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COMPRESSIVE AND TENSILE STRENGTH OF CONCRETE LOADED AND SOAKED IN CRUDE OIL

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ABSTRACT

Effect of crude oil on compressive, splitting-tensile, and flexural-tensile strength of concrete under short-term and long-term loading, were investigated. Results show that the rate of crude oil absorption is high at early stages of soaking, but this rate decreases with time. There is a reduction in the absorption by 30 to 40 percent of ultimate strength in specimens exposed to instantaneous loading as compared with unloaded specimens. While the absorption increases moderately at 70 percent loading, compressive and splitting-tensile strengths of concrete after 60 days of soaking are reduced by 12.52 and 11.00 percent, as compared with initial unsoaked strength. Due to soaking, loading levels up to 50 percent have no effect on further strength reduction. Modulus of rupture increases by 4 percent after 60 days soaking. Loading causes some further increase in modulus of rupture. Continuously loaded specimens showed higher strength compared with short-term loaded specimens, for the same loading level and soaking time.

INTRODUCTION

Reinforced concrete tanks are used instead of steel tanks for petroleum products storage. Change from steel to concrete for storage purpose was due to low cost of repair, maintenance, and construction. In addition, concrete offers considerable resistance to fire and explosive during war times [1]. During the 1970's considerable experience was gained in the design of oil storage tanks. Now many concrete tanks for oil storage are in use under water, e.g .at Ekofisk-Field, the Shell Esso Brent offshore oil field and Strartfiord B offshore concrete platform.

However, the serviceability of reinforced concrete storage containers necessitates control of cracking and impermeability. Generally, concrete material suffers from the inherent characteristics of low tensile strength and tendency to crack under tensile stresses produced by external loads, shrinkage, creep, or thermal gradients [2]. In most cases, long-term loading extends the magnitude of cracks in both plain and reinforced concrete [3].

Practically ,concrete structures, tanks used for oil storage purposes, pump machine basements, and factory garage floors suffer from loading before and at the time of usage during their life time. Loading on concrete may affect its strength and permeability. Previous studies [4-9] dealt with the strength and the permeability of concrete in contact with crude oil and some oil products, like gasoline and fuel. The objective of this work was to study the relationship between crude oil absorption for both short-term and long-term loading and concrete strength.

EXPERIMENTAL PROGRAMME

Materials

An experimental work was carried out in the laboratory to determine the relationship between internal damage due to loading characteristics and crude oil absorption. Ordinary Portland cement produced by Kubayisa Cement Factory was used in this research having 444 m^2/kg fineness, with the initial and final setting times of 130 min and 257 min respectively .

Table 1 shows the chemical composition of the cement used. National Center for Construction Laboratories (NCCL), Iraq conducted the tests of cement. Test results of the cement used conform to Iraqi specification No.5/1984.

Table 1. Chemical Composition of the Cement

Oxides	*Percentage by weight*
CaO	60.8
SiO_2	21.00
Al_2O_3	5.06
Fe_2O_3	2.94
M_gO	3.98
SO_3	2.23
Loss on ignition	1.99
Insoluble Residue	1.20
Lime Saturation Factor ($C_4AF_{+}2C_3A$)	0.89
Main Compounds	
C_3S	43.29
C_2S	27.63
C_3A	8.44
C_4AF	8.94

The fine aggregate used was brought from Al-Ukhaidher (South-western region of Iraq). It has a specific gravity of 2.6, 1.54% absorption (24 hr in water at 23±1.7°C), and 0.07% sulfate (as SO_3) content, by weight. Round shaped gravel from the river was used as coarse aggregate. The maximum size of the aggregate was 9.5 mm .It has 0.94% absorption (24 hr in water at 23±1.7°C), and has a 2.64 specific gravity. The amounts of finer than 9.5 mm and 4.75 mm opening sieves were 94.56% and 10.06%, respectively. Coarse and fine aggregates conform to the ASTM C33-86 Specification[10].Crude oil in this investigation was brought from one of Kirkuk (Iraq) oil fields. It was stored in air tight plastic containers to prevent losses due to evaporation. Properties of the crude oil are given in Table 2.

Table 2. Crude oil analysis was carried by fuel laboratory in the department of chemical engineering, University of Technology, Iraq: salt: sulphur and mix contents were determined by Al-Danra Laboratory Iraq.

Properties of crude oil

Test	Results
Specific gravity at 20°C	0.845
Moisture content (% by volume)	0.40
Carbon residue (% by weight)	2.0
Ash content (% by weight)	0.5
Acidity	Not detected
Salt content (% by weight)	0.0007
Viscosity at 20°C (centipoise)	5.22
Sulphur content (% by weight)	1.92
Wax content (% by weight)	3.94

SPECIMEN PREPARATION

Experimental work scheme involves preparing two groups of specimens. Specimens in group one were initially loaded for 5 seconds before immersing in crude oil, and in group two were continuously loaded at the time of soaking:

Group One

Cylindrical specimens (100 mm diameter and 200 mm high) were used for compressive and splitting tensile strength of concrete were exposed initially to short-term loading. Under the same condition, prismatic specimens (100 X 100 X 400 mm dimensions) were used for modulus of rupture test.

Group Two

Specimens were loaded continuously for 1,7 , 30 and 60 days, at the time of soaking in oil. For this purpose special cylindrical specimens, 52 mm diameter and 61 mm high, were prepared, by fabricating special moulds. Since it is difficult to load the specimen at the time of soaking, special loading technique was followed, as described below.

All concrete specimens were prepared from a single mix of 1:1.5:3, cement: fine aggregate: coarse aggregate (by weight), respectively. Water/cement ratio of 0.45 was used which gave 30 mm slump. Mixing process was carried out inside the laboratory at the ambient temperature of 23±1.7°C . Curing was done in potable water at 23±1.7°C for 28 days. To obtain quick saturation with oil for concrete specimens, all of them were fully dried in oven at 100±5°C to a constant weight or until a weight loss of 1 g/day was observed in about 14 to 20 days.

After completing oven drying, the test specimens were left to cool to the laboratory temperature and the load required for failure was calculated for each test series. By using equations, available in text books on properties of concrete, compressive, splitting tensile strength, and modulus of rupture were calculated according to load capacity and dimensions of the specimens[3]. For the modulus of rupture two point load test were applied. Three tests were conducted for each series and the average for each series was calculated. The calculated strength, for all the tests is used as a reference for specimens soaked in crude oil.

LOADING TECHNIQUE

Short-term load was applied by increasing the load by 20 MPa/min. until the specified level is reached (percent of ultimate strength or load capacity). For compressive strength 30,40,50 and 70 percent loading were applied, while 30,40 and 50 percent loading were applied for other tests. Test specimens were kept under short-term loading for 5 seconds. Any crack due to short-term loading will occur after 5 seconds, as studied in detail by other researchers[1]. The specimens were then reloaded and prepared for soaking in oil.

Continuous loading was applied and the stress-strain relationship for three specimens in group two was determined automatically by means of test machine (EEL-digital Elect. 2000), in which specimens were located vertically between the two plates, and loaded to failure. For each specimen, two demec discs, 50 mm apart were fixed vertically on it's surface along the height. Two thick square plates (100

X 100 X 10 mm) having four holes on the corners, in addition to four 100 mm long bolts, for each specimens, were prepared .

The specimen was put between the two plates, which were connected by mean of bolts, and the four nuts slowly tightened. In each cycle the strain was checked in the two demec discs by using mechanical strain gauge (sensitive to 2.05 X 10^{-6} mm/mm).

Finally, from the stress-strain relationship the load applied could be controlled to the required level: 30,40, and 50 percents of ultimate strength. Each specimen in this loaded condition was immersed in oil for different periods of times.

SOAKING TECHNIQUE

In the present investigation, a gravimertric method was used to measure the amount of oil absorbed . All the specimens were weighed initially after drying in the oven at 105°C for a sufficient period to reach a constant weight and after being soaked in oil for required periods 1,7,30 and 60 days .

The excess oil from specimens surface was removed after the soaking was complete. The differences in weight before and after soaking gives the weight of oil absorbed, which represents as percentage of unsoaked concrete weight. After completion of soaking, continuously loaded specimens were unloaded by releasing the bolts and removing the two plates. The specimens were then tested with the other specimens for absorption and final oil soaked strength.

A soft plywood instead of sulphur capping was used (between specimens and machines plates) in the loading process. This type of capping is used for separating specimens surfaces (that were soaked with oil) from test machine plate surfaces.

RESULTS AND DISCUSSION

Effect of Crude Oil on The Strength of Short-Term Loaded Concrete

Crude oil absorption

Crude oil absorption, as percentage by weight, is shown in Table 3 for all loading levels at various soaking times. Oil absorption for short term loaded specimens in compression versus the duration of soaking is plotted in Figure 1. Test results show that the rate of oil absorption is high at earlier stages of soaking and the rate of absorption decreases with time at later stages. The high absorption at early stages is attributed to oven drying of concrete specimens before soaking, and also to low viscosity of crude oil used. Low viscosity oil contains large amount of lighter fractions that can ingress small pores in cement paste structure. At a later stage the rate of absorption decreases because of presence of wax in crude oil which clogs up the narrow neck entry pores[5].

Table 3. Variation in oil absorption with loading levels and soaking time of concrete (28 days cured and 14-20 days oven dried)

Type of test specimens	Loading level (percent of ultimate)	Crude oil absorption (% by weight) After four periods of soaking			
		After 1 day	After 7 days	After 30 days	After 60 days
Compressive Test Specimens	0	3.29	4.07	4.61	5.22
	30	3.26	3.95	4.05	4.66
	40	3.28	3.91	3.97	5.83
	50	3.19	4.01	4.71	5.11
	70	4.81	4.45	4.86	5.52
Splitting-Tensile Test Specimens	0	3.35	3.86	4.52	5.03
	30	3.29	3.78	4.20	4.49
	40	3.38	3.62	4.26	4.68
	50	3.52	3.60	4.24	4.46
Modulus of Rupture Test Specimens	0	1.77	2.76	3.36	4.13
	30	1.69	2.88	3.04	3.97
	40	1.75	2.81	3.25	3.71
	50	1.77	2.86	3.62	3.91

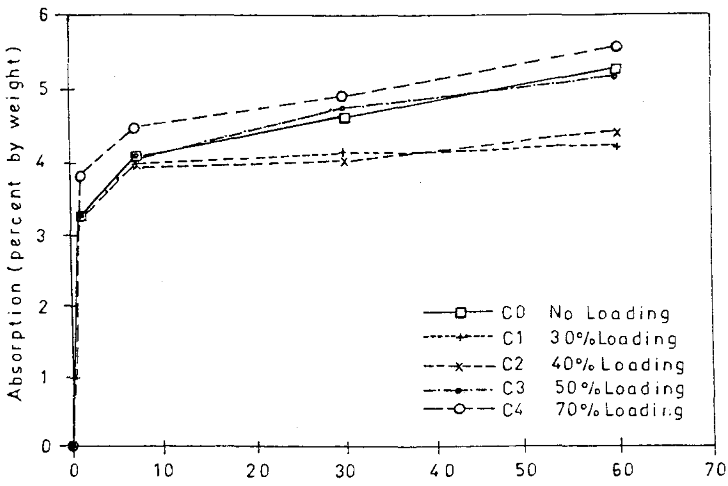

Fig. 1. Crude oil absorption of short term loaded specimens in compression.

Results presented in Table 3 indicate that oil absorption by cylindrical specimens used in compressive and splitting-tensile tests is greater than that of prisms used in modulus of rupture test. The reason for this may be due to the high surface area/volume ratio of cylinders as compared to prisms .Relative absorption, which is the ratio of absorption for initially loaded to unloaded specimens, versus loading level is shown in Figure 2 for the splitting, flexural and compression tests. Some reduction in absorption is observed for loading levels between 30-40 percents, especially for specimens loaded in compression. This may be due to some compaction.

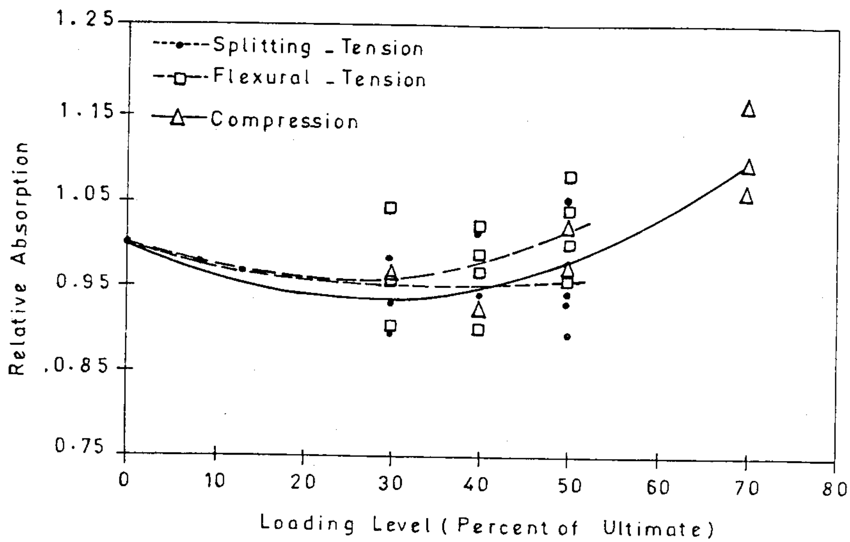

Fig. 2. Variation in oil absorption with short term loading.

Previous tests [11] on concrete under short-term loading indicate that microcracks were negligible at lower levels of loading, and cracks increase after 70 percent loading level. Jones [12] proposed that compressive loading has some compacting effect on the flaws and fissures inside the cement paste .

Compressive strength

Test results for compressive strength of concrete under short-term loading are given in Table 4. The results are presented in Figure 3. It is observed that compressive strength after 60 days of soaking is reduced with time up to 12.25 percent compared with unsoaked specimens. Loading of up to 50 percent has little effect on compressive strength, compared to unloaded concrete. It may be noted that some of the present results are unrealistic.

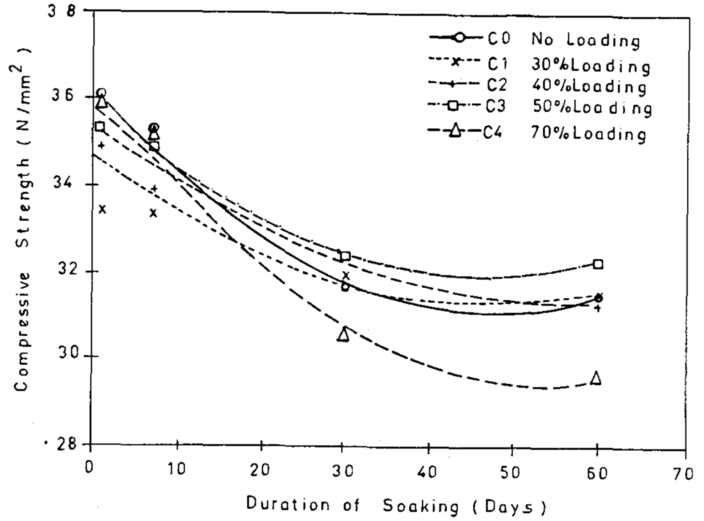

Fig. 3. Variation in compressive strength with soaking time for short term loaded specimens

Table 4. Oil soaked concrete strength of specimens (concrete specimens cured for 28 days and dried for 14-20 days)

Type of test specimens	Loading level (percent of ultimate)	Concrete strength (N/mm^2)			
		After 1 day	*After 7 days*	*After 30 days*	*After 60 days*
Compressive Test Specimens	0	36.09	35.13	31.67	31.49
	30	33.47	33.35	31.98	31.53
	40	34.94	33.92	32.50	31.28
	50	35.33	34.90	32.40	32.30
	70	35.91	35.30	30.51	29.55
Splitting-Tensile Test Specimens	0	3.53	3.50	3.11	2.98
	30	3.44	3.49-	3.37	3.27
	40	3.31	3.29	3.21	3.19
	50	3.54	3.51	3.27	3.17
Modulus of Rupture Test Specimens	0	4.96	5.05	5.09	5.11
	30	5.06	5.08	5.25	5.32
	40	5.07	5.09	5.12	5.23
	50	5.09	5.11	5.26	5.28

The first reason is attributed to oven drying at 105°C. This temperature affects the strength and the porosity or crack growth in concrete specimens. The second reason is related to crude oil properties, such as specific gravity, viscosity (as a function of time) and the amount of impurities which may escape out of containers in the form of vapour . As a result, viscosity is reduced and this reduction affects oil absorption, which directly affects strength. At 70 percent loading a significant reduction in compressive strength takes place, reaching about 17.9 percent. Previous tests[4-7] also showed that compressive strength of concrete is reduced when concrete is exposed to crude oil ,gasoline, and fuel. Compressive strength reduction depends on oil absorption, which in turn depends on soaking time, and the amount of impurities like sulphur in oil product.

Compressive strength of concrete soaked in crude oil for different loading levels can be expressed by the following polynomial equation:

$$\frac{[f'c]t}{[f'c]d} = a+bt+ct^2 \qquad (1)$$

where $[f'c]d$ is the compressive strength of concrete before soaking in oil [36 N/mm^2], $[f'c]t$ is the compressive strength [N/mm^2] after soaking in oil at any time t[days], which equals or greater than one day.

Splitting-tensile strength

Splitting – tensile strength of concrete soaked in crude oil for short-term loaded specimens is given in Table 4. Figure 4 shows the variation in splitting-tensile strength with soaking time. Splitting-tensile strength of concrete before soaking in crude oil was 3.35 N/mm^2. For unloaded specimens, there is an increase in splitting-tensile strength varying between 3-5 percent after 1 day soaking, while about 11 percent reduction takes place after 60 days soaking.

There is no clear explanation for lower tensile-strength of loaded specimens as shown in Figure 4. However, it is concluded that up to 50 percent of the initial short-term loading has a little effect on oil soaked splitting – tensile strength .

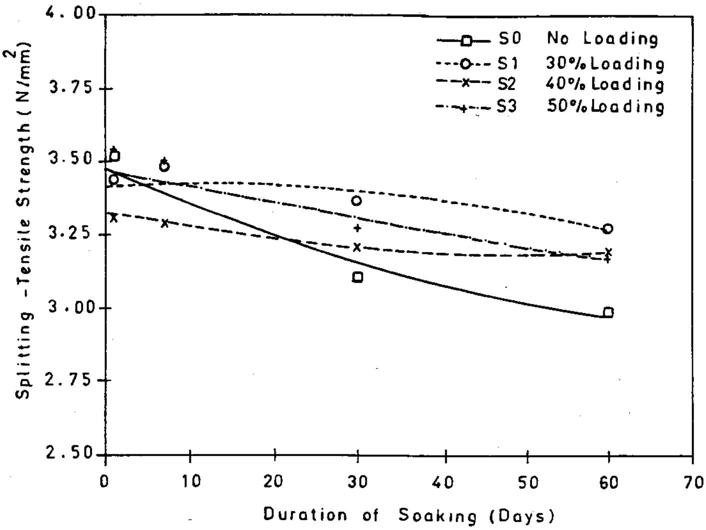

Fig. 4. Variation in splitting tensile strength with soaking time for short term loaded specimens

Modulus of rupture

Modulus of rupture for oven dried concrete specimens tested before soaking in crude oil was found to be 4.91 N/mm^2. Modulus of rupture for oil soaked concrete subjected to short-term loading is shown in Table 4, and plotted against soaking time in Figure 5. Test results indicate that modulus of rupture increases due to soaking in crude oil, reaching up to 4 percent after 60 days soaking. Previous investigators[4.5] have shown that modulus of rupture, in general, increases with crude oil absorption; they attributed the increase in modulus of rupture to closing and autogeneous healing of cracks and flaws in concrete due to possible volume change by the effect of oil[4]. On the other hand the increase in modulus of rupture is attributed to deposition of crude oil waxy molecules in the pores and cracks which cause the increase in resistance against the induced tensile stress[5]. As shown in Figure 5, short-term loading of prism specimens increased the modulus of rupture as compared with unloaded specimens, and the increase varied between 6-8 percent. Apparently, there is no explanation for this, however like the results of splitting tensile strength, it is concluded that up to 50 percent loading, there is negligible effect on flexural – tensile strength loss .

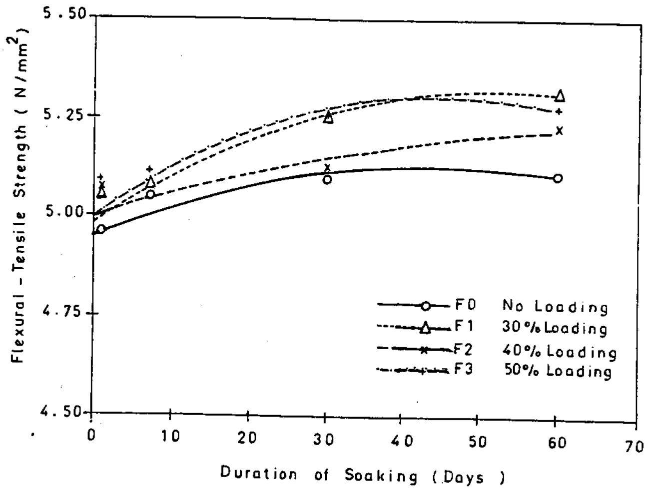

Fig. 5. Variation in flexural tensile strength with soaking time for short term loaded specimens.

Compressive – Tensile Strength Relationships

Figure 6 shows the relationship between splitting-tensile and compressive strengths of concrete soaked in crude oil, for various loading levels. The relationship is linear. Any reduction in compressive strength is accompanied with a reduction in splitting-tensile strength for both loaded and unloaded specimens. The inverse relationship was observed for modulus of rupture and compressive strength, as shown in Figure 7. Values of splitting-and flexural-tensile strength versus compressive strength are higher for loaded specimens, this means that loading levels have a positive effect on splitting and flexural tensile strengths than those on compressive strength. By using regression analysis, variation in splitting-tensile and modulus of rupture with compressive strength can be represented by the following power equations:

$$f_{tsp} = a[f'c]^{b} \quad (2)$$

$$f_{r} = c[f'c]^{d} \quad (3)$$

where f_{tsp} is the splitting-tensile strength, f_r is the modulus of rupture, and f'_c is oil soaked compressive strength.

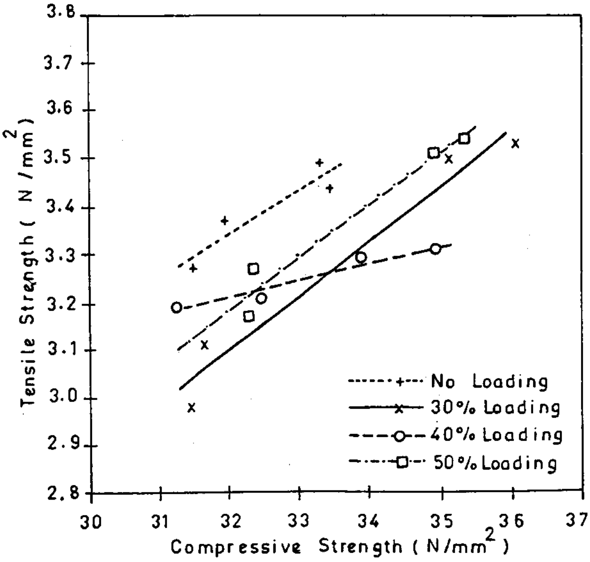

Fig. 6. Relationship between compressive and splitting tensile oil soaked strengths exposed to short term loading.

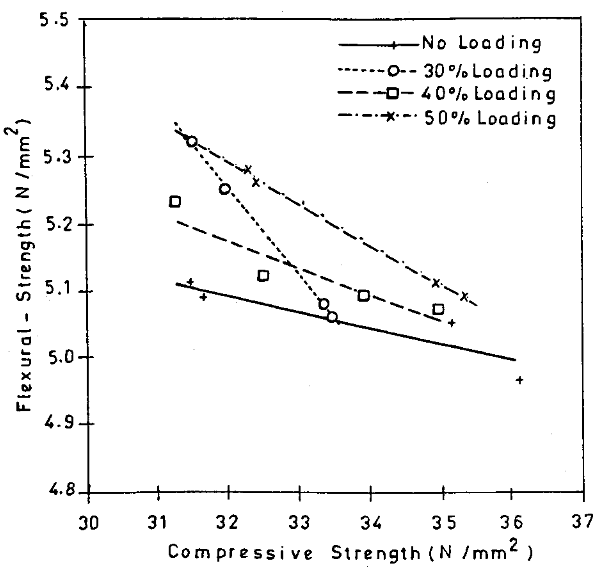

Fig. 7. Relationship between compressive and flexural tensile oil soaked strengths exposed to short term loading.

STRENGTH OF CONCRETE SOAKED IN CRUDE OIL AND SUBJECTED TO CONTINUOUS LOADING

Compressive strength of concrete before soaking in oil was 38.45 N/mm^2. Compressive strength of concrete samples soaked in crude oil for continuous (long-term) loading levels is shown in Table 5. It is also represented diagrammatically against soaking time in Figure 8. Crude oil absorption for continuously loaded specimens is shown in Figure 9. It is observed that in long-term loading, the difference in oil absorption between loaded and unloaded specimens is too low as compared to that of short-term loaded specimens. In this series, any compaction effect that may reduce oil absorption is accompanied by cracking. Since test specimens used in this series were small, cracking due to loading is expected and as a consequence an increase in absorption is also expected.

As shown in Figure 8 compressive strength due to oil absorption is reduced with time, this reduction is greater than that of short-term loading, for both unloaded and loaded specimens.

Previous test results[13] indicate that under the effect of sustained loading, high stresses occur at the tips of microcracks existing in concrete as a result of tensile or compressive strain. These high stresses are relieved by the growth of the hair cracks in the matrix and bond cracks at the interface boundaries between the matrix and aggregate particles, and therefore result in material failure. By using regression analysis, compressive strength of concrete exposed to long-term loading can be expressed mathematically in the following polynomial equation:

$$\frac{[f'c]t}{[f'c]d} = a+bt+ct^2 \qquad (4)$$

where $(f'c)t$ is the compressive strength (N/mm^2) at any time t (days) of oil soaked concrete. $(f'c)d$ is the initial unsoaked compressive strength, a is a constant, b and c are coefficients. Table 6 contains constant and coefficient values, with the statistical coefficients. According to the test results presented in this investigation the combined effect of long-term loading (especially high levels) and oil exposure may affect concrete strength to a large extent.

Table 5 Compressive Strength Results of Oil Soaked Concrete Exposed to Long-term loading .

Loading level (percent of ultimate)	Compressive strength (N/mm^2) at different periods of soaking				
	Unsoaked	1 day	7 days	30 days	60 days
0	3845	35,09	38.35	33.96	33.53
30	=	40,56	38.62	33.20	33.45
40	=	39,78	36.23	34.95	32.99
50	=	37.74	35.48	34.93	32.10

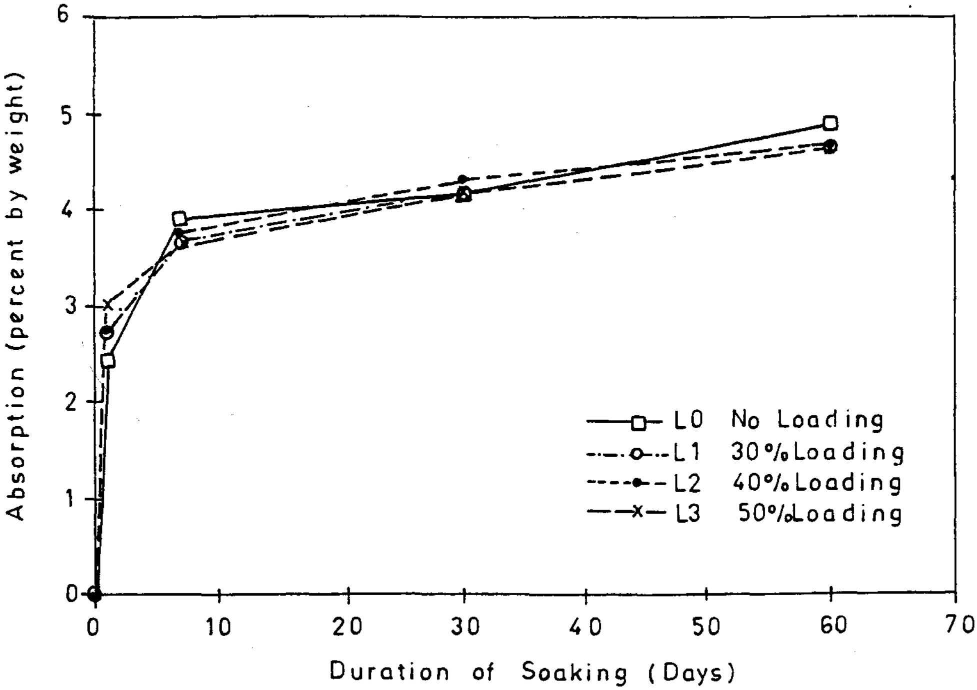

Fig. 8. Crude oil absorption of long term loaded specimens in compression.

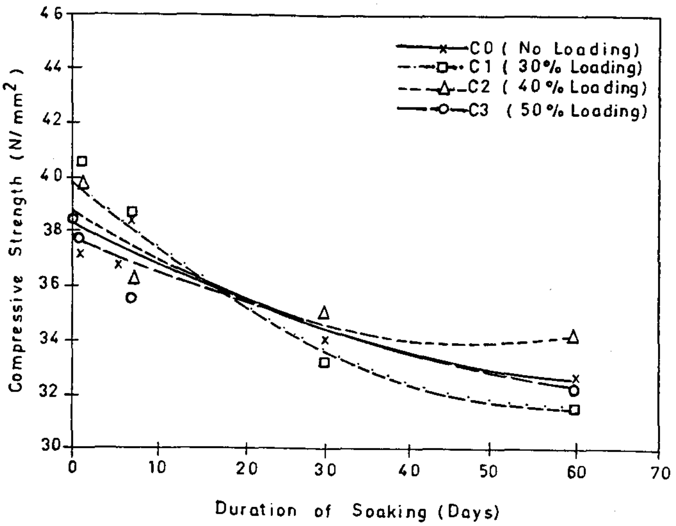

Fig. 9. Variation in compressive strength with soaking time for long term loaded concrete.

Table 6. Statistical coefficients for Eq.(1) through Eq. (4)

Equation Number	Loading Level (percent of ultimate)	A	B	c	d	r*	c.o.v** (%)
1	0	1.0111	-0.0064	0.000059	-	99.80	0.8427
	30	0.9361	-0.00201	0.000017	-	99.20	0.5916
	40	0.9694	-0.0029	0.000021	-	99.30	0.8949
	50	0.9917	-0.00431	0.000040	-	99.30	0.8760
	70	1.0167	-0.00760	0.000072	-	99.30	1.8780
2	0	0.05128	0.0513	-	-	97.80	2.149
	30	0.1587	0.1587	-	-	93.20	1.260
	40	0.9080	0.3643	-	-	97.50	0.494
	50	0.0686	1.1068	-	-	97.70	1.404
3	0	-	-	9.1830	-0.1701	90.33	0.695
	30	-	-	90.6240	-0.8218	99.95	0.100
	40	-	-	13.0443	-0.2668	88.20	0.80
	50	-	-	21.1419	-0.4000	99.90	0.14
4	0	0.9935	-0.0044	0.000040	-	91,14	4,31
	30	1.0663	-0.0098	0.0001010	-	99,999	4,23
	40	1.0143	-0.0053	0.000046	-	93,11	4,69
	50	0.9649	-0.0023	0.000002	-	94,60	3,39

* correlation coefficient
** coefficient of variation

CONCLUSIONS

High reduction in the compressive strength takes place due to the absorption of large amount of the oil. Such reduction reaches up to 12.52 percent, after 60 days soaking. However under 50 percent short-term loading there is insignificant reduction in the compressive strength, while at 70 percent loading level a significant reduction occurs, reaching 17.9 percent of the compressive strength.

Splitting-tensile strength was reduced due to oil absorption, reaching up to 11 percent while the modulus of rupture increased by 4 percent after 60 days soaking. Loading level up to 50 percent has negligible effect on splitting-tensile strength reduction.

For the same loading level and soaking time, compressive strength of continuously loaded concrete was lower than that of short-term loading.

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