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Strength and Permeability of Concrete in Constructing Oil Storage Tanks

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Abstract
Nowadays, oil storage tanks play a strategic role in industries; therefore, it is essential to consider required facilities for them against explosion and fire problems. This can be achieved by using an appropriate concrete to ensure security and durability; furthermore, economical benefits, possibility of construction of buried tanks and increase of concrete strength without structural flexibility reduction can be gained in comparison with steel tanks.

Effect of crude oil on concrete has been partially studied in the past. The concrete used in constructing oil storage tanks should have some characteristics such as low permeability and enough durability against petroleum substances along with salty or sea water; therefore, silica fume was replaced for part of cement in concrete.

In this paper, we can see the results of compressive strength and permeability tests on ordinary and silica fume containing specimens with two water-cement ratios (0.4 and 0.5) which are cured in different environments (water and oil).

According to the test results some recommendations can be given as follows:
- In order to achieve the characteristic strength of concrete, there should be at least 28 days gap between pouring of concrete and filling the tanks with oil.
- Replacement of 7.5 % of cement with silica fume increases the compressive strength of concrete noticeably; furthermore, it decreases the concrete permeability coefficient for 100 times; therefore, to prevent concrete or steel bars corrosion and also leakage of oil from the tanks, it is recommended to use silica fume in constructing oil storage tanks.

Keywords
Concrete oil storage tanks, Effect of crude oil on concrete, Silica fume, Low permeable concrete, Compressive strength

1. Introduction

Crude oil and its products are considered among the strategic and vital goods for most countries of the world. In order to achieve civilian and military intentions, the procedure of the reservation of these products in the assembly line and their transmission to refineries ,ports and airports are essential. The extensive use of metal tanks is common in Iran and other parts of the world, but with the growth of technology in constructing concrete structures and the undeniable benefits of them, the necessity of considering the possibility of constructing concrete oil tanks is unavoidable (Behin Saman Sarzamin Company, 2001).

Based on the previous researches, when petroleum products are free from fat oil additives or other potential acidic substances, they are not usually harmful for the concrete which has been approximately reached its ultimate strength, but despite this some of them cause an unsuitable change of color in the concrete (Portland Cement Association (PCA), 1997).

According to a similar research, the concrete put at the exposure to cruide oil, should be at least from the C50 class (Health and Safety Executive (HSE), 2001).

The purpose of this research is to study the effect of silica fume on the compressive strength and permeability of the concrete exposed to oil to achieve an appropriate concrete for constructing concrete oil storage tanks without the use of an overlay.

1.1 Compressive Strength

By increasing the compressive strength of the concrete its permeability decreases and its durability increases. To construct concrete oil storage tanks, it is recommended to use a concrete with high strength. In this paper we study the effects of silica fume on the strength of concrete in the long term. Since the crude oil will be poured inside the concrete tank after a while the effect of exposing concrete to crude oil on the concrete strength (in order to reach the charactristic strength determined in the designation) should be studied.

Based on the past researches, it is observed that exposing concrete to the crude oil leads to decreasing the compressive strength of the concrete which in some cases its compressive strength decreases up to 30 percent. The loss in the compressive strength increases with the increse of the age of concrete, higher temperature of oil at the time of its storage and increase in absorption of crude oil by concrete ,but when the absorption of crude oil remains constant the compressive strength of concrete will not change (Onbolu, 1989).

Figure 1 demonstrates the effect of the amount of crude oil absorbed on the concrete compressive strength. As it can be seen, compressive strength decreases by the increase in the amount of crude oil absorbed to the concrete.

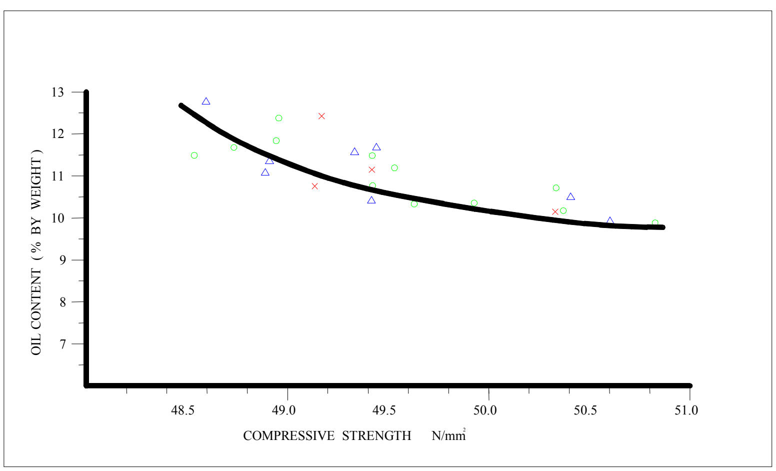

Figure 1: Effect of Oil Content on the Compressive Strength

In other research it is being seen that oil soaked specimens showed lower strengths by 8-15 percent as shown in Table 1 (Matti *et al.*, 1975).

Table 1: Compressive Strength as a Percentage of 28 Days Reference Strength

Mix Designation	Age Days	Oil Soaked Concrete		Reference Concrete		Oil Soaked Strength / Reference Strength
		% of 28 Days Reference Strength	% Scatter between Mean and Extremes	% of 28 Days Reference Strength	% Scatter Between Mean and Extremes	
A W/C=0.4	28	88.1	± 4.50	100.0	± 2.60	88.10
	60	97.0	± 4.40	110.8	± 1.50	87.58
	91	100.1	± 1.49	113.6	± 1.39	88.17
	180	101.9	± 1.79	114.1	± 0.50	89.30
B W/C=0.55	28	90.1	± 0.40	100.0	± 2.50	90.1
	60	99.1	± 2.40	110.9	± 1.80	89.3
	91	104.4	± 1.20	116.1	± 5.10	90.0
	180	107.6	± 1.60	116.8	± 0.60	92.0

1.2 Congestion and Impermeability

In order to improve durability against corosion resulting from the ingress of chloride, sulfate etcetera (which is in the salty water accompanying with crude oil) and probable damages to reinforcement originating from probable contact of tanks with sea water ,and also to prevent the leakage of oil from tanks it is recommended to use low permeable concrete. The more congested is the concrete, the lower permeability it will have and, therefore, its durability will be more.

According to the past researches the impermeability increased with age, and with the passage of time more oil flowed into the concrete (Matti *et al.*,1975).

Permeability tests have been carried out on cores drilled from North Sea platforms in operation ,and water penetration was measured according to ISO/DIS 7031 which gave typical values 10-15 mm. A permeability test programme was carried out on a platform made of concrete grade C50. The cement content was 480 Kg/m^3 and the w/c ratio slightly below 0.40. Core samples were drilled after 8 years and exposed to 4 MPa (400 m) hydrostatic head. The permeability was found to 10^{-13} m/s or better, i.e. an improvement relative to tests made during construction. The maximum permeability accepted for offshore concrete in Norwegian waters is 10^{-12} m/s. This very low permeability effectively prevents ingress of water, oxygen, chlorides or other substances which might affect concrete durability (FIP State of the Art, 1996).

2. Effect of Silica Fume on Concrete Characteristics

Silica fume is one of the appropriate materials to replace part of cement in the concrete which due to its several physical and chemical effects improves the concrete properties. Workability and setting time of concrete containing silica fume is less and segregation will decrease. Bleeding is less, but shrinkage is more. Also the color of concrete becomes darker. Using silica fume will increase compressive strength and abrasion resistance of the concrete, and its permeability will decrease dramatically. This will improve the durability of concrete.

As it was mentioned, by using silica fume we can prevent corrosion effectively; this happens because of reduction in the permeability of concrete. Usually 7-7.5 percent of silica fume is recommended to replace cement. Also in the marine and submarine structures silica fume is being used regularly. For example Gulfaks C platform in the North Sea can be mentioned. Many piles, platforms and piers constructed by using concrete containing silica fume demonstrate its suitable performance (FIP State of the Art, 1996).

3. Materials

Materials used in this research are as follows:

– Angular calcareous coarse aggregate corresponding to grading of BS 882 standard (British Standard Institution (BSI), 1973), maximum size of aggregate of 20 mm, specific gravity of 2.68 and water absorption of 0.45 percent.

– Before making specimens, coarse aggregates were completely washed to remove harmful materials from their surface.

– Calcareous fine aggregate corresponding to allowable grading of BS 882 standard (British Standard Institution (BSI), 1973), fineness modulus of 2.8, specific gravity of 2.57 and water absorption of 2.80 percent.

– Cement type II (from Tehran cement factory) according to ASTM C150 standard (ASTM, 1997).

– Silica fume with specific gravity of 2.30 in powder shape.

– The water used in the making specimens was drinking water.

– Super plasticizer with the commercial name of MELCRETE.

4. Method of Making, Curing and Preparing Specimens

The mix design was used to make all types of concrete specimens was according to Road Note 4 (Road Research Laboratory,1950) as shown in Table 2.

Table 2: Mix Design of Reference Specimens and Specimens Containing Silica Fume

<table>
<tr><th rowspan="2">W/C</th><th>Silica Fume</th><th>Net Water</th><th>Water Correction</th><th>Mixing Water</th><th>Cement</th><th>Silica Fume</th><th>Fine Aggregate</th><th>Coarse Aggregate</th></tr>
<tr><th>%</th><th>Kg/m³</th><th>Kg/m³</th><th>Kg/m³</th><th>Kg/m³</th><th>Kg/m³</th><th>Kg/m³</th><th>Kg/m³</th></tr>
<tr><td rowspan="2">0.5</td><td>0</td><td rowspan="2">230</td><td rowspan="2">10.6</td><td rowspan="2">240.6</td><td>430</td><td>0</td><td rowspan="2">852.5</td><td rowspan="2">852.5</td></tr>
<tr><td>7.5</td><td>397.75</td><td>32.25</td></tr>
<tr><td rowspan="2">0.4</td><td>0</td><td rowspan="2">243</td><td rowspan="2">11</td><td rowspan="2">254</td><td>562.5</td><td>0</td><td rowspan="2">796.3</td><td rowspan="2">796.3</td></tr>
<tr><td>7.5</td><td>520.3</td><td>42.2</td></tr>
</table>

– In making specimens the super plasticizer was added; therefore, the concrete slump was 7-10 cm.

– Half of compressive strength specimens were cured in water, and the other half were placed in crude oil containing 10 percent of salty water after being cured in water for 7 days.

– All permeability cylindrical specimens cured in water.

– All specimens were got out from the curing environment 24 hours before testing.

5. Method and Schedule of Testing

5.1 Compressive Strength Test

Three cubic specimens 10 cm × 10 cm for all ages in two types; reference and silica fume containing with two w/c ratios; 0.4 and 0.5 were made. The specimens were tested at the ages of 7, 28, 90 and 180 days.

5.2 Permeability Test

Two cylindrical specimens in two types; reference and silica fume containing with two w/c ratios; 0.4 and 0.5 were made. The specimens were tested after 28 days curing in water.

5.2.1 Method of testing permeability using oxygen gas

Testing apparatus is consisted of a set of cells which are under pressure and a hydraulic system which has the capability of putting the cells under pressure. Each cell is consisted of a cylinder with diameter of 10 cm and height of 10 cm which gas can pass throught it longitudinally. A pump exerts 8 bar pressure of air to specimens. When the rate of gas outflow became constant (usually in some minutes) permeability coefficent can be calculated based on Darcy's law in m/s.

6. Test Results

6.1 Compressive Strength Test

Effect of placing specimens in crude oil after 7 days curing in water is shown in Figures 2 and 3. It is noticeable that the compressive strength of oil soaked specimens at the age of 28 days is averagely 15 percent less than reference specimens.

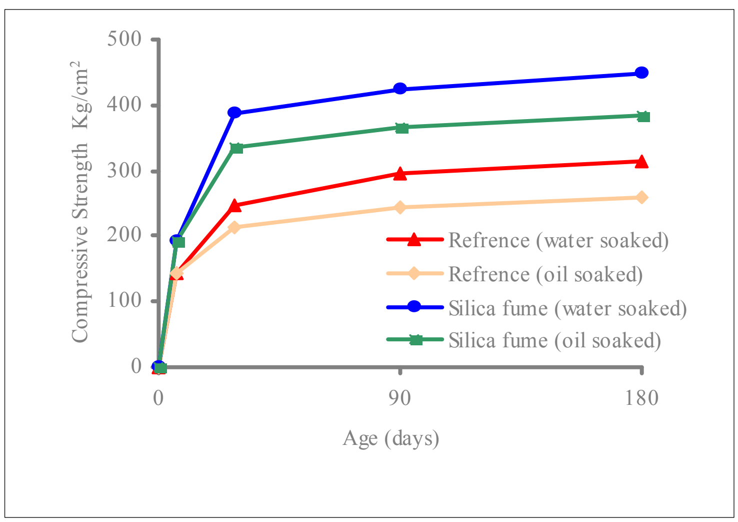

Figure 2: Compressive Strength of Reference Specimens and Silica Fume Containing Specimens Cured in Water and Crude Oil (W/C=0.5)

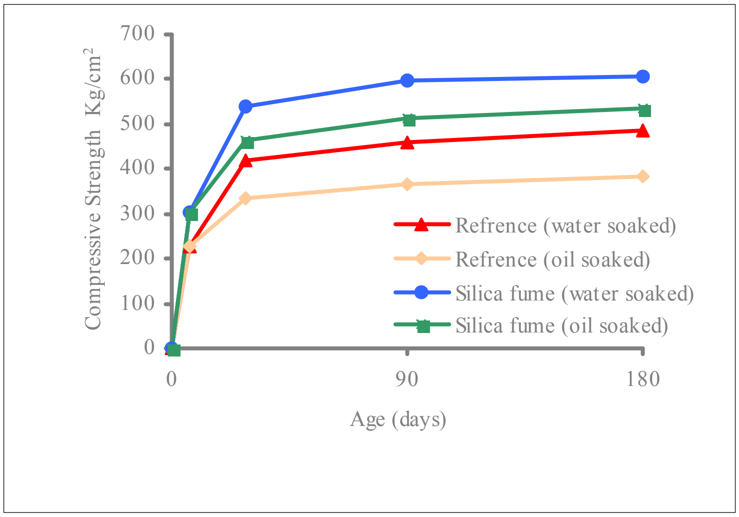

Figure 3: Compressive Strength of Reference Specimens and Silica Fume Containing Specimens Cured in Water and Crude Oil (W/C=0.4)

Figures 4 and 5 show the effect of replacement of 7.5 percent of silica fume with cement on the concrete compressive strength at different ages. As it can be seen, in the concrete with w/c ratio of 0.5 using silica fume has increased the compressive strength by 50 percent. This ratio for specimens with w/c ratio of 0.4 is about 25 percent which is probably related to calcareous aggregate weakness (this is proved when the broken aggregates were observed after testing).

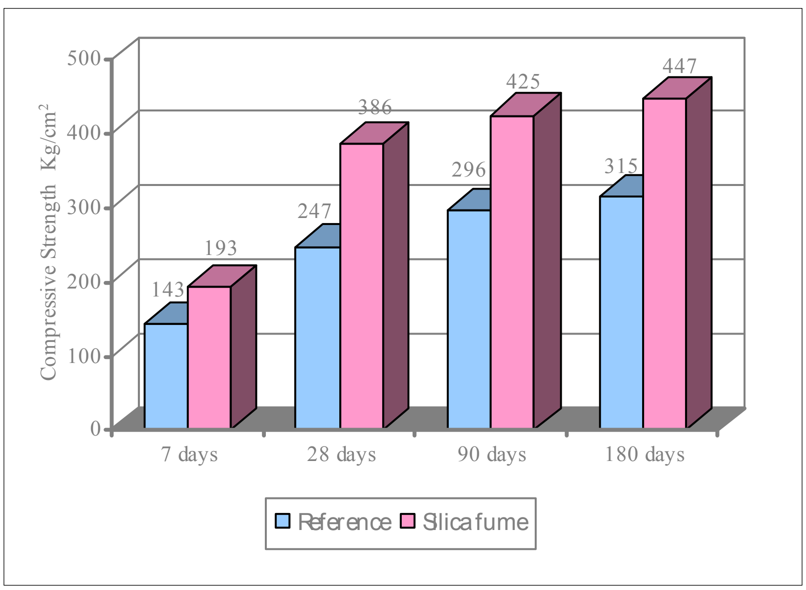

Figure 4: Comparison of Compressive Strength of Reference Specimens and Silica Fume Containing Specimens at Different Ages (W/C=0.5)

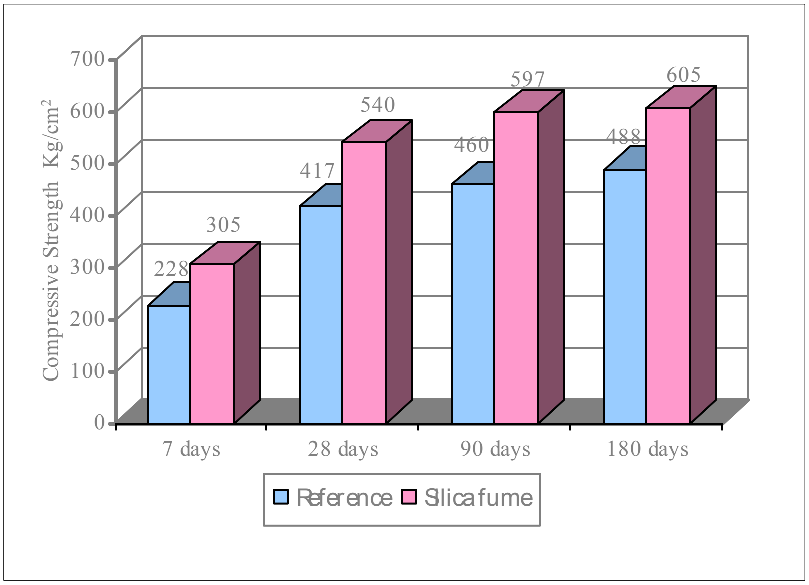

Figure 5: Comparison of Compressive Strength of Reference Specimens and Silica Fume Containing Specimens at Different Ages (W/C=0.4)

6.2 Permeability Test

As it can be seen in Table 3, permeability of the concrete containing silica fume is about 100 times less than ordinary concrete.

Table 3: Permeability Coefficient of Different Types of Concretes at the Age of 28 Days (m/s)

	W/C = 0.5		W/C = 0.4	
	Reference	Silica Fume	Reference	Silica Fume
Gas Permeability Coefficient	3.33×10^{-12}	3.74×10^{-14}	1.43×10^{-12}	1.30×10^{-14}

7. Conclusion and Recommendations

– As vicinity of concrete and oil weakens or stops the process of gaining strength of concrete ; therefore, In order to achieve the characteristic strength of concrete there should be at least 28 days gap between pouring of concrete and filling the tanks with oil.

– Replacement of 7.5 % of cement with silica fume increases the compressive strength of concrete noticeably; therefore, it is recommended to use silica fume in constructing oil storage tanks.

– Using silica fume decreases the permeability coefficient by about 100 times; therefore, to prevent concrete or steel bars corrosion and also leakage of oil from the tanks ,it is recommended to use silica fume in constructing oil storage tanks.

8. References

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