period(days)	Static modulus of elasticity for SCC(GPa)					
	28	60	90	120	150	180
Water	54.58	62.93	63.58	64.658	65.44	67.13
Crude oil	56.56	51.96	50.65	49.503	47.5	47.3
Gas oil	59.22	62.73	54.35	53.47	52.251	49.2
Motor oil	54.78	49.81	47.73	44.83	39.242	38.71
Fuel oil	59.2	52.6	50.13	48.3	47.96	40.641

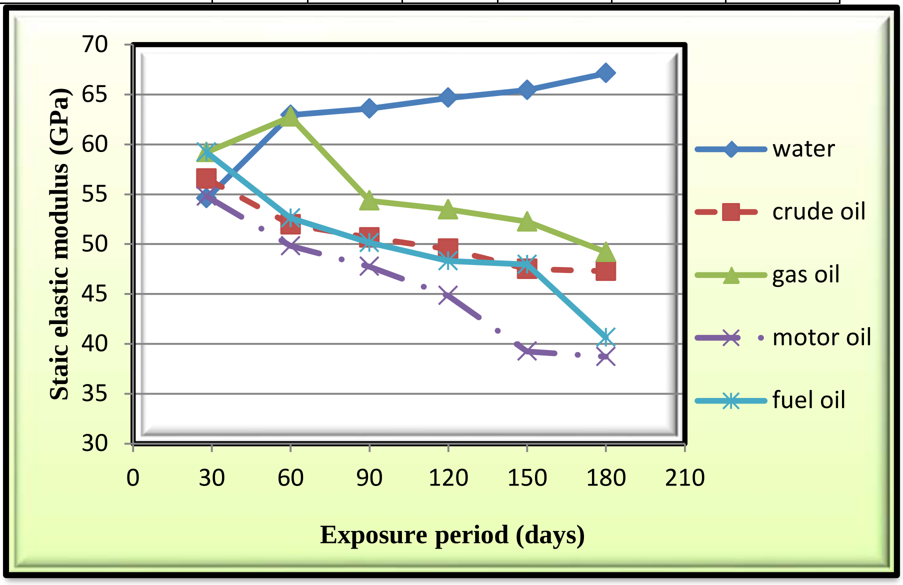


Figure.(4) Relationship between static modulus of elasticity of SCC specimens and period of exposure to water or oil products .

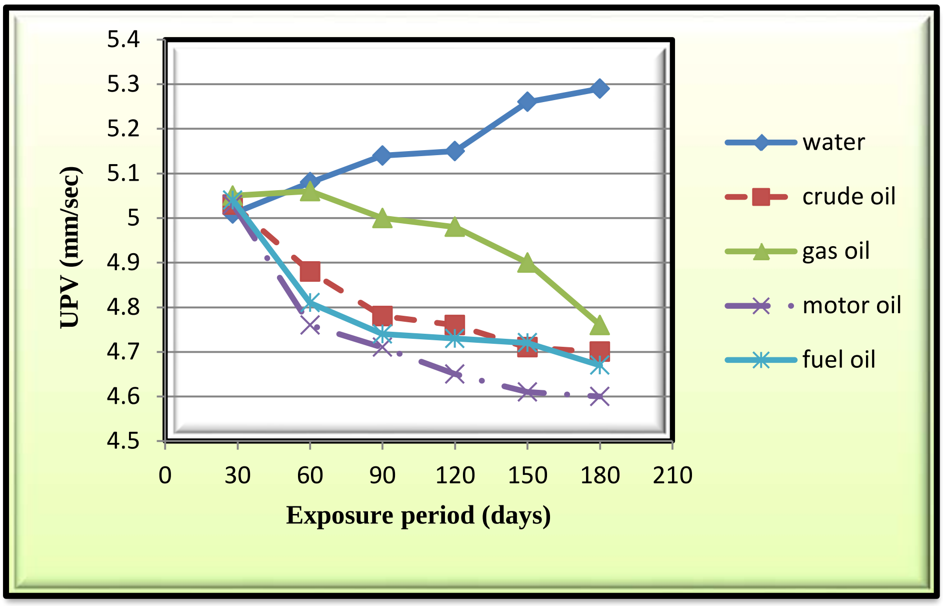


Figure. (5) Relationship between Ultrasonic-pulse velocity for SCC after various exposure periods to water or oil products.

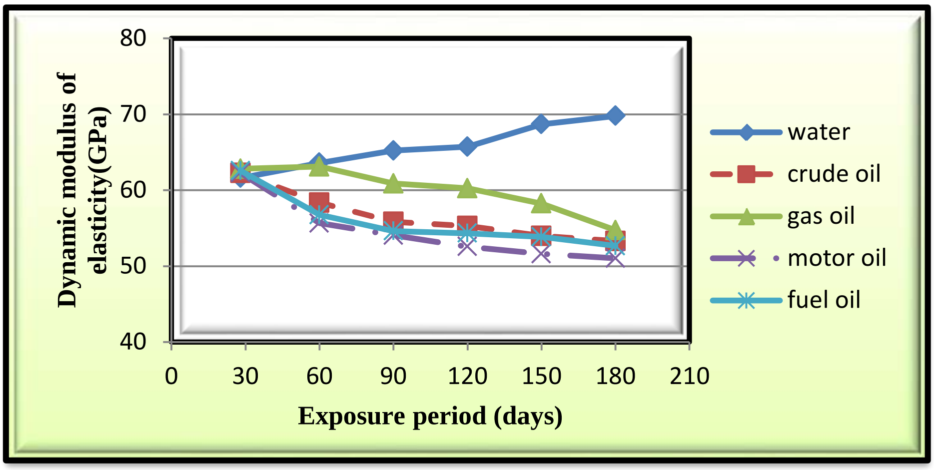


Figure. (6) Relationship between dynamic modulus of elasticity of SCC and exposure period to water or oil products.

Table (20) Length change results for SCC specimen at various periods of exposed to water or oil products.

Type of exposure	Length change SCC (%)

Exposure Period(days)	28	60	90	120	150	180
Water	-0.0024	0.0036	0.004	0.0136	0.0146	0.018
Crude oil	-0.0258	0.0064	0.0154	0.0158	0.0252	0.026
Gas oil	- 0.016	-0.0214	0.024	0.0248	0.0254	0.027
Motor oil	-.00212	0.0037	0.0272	0.0308	0.034	0.0344
Fuel oil	-0.0024	0.0036	0.004	0.0136	0.0146	0.018

Table (21) Total Absorption results for SCC specimens continuously immersed in Water and oil products.

Type of exposure / Exposure Period(day)	Total Absorption of SCC (%)					
	28	60	90	120	150	180
Water	3.16	2.72	2.44	1.72	1.6	1.26
Crude oil	0.812	1.21	1.24	1.27	1.63	1.9
Gas oil	0.79	1.23	1.44	1.61	2.4	2.64
Motor oil	0.81	1.6	1.63	1.84	2.69	2.91
Fuel oil	1.05	1.14	1.64	1.73	2.66	3.06

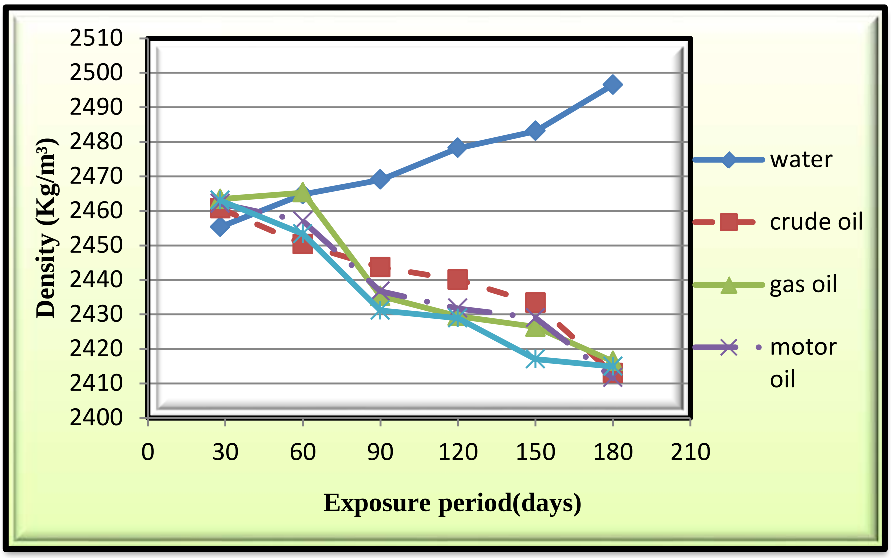
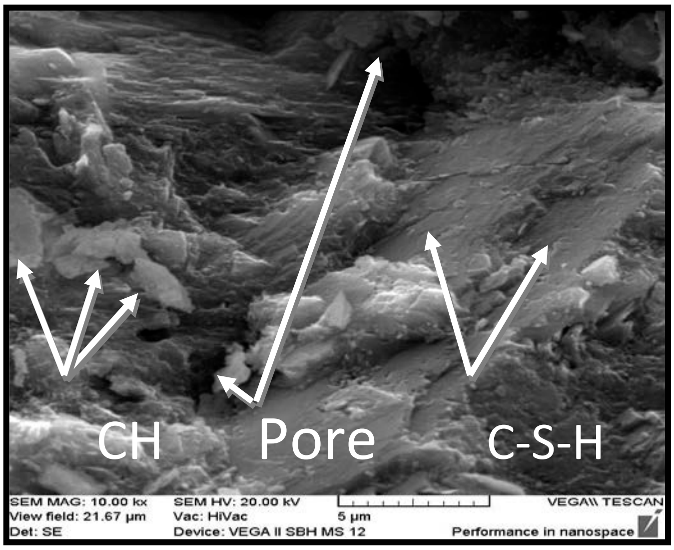
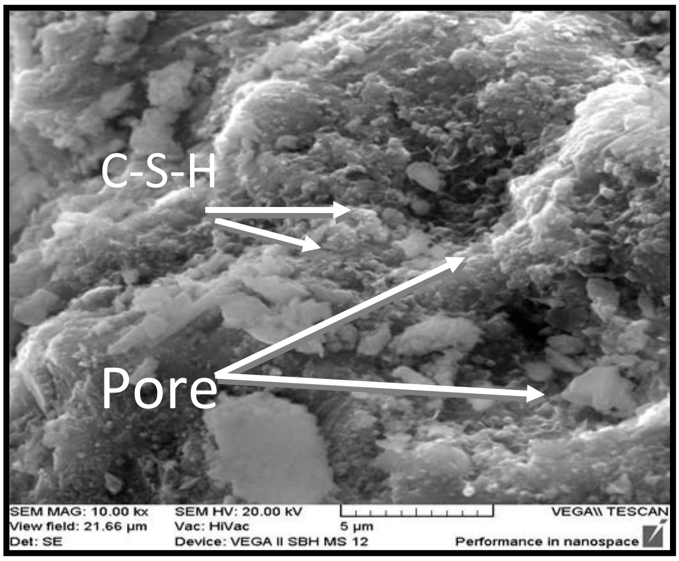


Figure.(7) Relationship between density of SCC and exposure period to water or oil products.

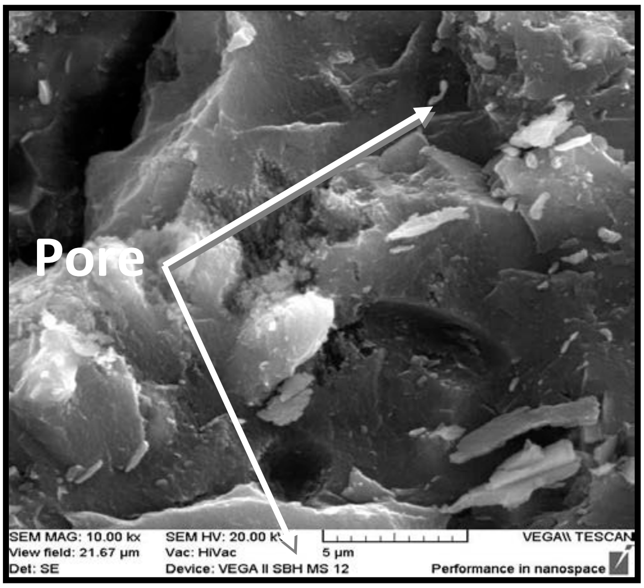


a-10mm from the surface of the specimen
- The black color is pore space
- The bright gray is calcium hydroxide (CH).
-The intermediate gray is calcium silicate hydrate C-S-H [16] .

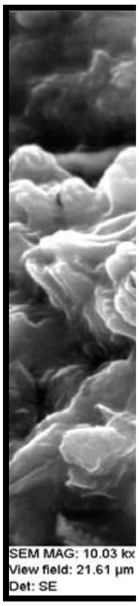


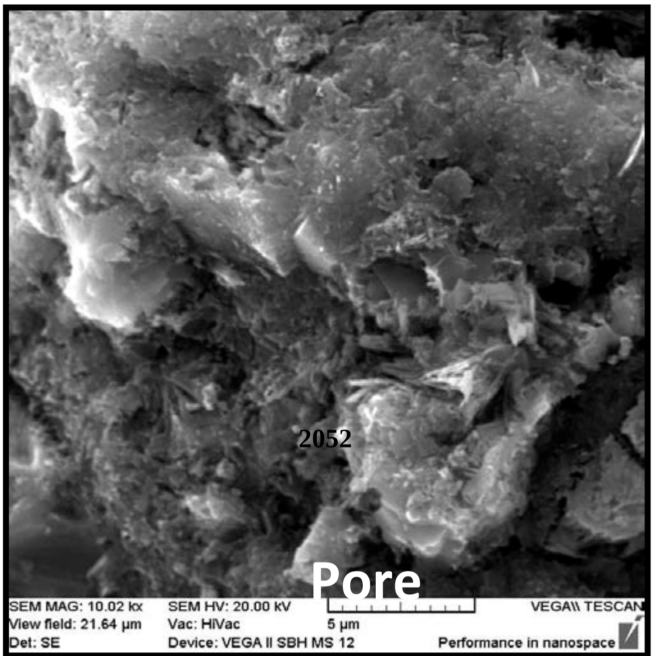
b- 25mm from the surface of the specimen
- The white rim surrounding the agglomerate is an outer zone of C-S-H of higher calcium content.

Figure.(8) SEM for SCC specimens continuously immersed in water for 180 days.



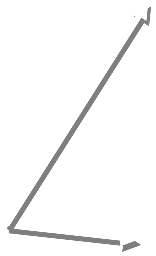
a- 10mm from the surface of the specimen.



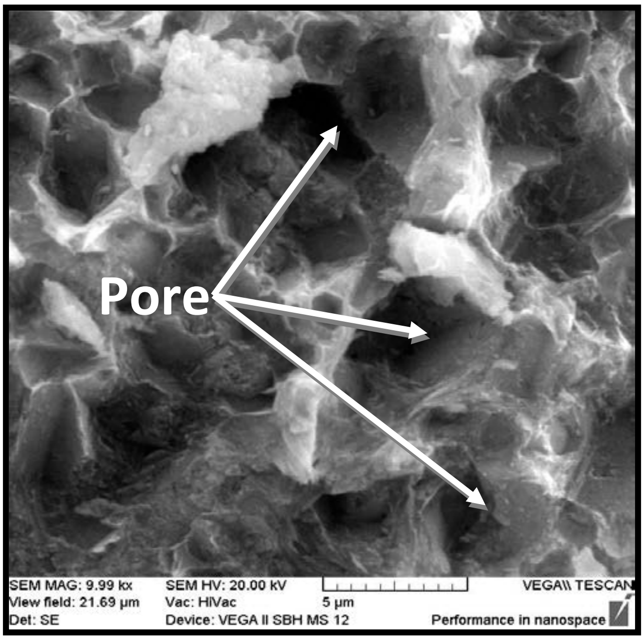


b- 25mm from the surface of the specimen .

Figure.(9) SEM for SCC specimens continuously immersed in crude oil for 180 days.

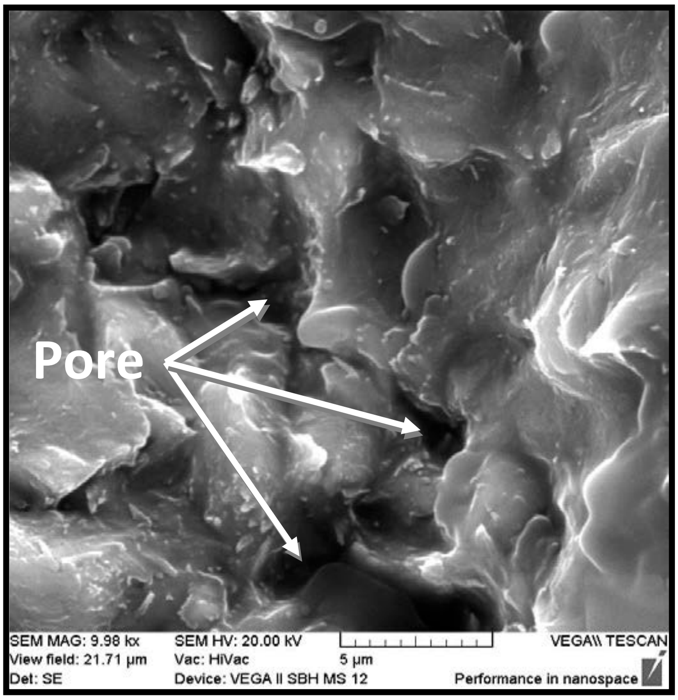


a- 10mm from the surface of the specimen.

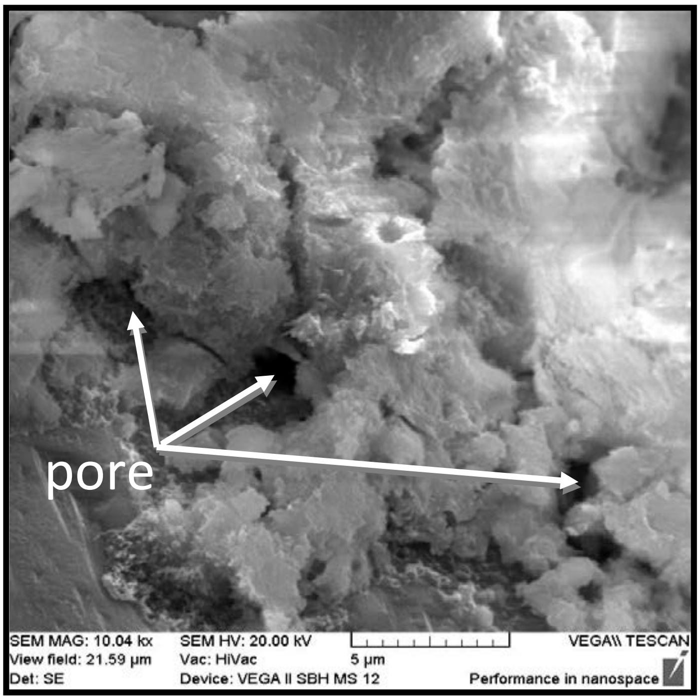


b- 25mm from the surface of the specimen.

Figure.(10) SEM for SCC specimens continuously immersed in gas oil for 180 days.

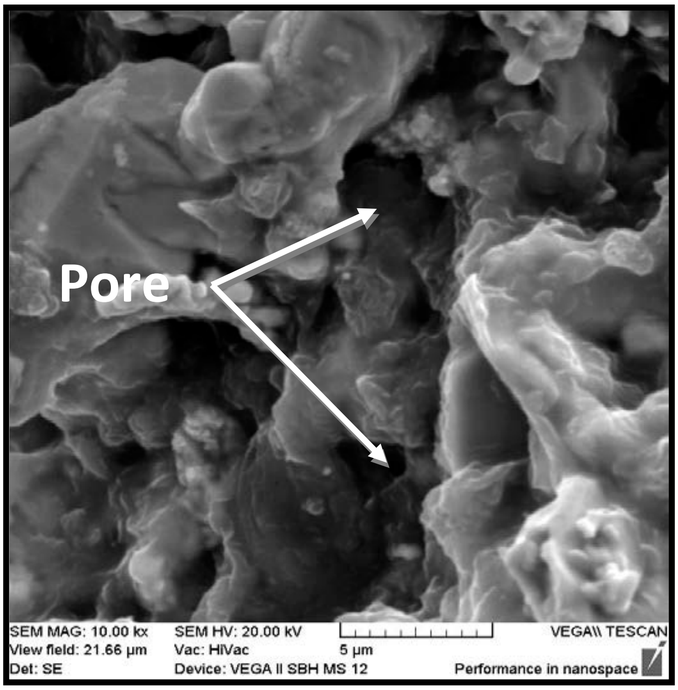


a- 10mm from the surface of the specimen .

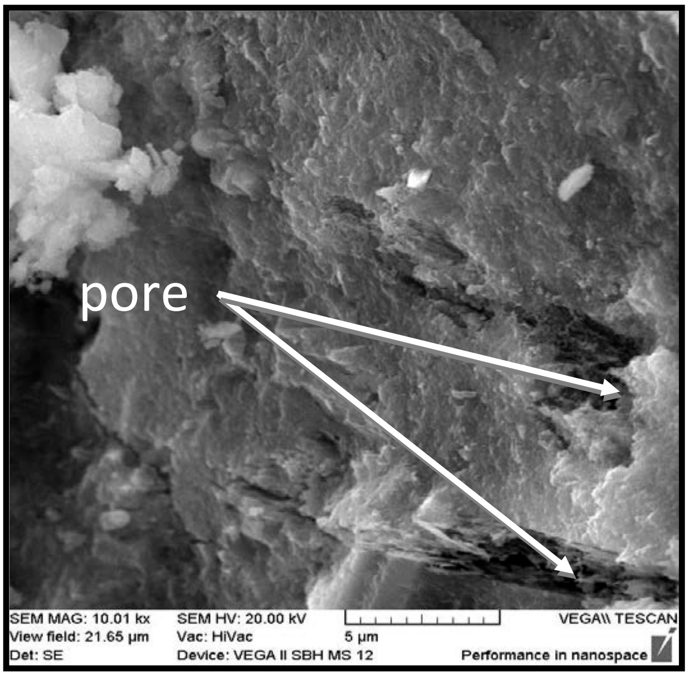


b- 25mm from the surface of the specimen .

Figure.(11) SEM for SCC specimens continuously immersed in motor oil for 180 days.



a- 10mm from the surface of the specimen.



b- 25mm from the surface of the specimen

Figure.(12) SEM for SCC specimens continuously immersed in fuel oil for 180 days.