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EFFECT OF FIELD ENVIRONMENTAL EXPOSURE CONDITIONS ON THE PROPERTIES OF HARDENED CONCRETE

W. A. AL-KHAJA and N. M. AL-BASTAKI
Assistant Professors, Department of Physical & Engineering Sciences
Arabian Gulf University

M. H. EL-HADDAD
Professor, Department of Civil Engineering
Qatar University

A. S. MOHAMED
Senior Engineer, Maintenance Department
Ministry of Information, Qatar

and

P. Padmore
Head of Civil Engineering Laboratory
Ministry of Industry and Public Works, Qatar

ABSTRACT

The effects of harsh field environmental exposure conditions on compressive, tensile and flexural strengths and durability aspects of concrete such as chloride penetration, sulphate attack and carbonation were investigated for a period of 240 days. The environmental variables studied were control laboratory condition at Qatar University, chloride and sulphate rich ground field condition (Zone A) located 10 Km from Doha City, and below the water table field condition (Zone B) exist at the same selected site. The results indicate that concrete specimens kept at ground field condition (Zone A) exhibit lower compressive, tensile and flexural strength values than both the control laboratory and the below water table field conditions. The loss in strength has been attributed to the cessation of hydration due to drying of the concrete. The strength values of control laboratory condition and below water table field condition (Zone B) were marginally comparable in spite of the considerable difference of chloride, sulphate and carbonation values.

INTRODUCTION

The premature deterioration of concrete structures and the factors involved in all aspects of maintenance and repair are currently of concern in the state of Qatar. The main causes of concrete deterioration in hot climate countries are attributed to the corrosion of steel reinforcement, chloride penetration , sulphate attack, carbonation and cracking due to shrinkage and thermal gradients as indicated by many workers (1-5). In the hot, arid and salt laden environment of the Arabian Gulf coast, a poor quality concrete deteriorates rapidly, even when high standards are set in design and specification requirements, unless these can be matched by high standards of construction works.

In Qatar, the field environmental condition is considered to be one of the most aggressive environments for concrete properties and durability in the world. It is characterized by adverse geomorphic and climatic conditions, severe ground ambient salinity, high temperature and humidity regimes and variations. Moreover, chloride and sulphate salts extensively contaminate the ground soil, ground water and moisture laden environment.

During summer, the ambient temperatures at Qatar are frequently in the range of 35-50^{o}C, and humidity is high along the coast, particularly at night having average relative humidity ranges from 60% to 80% in summer and winter respectively (6).

To produce good concrete structures in the harsh environmental conditions in Qatar, good construction materials and better understanding of the environmental effects are needed. The present test programme was, therefore, carried out to determine the effect of field environmental exposure conditions on the mechanical properties and durability of concrete in the state of Qatar.

MATERIALS AND EXPERIMENTAL PROGRAMME

Locally produced ordinary Portland cement satisfying the requirement of BS12: part 2, 1971, was used. Laboratory chemical composition results of cement samples are given in Table 1. Washed desert sand located 40 Km from Doha City was used, having a saturated surface dry specific gravity of 2.531 and absorption of 1.8 percent. Crushed limestone coarse aggregate with maximum size 12 mm (from Alkhayade crushing factory) was used,

Table 1
Chemical composition of Qatar ordinary Portland cement

Oxide and Compound Composition	Composition Percentage
CaO	64.3
SiO_2	20.8
Al_2O_3	4.3
Fe_2O_3	3.3
MgO	2.5
SO_3	2.6
Na_2O	0.3
K_2O	0.35
Others	0.27
C_3S	61.64
C_2S	13.11
C_3A	5.54
C_4AF	10.12

having a saturated surface dry specific gravity of 2.6 and water absorption of 2.4 percent. The sieve analysis of fine and coarse aggregates were carried out according to BS812: part 1, 1975. The results are presented in Table 2.

Table 2
Sieve analysis of fine and coarse aggregates

Sieve Size (mm)	Percentage Passing	
	Coarse Aggregate	Fine Aggregate
14.00	100	
10.00	54	
5.00	1	100
2.36		94
1.18		82
0.60		61
0.30		14
0.15		2

The chemical analysis of the desert sand and limestone coarse aggregate has indicated that desert sand has 0.13% sulphate and 0.03% chloride, while the limestone coarse aggregate has 0.31% sulphate and 0.08% chloride.

The concrete mix used in the investigation was a typical mix used in Qatar and it was chosen to achieve a cube compressive strength of about 24 MPa at 28 days. The cement content was 350 kg/m^3 in the mass proportions of 1 : 2 : 3.5 with water to cement ratios of 0.60. The workability of the mix was 55-60 mm slump. The concrete mix remained the same in all cases to permit comparison. The test specimens used were 150x150x150 mm cubes for compressive strength, 300x150 mm cylinders for splitting tensile strength and 100x150x700 mm prisms for flexural strength. The concrete specimens were prepared in laboratory condition at 23$\pm$1^o and 68% R.H. with mechanical compaction in two layers. After casting the concrete, moulds were covered with damp hessian and polythene sheets, and kept at laboratory condition for 24 hours, then moulds were demoulded and placed in water until seven days old. Thereafter field specimens were transferred to their respective exposure sites and laboratory specimens were retained in the laboratory as a control specimens. The selected exposure site located near Qatar University is shown in Figure 1, approximately 10 km from Doha City

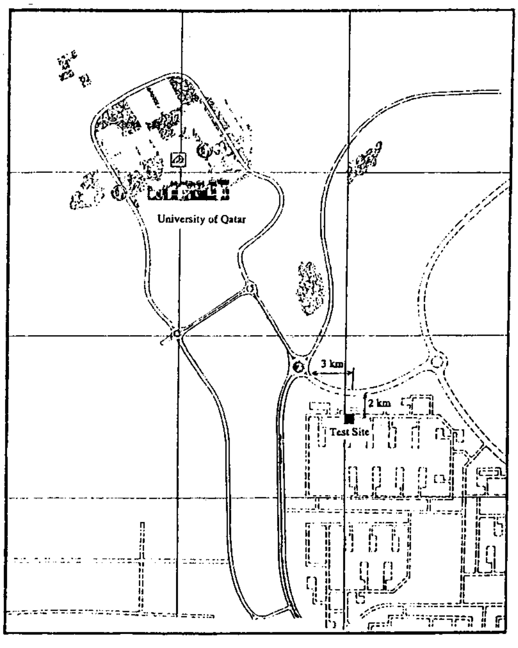

Figure 1: Location of test site exposure condition

and 1 km from the North-East coast of Qatar. Figure 2 illustrates the exposure site details having two exposure conditions chosen to represent the actual locations of concrete building elements and also to assess the effect of exposure site on concrete properties and durability. For the first exposure

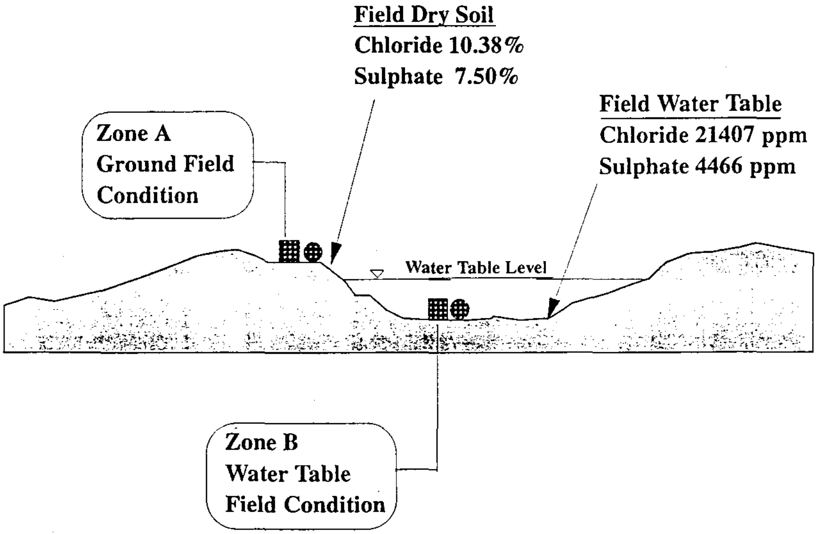

Figure 2: Exposure site details

condition, specimens were placed in salty chloride rich moisturized ground in order to simulate concrete superstructure elements. The ground soil has a high percentage of chloride about 10.38% and sulphate was 7.50%. As for the second exposure conditions, specimens were completely submerged and occasionally partially submerged in ground water depending on the level of water table and the tidal movement of the sea water in order to simulate concrete foundation elements. Chemical analysis of site ground water were carried out and compared with chemical analysis of the sea water as shown in Table 3. Similarly ground soil was tested for sulphate and chloride, the test results are compared with results of soil samples collected from five different locations in Doha as shown in Table 4. It is noted the sulphate content of ground water was much higher than the sea water sulphate content, whereas chloride content values were comparable for the site and sea water. Furthermore, the sulphate and chloride contents of site ground soil and various location sites in Qatar are high and exceed the specification limits as shown in Table 4. Therefore, this would indicate the severity of the selected site condition and the harsh environmental field condition.

Table 3
Water test results

Origin	Chloride Cl, ppm	Sulphate SO_3, ppm
Sea Water	23800	2776
Site Water	21407	4466
Tap Water	250	86

Table 4
Chemical analysis of dry soil at various locations in Qatar

Location	Chloride percentage, Cl %	Sulphate percentage, SO_3 %
Test Site	10.38	7.50
Old Rayan	0.68	3.50
New Rayan	1.14	3.02
Gharafa	1.40	8.64
Abu Hammoor	1.88	4.73
Muntaza	0.20	10.23

Compressive, splitting tensile and flexural strengths testing were done at 7, 28 and 240 days ; strength results are the average of three specimens and the scatter between the specimens was negligible. Chemical analysis of concrete specimens was carried out at 240 days to determine the chloride and sulphate contents of concrete at different exposure conditions. Rate of carbonations were also measured using phenolphthalein indicator solution.

TEST RESULTS AND DISCUSSION

Comparison of the development of compressive strength with time of the cubes positioned in the exposure field conditions of the water table (Zone A) and ground soil (Zone B) and their laboratory controls is presented in Figure 3. The below water table exposure field condition specimens of Zone B showed the highest increase in strength over the whole testing period having

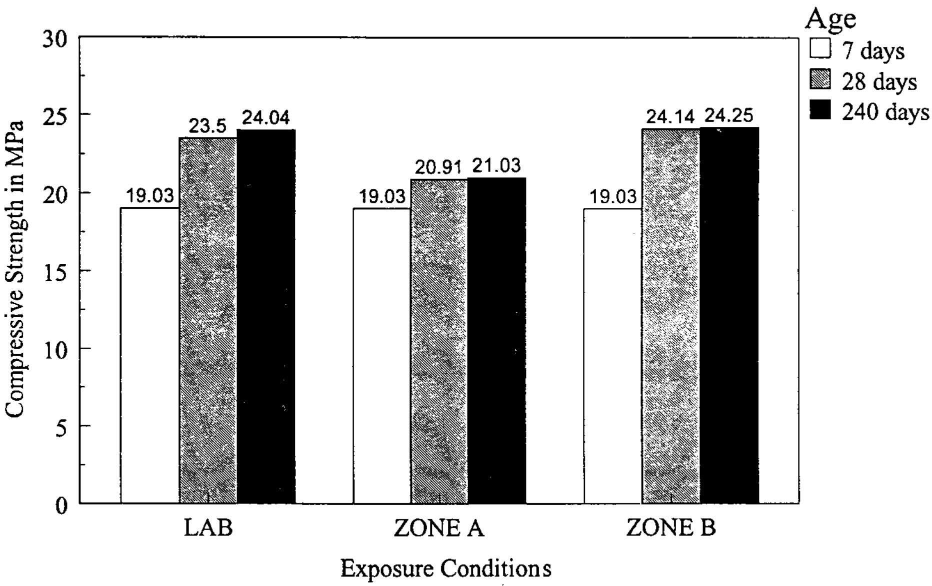

Figure 3: Compressive strength depending on age of cubes of different exposure conditions

an average strength of 24.25 MPa at 240 days when compared with control laboratory and Zone A specimen strengths of 24.04 MPa and 21.03 MPa, respectively. The increases in strength of Zone B specimens at 28 days and 240 days as compared to the control laboratory condition values were only 2.7% and 0.9%, while with respect to ground field condition of Zone A values were 13.4% and 13.3% , respectively. It can be seen that the below water table specimens of Zone B exhibited about the same strength values as the control laboratory specimens irrespective of the environmental variations between laboratory and Zone B conditions, i.e., Zone B condition specimens are influenced by temperature and ambient humidity variations, radiation of the sun and salt weathering. An important aspect of the results is the degradation in strength of Zone A ground field specimens over the whole testing period. The loss in strength can be attributed to the drying effects of higher temperature and short curing regime (7 days curing) leading to cessation of hydration which is the most important consideration in the early life of concrete. It is also possible that strength development of Zone A specimens is retarded under particularly aggressive sulphate forms or complex salts, such effects may well be related to geochemistry of local soils and groundwaters (7).

Figure 4 shows the cylinder splitting tensile strength difference of field exposure specimens which have been compared to the laboratory ones. In general, the effects of exposure field conditions are similar to the results from the compressive strength. The Zone B below water table specimens test

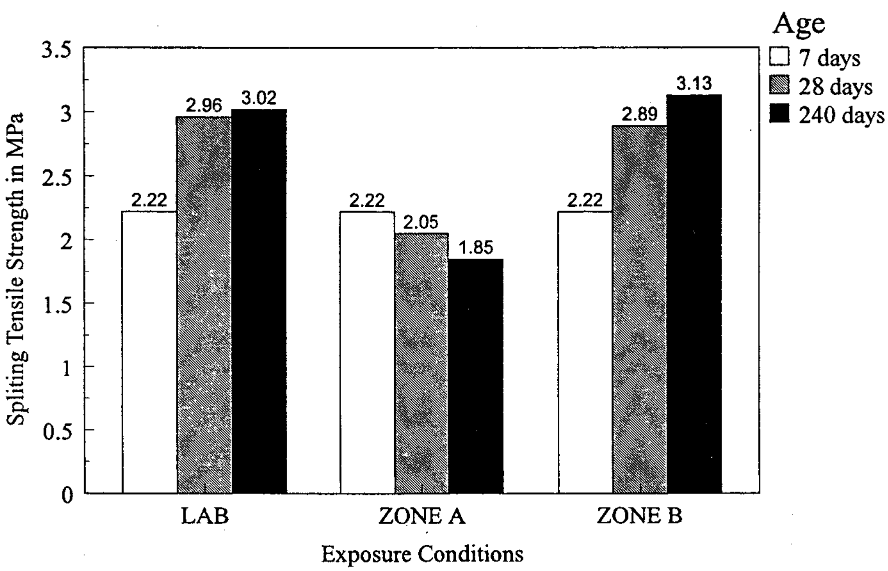

Figure 4: Splitting tensile strength depending on age of cylinders of different exposure conditions

results showed the highest increase in splitting tensile strength having an average strength of 3.13 MPa at 240 days when compared with the control laboratory and Zone A ground field specimens strengths of 3.02 MPa and 1.85 MPa, respectively. The increases in strength of Zone B specimens at 240 days as compared to the control laboratory and Zone A specimen values were 3.5% and 40.9%, respectively. It is clear that the strength values of Zone A specimens were considerably reduced while strength values of Zone B and control laboratory specimens were comparable. The considerable strength reduction of Zone A specimen was caused by the lack of saturation during the prolonged exposure testing and also by the same factors previously mentioned for compressive strength. It should also be noted that a gradual reduction in splitting tensile strength of Zone A specimens was noticed when comparing the 28 and 240 days values with its 7 days values. This finding shows the aggressive environment of the chloride and sulphate rich ground field condition of Zone A. This effect is considered to be mainly due to physical deterioration of the test specimen, consequently the results are considered significant.

The flexural strength depending on age of prisms of different exposure conditions is shown in Figure 5. The trend of measured results is similar to the trend of the compressive strength results. It is obvious that the control

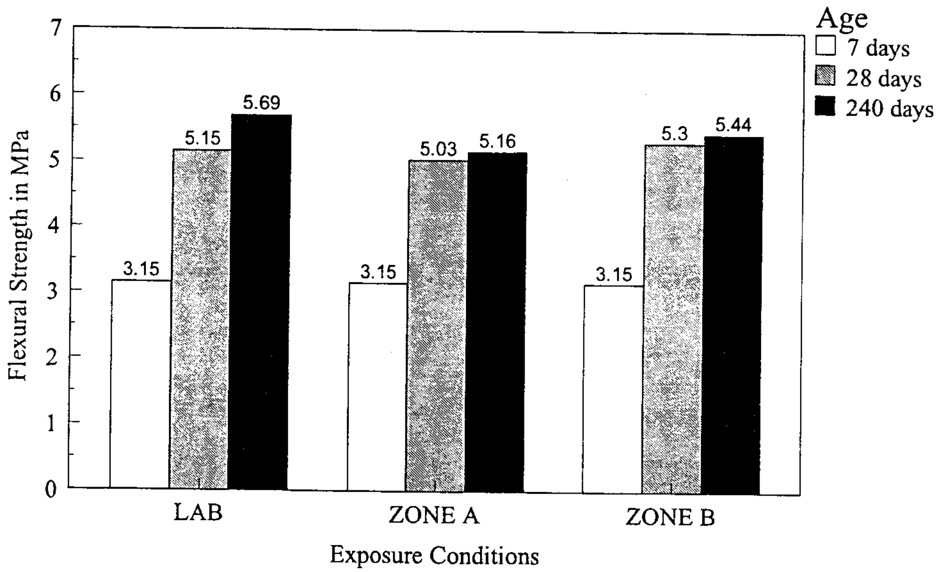

Figure 5: Flexural strength depending on age of prisms of different exposure conditions

laboratory specimens test results showed the highest increase in flexural strength at 240 days having a strength of 5.69 MPa when compared with the Zone A ground field and Zone B below water table specimen strengths of 5.16 MPa and 5.44 MPa, respectively. The reduction in strength for various exposure field specimens at 240 days was 9.3% and 4.4% for Zone A ground field and Zone B below water table specimens, respectively. This effect is considered to be mainly due to physical deterioration of the flexural test specimens after 8 months of field exposure. It should be noted that the development of flexural strength with time shows that the percentage variations of 240 days to 28 days strength values of Zone A and Zone B were ranging from 2.5%-2.6%, while the percentage variation of control laboratory was 9.5%. These results suggest that in harsh environmental condition, the long-term flexural strength of the concrete can be very identical to the 28-day strength.

Table 5 presents the 240-day chloride and sulphate contents in concrete and depth of carbonation of specimens kept at various exposure conditions.

Table 5

Chloride and sulphate contents in concrete and depth of carbonation of concrete specimens at an age of 240 days kept at various exposure conditions

Exposure Condition	Chloride % By Weight of Concrete	Sulphate % By Weight of Concrete	Depths of Carbonation in mm
Lab	0.050	0.60	12.0
Zone A	0.345	0.89	7.0
Zone B	0.354	1.01	0.1

From the chloride results, it is apparent that the chloride percentage by weight of concrete of exposure site specimens is high having chloride percentage values of 0.345 and 0.354 for Zone A and Zone B, respectively, while the laboratory chloride percentage values was 0.05. The various site exposure specimens typically showed 7 times the laboratory specimens chloride concentrations. This difference is a clear illustration of the effect of site exposure condition on the chloride content of concrete. The high percentage of chloride content in concrete exposure site specimens is influenced by the high site water chloride content of 21407 ppm for Zone B and high ground soil chloride content of 10.38% for Zone A, as presented in Table 3 and Table 4, respectively. It should be noted that the chloride content of ground field condition of Zone A and below water table condition of Zone B was more or less the same in spite of the different exposure condition. However, the sulphate percentage average value of below water table condition of Zone B was about 12% higher than ground field condition of Zone A having sulphate percentage of 0.89 and 1.01 for Zone A and Zone B, respectively, whereas the control laboratory sulphate content was 0.6% by weight of concrete. The high percentage of sulphate content in concrete exposure site specimens is influenced by the high site water sulphate content of 4466 ppm for Zone B and high ground soil sulphate content of 7.50% for Zone A.

Depths of carbonation measured in prisms from different sites for 240 days have indicated that the below water table field specimens of Zone B exhibited the lowest values as expected (less than 0.1 mm penetration), whereas the control laboratory and ground field specimens of Zone A have exhibited a considerable greater values of 12 mm and 7 mm, respectively. The high carbonation rates of the control laboratory may be due to the air conditioning system of the laboratory. However, no firm conclusions can be drawn concerning these findings since only short-term carbonation depth results are presented.

CONCLUSIONS

The following points can be concluded from this preliminary limited study on the effect of field environmental exposure conditions on properties of concrete in Qatar:

(a) Over the whole testing period, the prolonged exposure field condition has caused a degradation in compressive, tensile and flexural strengths of Zone A ground field specimens when compared with control laboratory and Zone B below water table specimens.

(b) Strength values of control laboratory specimens and Zone B below water table specimens were comparable, having Zone B compressive and tensile strength values slightly higher than control laboratory strength values in spite of the significant difference in the environmental conditions. However, it is found that the flexural strength values of control laboratory specimens are relatively higher than the Zone A and Zone B exposure specimens.

(c) The compressive and flexural strength results of specimens kept at various field exposure environmental conditions generally suggest that long-term strength of field exposure concrete (at 240 days) can be very identical to the 28-day strength.

(d) Chloride ingress was high for various exposure site specimens having chloride concentrations 7 times the control laboratory specimens chloride concentration. The high chloride concentrations of exposure site specimens are influenced by the high ground soil chloride content and high site water chloride content for Zone A and Zone B, respectively.

(e) Sulphate ingress was greatest in the Zone B below water condition specimens followed by the Zone A. The high sulphate content of exposure site specimens is influenced by the high ground soil sulphate content and high site water sulphate content for Zone A and Zone B, respectively.

(f) Depths of carbonation measured over the limited exposure period were high for control laboratory specimens and ground field specimens of Zone A, respectively, whereas values for the below water specimens of Zone B were minimal.

(g) It is therefore essential that careful site tests and field exposure investigation should be made before construction is begun in an unknown climate.

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