Acta Technica *62* (2017), No. 6A, 191–200

Study on durability testing of concrete under the condition of sulfate

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Abstract. According to the material degradation of concrete under the condition of sulfate, analysis of concrete durability testing is made. The concept of small-invasive detection based on the rebound method and core drilling method for sulfate attack is proposed. Through the alternation test of wetting and drying on concrete members, the evaluation of durability on sulfate attack is given, which can be used as a reference when detecting and estimating the durability of concrete structures.

Key words. Bridge engineering, concrete, durability, sulfate.

1. Introduction

It is well-known that the deterioration of durability on concrete under the condition of sulfate is contributed by chemical reaction between hydration products of concrete and sulfate ion, which leading to the loose in texture and decreased in strength of concrete. It can cause the deteriorated of concrete through the long-term association with sulfate environment. XUE Peng-fei formulated a multi-factor diffusion model of chloride in concrete based on the modified hypothesis of Fick's rule [1]. In severe cases, it will directly threaten the operation service period of bridge. Therefore, how to accurately obtain the detection index under the condition of sulfate becomes the key to establish the method of structural durability assessment [2, 3].

At present, there are few researches on the material degradation of concrete under the condition of sulfate. Most experts focus on the changing regularity of parameters, such as strength, relative dynamic modulus of elasticity and mass loss in

[1]Acknowledgment - This work is financially supported by the Special Basic Foundation for Central Public Research Institutes (2017-9023) and Construction Technology Projects Motivated by Ministry of Communication (2013-318-223-040).

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the laboratory [4]. In particular, the rebound method is suitable for site tests, which need a certain pressure to meet the need of small specimens. However, it will cause some concomitant injury. The compression strength based on ultrasonic method always combined with the rebound method, otherwise, the accuracy of strength could be affected by the humidity, aspect ratio and the location of steel in the concrete. This makes the scope of application of testing curve are limited, and the pull-out method can only be used to test the strength of structures, which can not evaluate the durability of concrete structures under the condition of sulfate. The core drilling method directly drills the samples taken from concrete members for destructive testing. However, it has caused a certain extent of damage to the structural. Based on these reason, the method of durability evaluation on sulfate attack of concrete is given by synthetic analysis.

2. Advantage of hardness testing under the condition of sulfate

The hardness testing takes fewer specimens to meet the requirements of alternation test of wetting and drying on concrete, and it gets more data for durability analysis and more accurate in evaluating the durability. Compared with the resiliometer, the durometer is only about 0.5% in impact energy and the ball diameter is much smaller, for details see attached Tables 1.

Table 1. Hardness tester and the resilience of the indicators of contrast

Competency Indicators	**M225 Resiliometer**	**TIME5302 Durometer**
Impact Energy	2.207J	0.011J
Ball Head Diameter	25mm	3mm

3. Experiment scheme of durability inspection

3.1. mix proportion design of concrete

Table 2. Mix proportion design of concrete

strength grade	**water-cement ratio**	**water kg/m3**	**cement (kg/m3)**	**sand (kg/m3)**	**stone (kg/m3)**	**water-reducing agent (kg/m3)**
C30	0.48	184	385	775	1050	3.465
C40	0.40	183	460	730	1065	4.600
C50	0.35	180	515	700	1080	5.665

The mix proportion design of concrete depends on the Specification for Mix Proportion Design of Ordinary Concrete (JGJ55-2000) in the test [5]. The grade of strength for the concrete is ranged from C30 to C50, and water cement ratio are

0.48, 0.40 and 0.35. For the concrete pump used in practical project, it is required that the slump of concrete should be maintained in the range of 15-20cm. According to the result of laboratory test, the dosage of water-reducing agent is 0.9% for C30, 1.0% for C40 and 1.1% for C50. The mix proportion design of concrete is shown in Table 2.

3.2. Concrete block

In order to study on the relationship between hardness and strength under the action of sulfate attack, two types of molding specimens, namely group A and group B, are made. The size of group A is 100 mm × 100 mm × 100 mm, which is used to test the compressive strength. The size of group B is 100 mm × 100 mm × 400 mm, and it is used to detect the change of dietmar Leeb, dynamic elastic modulus and mass loss. For details of concrete test block see attached in Figure.1 [6].

Fig. 1. Concrete test block

3.3. Concentration of sulfate

This experiment takes Na_2 SO_4 as the concentration of sulfate. According to the grade of corrosion environment on water and soil, which is shown in Table 3. The concentration of sulfate is confected in different concentration, from 0 mg/L, 1000 mg/L, 4000 mg/L to 7000 mg/L. It regards 0 mg/L as the basic concentration leavel, and the 1000 mg/L, 4000 mg/L and 7000 mg/L are represented as V-C, V-D and V-E respectively [7].

Table 3. Grade of corrosion environment on water and soil

Factor / Level	Sulfate ion concentration in water (mg/L)	Soil sulfate ion concentration water-soluble value (mg/L)
V-C	200 ∼ 1000	300 ∼ 1500
V-D	1000 ∼ 4000	1500 ∼ 6000
V-E	4000 ∼ 10000	6000 ∼ 15000

3.4. Process of experiment

The method of wetting and drying on concrete members is reference to the standard of ordinary concrete long-term performance and durability test method [8]. In the experimental process, the specimens are firstly enclosed in a box that filled with concentration of sulfate, then the specimen is dry out for 30 minutes after soaking for 16 hours. After that, the specimens are stetted into the baking chamber at 80 ± 5 °C for 6 hours, and cooled for 2 hours after that. Repeat these steps until the number of cycles reached 15, 30, 60, 105, 165, 210 times, then compressive strength is carried out on group A, and the dynamic modulus of elasticity on group B. For details see attached Figure 2.

Fig. 2. Baking chamber for specimens

4. The test results analysis

4.1. Relationship between hardness and strength of concrete

Concrete strength and hardness values in the test are summarized in Table 4, which give its change rule. The data of test shows that when the repeat tests after 150 times, the strength of concrete specimens shows slowly declined.

Table 4. Concrete strength and hardness values of the table

	concentration							
	0 mg/L		1000 mg/L		4000 mg/L		7000 mg/L	
strength grade	strength	hardness	strength	hardness	strength	hardness	strength	hardness
C30	44.1	479.95	38.3	489.0	45.0	488.5	47.4	472
	45.6	463.1	46.4	500.2	46.7	484.8	51.6	498.35
	51.0	504.9	50.1	512.6	49.0	505.9	52.9	519.6
	48.7	492.8	48.3	525.9	53.0	516.7	48.8	537.3
	46.7	498.2	52.8	528.6	55.3	532.4	53.8	549.0
	46.6	468.6	48.8	506.3	57.4	558.7	50.1	555.3
	44.1	440.5	50.3	511.5	57.7	556.9	44.3	541.5
C40	49.4	427.7	50.5	496.3	43.1	518.5	55.7	474.95
	56.5	441.4	58.8	497.3	52.8	531.8	53.0	489.7
	65.9	458.8	62.1	504.6	55.8	542.8	63.4	526.25
	61.6	466.3	59.2	512.9	68.2	546.1	66.5	521.5
	54.2	475.6	68.3	551.2	72.0	577.3	66.5	561.5
	58.5	518.8	64.6	544.0	64.9	552.4	66.9	571.9
	64.2	467.2	60.8	521.4	60.4	571.7	63.1	554.6
C50	56.9	493.4	56.2	522.6	62.3	498.7	55.5	483.55
	66.8	488.1	59.4	515.4	66.6	502.7	53.1	493.8
	74.1	520.5	75.4	530.5	68.0	522.1	68.4	513.2
	63.3	520.6	67.1	542.2	70.8	537.9	66.8	506.3
	72.3	531.0	74.8	557.2	74.3	565.0	79.8	560.9
	66.2	498.8	68.4	546.1	67.9	578.9	73.8	555.9
	62.0	484.9	72.8	542.1	67.6	557.9	74.5	534.5

Table 5. Strength and hardness values in 5% sodium sulfate

C30		C40		C50	
strength	hardness	strength	hardness	strength	hardness
29.1	419	39.6	473.4	50.3	505.1
28.2	413.8	44.0	488.8	54.6	529.5
29.9	429.6	43.0	487.4	51.4	510.9
6.9	339.8	16.7	396.8	48.5	488.2
5.4	300	11.9	378.1	41.3	485.2
6.3	326.9	12.5	394.6	48.0	486.9

In order to study the effect of different concentrations on the strength of concrete after sulfate attack, 5% concentration sulfate attack test is carried out. The test is

the same process of experiment above. According to the result in Table 5, it shows that under the high-concentration sulfate attack, the concrete strength shows a significant decrease.

It carry out the fitting analysis based on the acquired data Table 4 and Table 5 to realize the relationship between strength of concrete and hardness under the condition of sulfate, as it shows in Figure 3.

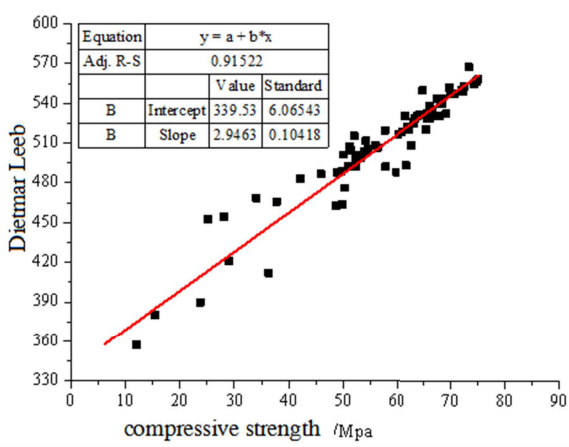

Fig. 3. The fit map of Concrete hardness and strength

$$LH = 2.9463 f_c + 339.53. \tag{1}$$

Where LH denotes Leeb hardness, f_c denotes the concrete compressive strength.

By the formula (1), the strength of specimen can be calculated from the hardness in the sulfate attack, which can be used to judge the damage level of the specimen.

4.2. Critical hardness

This is clear from the stand for test methods of Long-Term Performance and Durability of ordinary concrete that the standard for terminating of strength is about 0.75 time of compressive strength [9]. According to the principle of '0.75 times strength', the critical hardness of strength 30Mpa, 40Mpa, 50Mpa, 60Mpa, 70Mpa and 80Mpa are proposed, as shown in Table 6.

Compareing with the value of hardness and critical hardness from Table 6, the formula of critical hardness is obtained with application of least-square method

$$LH_D = 0.75 LH_w + 88.44. \tag{2}$$

In the formula (2), LH_w denotes hardness in the same ages without being sulfate attack, which also can be used for comparison the specimens by core sampling: LH_D denotes the critical hardness of concrete under the condition of sulfate. For predicting the durability of sulfate-eroded concrete components, the value of hardness obtained without being sulfate attack is taken as the reference hardness value

LH_w, then put them into the formula (2) to get the critical hardness value LH_D [10–13].

Table 6. Sulfate erosion critical state critical hardness value

Reduce the front intensity/Mpa	Reduce the after intensity/ Mpa	Reduce the front hardness	Critical Hardness	The hardness value is decreased by percentage
30	22.5	436.1	415.5	0.953
40	30.0	463.6	436.1	0.941
50	37.5	491.0	456.7	0.930
60	45.0	518.5	477.3	0.921
70	52.5	545.9	497.9	0.912
80	60.0	573.4	518.5	0.904

5. Application of bridge

Based on the results, It takes a in practical project to calculate the durability of concrete bridge, which shows as Figure 4 and Figure 5.

Fig. 4. Pier concrete wet and dry cycle erosion damage situation

Fig. 5. Hardness test of pier

The test includes the erosion by sulfate and without being sulfate attack on the pier of No.78 # -1. The test area of erosion is selected within 300mm above the contact surface between pier and soil, Eroded parts is above the base surface of 300mm range. For each test site, an average of 12 test areas is selected., and the average result is shown in Table 7.

$$LH_{\mathrm{x}} = LH_{\mu} - 1.645LH_{\sigma},$$

$$LH_s = 432.2 - 1.645 \times 21.6 = 396.7.$$

Table 7. 78 # -1 column by the hardness of sulfate erosion site test results

No.1	**No.2**	**No.3**	**No.4**	**No.5**	**No.6**	μ
438.9	395.2	398.3	452.3	415.9	460.8	432.2
No.7	**No.8**	**No.9**	**No.10**	**No.11**	**No.12**	δ
454.6	436.4	452.8	430.7	429.8	420.3	21.6

The hardness of the column by sulfate attack site hardness can be shown in Table 8.

Table 8. 78 # -1 column by Sulfate erosion site hardness test results

No.1	**No.2**	**No.3**	**No.4**	**No.5**	**No.6**	μ
441.7	462	445	451.2	456.1	460.8	455.7
No.7	**No.8**	**No.9**	**No.10**	**No.11**	**No.12**	δ
455.8	461.1	468.7	445.8	465.3	454.3	8. 5

The hardness of column without being sulfate attack is:

$$LH_w = 455.7 - 1.645 \times 8.5 = 441.8.$$

The critical hardness calculation formula:

$$LH_D = 0.75LH_w + 88.44 = 0.75 \times 441.8 + 88.44 = 419.79.$$

$396.7 < 419.79$, namely $LH_1 < LH_D$, Therefore, it is considered that the member has reached the sulfate erosion durability life.

6. Conclusions

(1) The relationship between the hardness and the strength of the eroded concrete is established, and it obtaines the critical hardness values of the concrete;

(2) The evaluation indexes and method of durability testing on concrete under the condition of sulfate are established;

(3) This method can be used for the long-term testing and evaluation of durability of concrete components under the condition of sulfate.

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Received November 16, 2017