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Deterioration of high-performance concrete subjected to attack by the combination of ammonium nitrate solution and flexure stress

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Abstract

The behavior of ordinary concrete and high strength concrete under a combinative effect of stress and chemical corrosion was studied in the present work. The concrete specimens were immersed in a variety of chemical solutions including 10%, 5%, 1% and 0.1% ammonium nitrate and simultaneously subjected to different flexural loads with load levels of 30%, 40% and 50% of their initial flexure strengths. The influences of the concentration of solutions, quality class of the concretes and load level of applied flexural stress on the strength of concretes were investigated. The relationships between life-time of the concrete and concentration of the solution, relative strength of the concrete and penetration depth of the ammonium nitrate solutions were determined. The mechanisms of stress corrosion of concrete exposed to ammonium nitrate solution and superimposed to a flexural stress was also discussed.

Keywords: High-performance concrete; Corrosion; Nitrate; Long-term performance; Durability

1. Introduction

It is known that materials, such as metals, ceramics, glass and polymers, are significantly affected by stress corrosion effect which generally takes place when the materials are exposed to a corrosive conditions with the addition of an external stress [1–3].

In practice concrete constructions are subjected to attack by the combination of chemical corrosion and mechanical stress. The study of simultaneous effects of chemical attacks and mechanical stresses was initiated and reported by Schneider and co-workers in 1984. It was reported [4–8] that several media, such as ammonium and sodium sulfate, sodium nitrate, magnesium sulfate and sodium chloride tended to cause stress corrosion.

As is well known [9–15,20–22], ammonium nitrate solutions are very corrosive to cementitious materials, which leads to dissolution of cement-based materials according to the following reaction:

$$2NH_4NO_3 + Ca(OH)_2 \rightarrow Ca(NO_3)_2 + 2NH_3 + 2H_2O \quad (1)$$

The reaction products are calcium nitrate and ammonia, both of which are easily dissolved in water. Furthermore, the dissolution of calcium hydroxide in the ammonium nitrate solution is higher than that in pure water. It is clear from the above-mentioned chemical reaction that the ammonium nitrate decalcifies the hardened cement paste due to removal of calcium hydroxide (Eq. (1)). This results in decalcification and dissolution of other products of the hardened cement paste and leads to a reduction of the pH-value. Consequently, steel reinforcement corrosion may occur at an accelerated rate. The deterioration and damage of the cement-based material must be intensified and accelerated, when the material suffers under a corrosive attack superimposed with a mechanical load.

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2. Materials and mixture proportions

2.1. Portland cement

Two types of portland cements, ÖNORM B3310 type PZ375 and PZ475 (ASTM Type I), were used. The chemical analyses of both the PZ475 and PZ375 are given in Table 1.

2.2. Aggregates

The aggregates were from natural gravel 4/8 and natural sand 0/4. The grading of the aggregates is given in Table 2.

2.3. Superplasticizer (SP)

A superplasticizer based on melamine sulphonate was used for the high strength concretes.

2.4. Retarder (R)

A retarder based on lignosulfonate was used for the high strength concrete C95.

2.5. Silica fume (MS)

The physical properties of the silica fume slurry are shown in Table 3.

2.6. Mixture proportions

Refer to [16–18] about the mixtures of high strength concrete the tested concretes were designed as ordinary concrete C40 and high strength concretes C80 and C95. The proportions of the concrete mixtures are summarized in Table 4.

The water (W)-to-binder (B) ratios (W/B) is calculated as follows:

$$W/B = \frac{W + 0.5MS + SP + R}{C + 0.5MS}. \quad (2)$$

3. Test method

In the present work, ammonium nitrate was selected as aggressive medium. To test the effect of a number of parameters on stress corrosion, the research program was designed with varying the type of cement-based materials (mortar, ordinary concrete and high strength concrete), concentration of solutions and load levels.

Table 1
Chemical analysis of the cement PZ 375(H)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	GV	C_3S	C_2S
PZ475	19.9	4.9	2.3	63.7	1.7	3.6	0.4	0.8	2.0	61.4	10.8
PZ375	21.7	5.7	2.1	59.8	2.5	3.4	0.5	0.9	3.4	27.6	41.5

Table 2
Grading of the aggregates

Sieve size (mm)	Cumulative percentage passage	
	Gravel 4/8	Sand 0/4
0.063	0.1	1.07
0.125	0.2	3.60
0.25	0.2	11.43
0.50	0.2	25.74
1	0.3	38.65
2	0.6	62.72
4	5.5	95.99
8	90.3	

Concrete prisms, 40×40×160 mm, were used as test specimens in this study. The concrete mixtures were designed to have compressive strengths of 40 MPa (ordinary concrete) and 80 MPa (HPC without silica fume), 95 MPa (HPC with silica fume). After 24 h of concrete placement, the models were stripped. The specimens were cured in water for the next 27 days.

At the age of 28 days, the flexural and compressive strengths were determined with three prisms of a series of the specimens and used as initial strength of the concrete. Thereafter, the test specimens were immersed into the aggressive solutions and simultaneously subjected to different flexural loads. The ammonium nitrate solutions were with various concentrations of 10% ($[NH_4^+]$=22,500 mg/l, $[NO_3]$=77,500 mg/l), 5% ($[NH_4^+]$=11,250 mg/l, $[NO_3^-]$=38,750 mg/l), 1% ($[NH_4^+]$=2250 mg/l, $[NO_3^-]$=7750 mg/l) and 0.1% ($[NH_4^+]$=1125 mg/l, $[NO_3^-]$=3875 mg/l), respectively. The load levels were 30%, 40% and 50% of their initial flexural strengths. The solutions were replaced as needed to maintain submersion of the samples, ensuring that the solution concentration was maintained. A series of specimens were immersed in water saturated by calcium hydroxide as reference. The flexural strength and compressive strength of the specimens were determined after immersion at regular intervals. The depths of penetration of the aggressive ions into the concretes were measured by

Table 3
Typical physical properties of silica fume (slurry)

Property	Dimension	Liquid
Density of the slurry	kg/dm^3	1.41±0.02
Proportion of silica solids	%	50
In the slurry		
Specific surface	BET (m^2/g)	18–20
Dry substance	%	min. 99
Fineness		
<0.001 mm	%	60±15
<0.04 mm	%	min. 85