Study on the corrosion resistance of slag and fly ash concrete

The adding of a certain amount of fly ash and slag in Ordinary Portland cement concrete may effectively improve the anti-sulfate corrosion of concrete under the premise of not reducing the strength of concrete. This paper mainly studies the anti-sulfate corrosion of different contents slag and fly ash concrete. Study has shown that the fly ash with content of 10%, 20% and 30% can meet the sulfate resistance index of concrete in each strength grade. For S95 slag, if the content reaches 30% in high-strength concrete (C40, C45), the sulfate resistance index of concrete can still be reached, while in slightly lower strength concrete (C30, C35), the strength of test piece after 150 times' sulfate attack has been less than 70%, failed to meet the standard requirements. In each strength grade proportion of mixture, sulfate resistance of concrete with fly ash is much better than the one with slag, but with the increasing of admixture content, the sulfate resistance of test piece will decrease slightly. For anti-sulfate, the sequence of optimizing mineral admixtures is: fly ash> S95 slag> S75 slag.

Key Words: High Strength Concrete; Anti-Sulfate Corrosion; Slag; Fly Ash.

1. Introduction

Acid rain mainly refers to acid precipitation containing H^+, SO_4^{2-}, NH_4^+, Mg^{2+}, and other media, and the PH value is less than 5.6 [1] . Under acid rain attack, $Ca(OH)_2$,C-S-H and other hydration products in concrete are prone to decompose and/or expand, resulting in the mechanical properties of concrete significantly reducing or even losing, in particular the rebar in concrete will be easily unprotected because of it, accelerating corrosion, resulting in the structure bearing capacity greatly attenuated [2] . Therefore, how to improve the capacity of anti-acid rain of the concrete structure has acid rain has been increasingly aroused widespread concern in civil engineering of hardest hit area.

The soil type of many areas in China (such as Xinjiang, Gansu, Qinghai and other western regions) belongs to inland saline soil, and the groundwater here contains large amounts of sulfate, chloride, magnesium and other strong corrosive substances. The existence of corrosive substance in stratum will have a significant corrosive damage for the construction of reinforced concrete structure and pile foundation. As for sulfate corrosion mechanism, it mainly refers to the sulfate which invaded to the inside of concrete reacts with certain chemicals of cement to produce insoluble saline minerals further leading volume expansion, forming in tumescent inner pressure. And when the pressure exceeds the tensile strength of concrete, the strength of concrete decreased or even cracked. Corrosive effect of chloride (chloride ion) is mainly that the chloride ions cause the rebar in concrete corrosive, the produced massive corrosion after corrosion may produce tensile stress within the concrete, and finally resulting in spilling, peeling and chipping.

The existence of sulfate and other corrosive materials is one of the key issues affecting the long-term durability of concrete, and its influencing factors are very complex, involving two major aspects of concrete working conditions and environmental conditions [3-4]. Among them, the working conditions of concrete mainly include concrete proportion of mixture, cement varieties, types of additives, construction methods, stress state and other properties, and environmental conditions include types of erosion solution, concentration, wetting-drying process, freezing-thawing cycles, etc. In recent years, durability issues of concrete have been attracted widespread attention, but the depth and breadth of their research are far from enough[5]. Here, the issues involving concrete's corrosion mechanism, influence factors, test methods, test level, evaluation criteria, anti-corrosion measures, etc. In order to achieve corrosion resistant effects, the used special cement (such as high sulfur resistant cement) not only significantly increases the project cost, the anti-corrosion effect is also remain to be tested. This test is trying to add a certain content of fly ash and slag into Ordinary Portland concrete to improve the corrosion resistance of concrete, and the durability of anti-sulfate corrosion is studied.

2. Testing program of concrete durability

2.1 Test Requirements

The prepared concrete mainly consists of cement, slag and fly ash three components (prepared in accordance with the

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required ratio). The anti-sulfate corrosion of prepared concrete as the above principles is mainly studied. The used cement is P·O 42.5 grade cement, slag using S95 and S75 grade these two types for comparative study.

Admixture dosage: fly ash mixes with 10% to 40%; slag adds 20% to 30%. It is required that water-cement ratio should be less than 0.4 (Actual preparation is 0.44). Concrete strength grade includes C30, C35, C40, C45, and others, at the same time a small amount of C20 grade concrete comparative tests are carried out. The prepared concrete requires meeting the performance of underwater concrete pile. According to the sulfate corrosion test methods in GB/T50082-2009, 150 times wetting-drying cycles are carried out, meeting the corrosion resistance coefficient of strength test for concrete as 0.85.

2.2 Test Method

Concrete slump is controlled in 140~180mm. On the basis of Ordinary Portland Cement Concrete (OPCC) ratio, concrete with mineral admixtures is prepared with equivalent mineral admixtures replaces partial cement. Epoxy resin is used for left and right surface of specimens for preservative treatment, after drying it will be immersed in solution (water or simulative acid rain), followed by etching of wetting-drying alternating cycles. Wetting-drying cycle system is as follows: after the specimen is immersed in the solution for 1d, and then naturally drying at about 25□ for 1d, and this is one cycle. In immersing process, PS-□ type acidimeter is used for daily real-time monitoring PH value of the solution, if PH value of the solution is changed, the dilute nitric acid should be used to adjust it to original acidity, each two times' wetting-drying alternating cycles should replace the solution.

According to the typical ion and acidity composition of Chinese acid rain, the simulated acid rain is prepared with concentrated sulfuric acid, ammonium sulfate, magnesium sulfate, and other analytical reagents, but in order to accelerate the corrosion rate, partial ion concentration is increased, wherein the concentration of SO_4^{2-} is 0.01mol/L. Simulated acid rain PH = 2.0.

The modulus of elasticity of relative surface of concrete Ers:

$$E_{rs} = \frac{E_{sa}}{E_{SW}} \quad \text{... (1)}$$

In which, Esa and Esw are respectively the surface elastic modulus (GPa) of concrete in simulated acid rain and in water after the same corrosion time t.

The dynamic modulus of elasticity of concrete Erd:

$$E_{rd} = \frac{E_{da}}{E_{dw}} \quad \text{... (2)}$$

In which, Eda and Edw are respectively the dynamic modulus of elasticity (GPa) of concrete in simulated acid rain and in water after the same corrosion time t.

2.3 Test Plan and Basis

Test mix design includes 5 strength grades (namely, C20, C30, C35, C40 and C45). C20 strength grade is only used for anti-sulfuric corrosion test, and mainly used for comparison with test result of other strength grades. Fly ash grade selects I level. Each proportion of mixture of anti-sulfate test wetting-drying cycle is 150 times. Test is carried out according to GB/T50082-2009 and the related specifications.

3. Results and analysis of anti-sulfate corrosion test

3.1 Performance of Concrete

In the prepared concrete specimens, the basic properties of each proportion of mixture concrete are shown in Table 1 to Table 4, from which can see that the main performance of each prepared strength grade concrete can meet the basic requirements, but when there are more slag content, the flowability of concrete of low strength grade will become poor (such as concrete C30, as in Table 1). For concrete with lower

Table 1 Basic property of C30 ordinary Portland concrete

Type	Amount of water reducer/%	Slump/ mm	Performance
Ordinary concrete (A)	0.65	180	Slight segregation, bleeding
With 10% fly ash (B)	0.55	100	No segregation, no bleeding, good cohesiveness
With 20% fly ash (C)	0.55	160	Slight segregation, bleeding
With 30% S75 slag (E)	0.60	40	Poor flowability
With 20% S75 slag (D)	0.60	75	Poor flowability
With 30% S95 slag (F)	0.60	75	Poor flowability

Table 2 Basic property of C35 ordinary Portland concrete

Type	Amount of water reducer/%	Slump/ mm	Performance
Ordinary concrete (A)	0.60	65	Poor flowability
With 10% fly ash (B)	0.55	65	Poor flowability
With 20% fly ash (C)	0.55	60	Poor flowability
With 30% S75 slag (E)	0.60	90	No segregation, no bleeding, good cohesiveness
With 20%S75 slag (D)	0.60	120	No segregation, no bleeding, good workability
With 30%S95 slag (F)	0.65	125	No segregation, no bleeding, good workability

TABLE 3 BASIC PROPERTY OF C40 ORDINARY PORTLAND CONCRETE

Type	Amount of water reducer/%	Slump/ mm	Performance
Ordinary concrete (A)	0.55	70	Poor flowability
With 10% fly ash (B)	0.55	130	No segregation, no bleeding, good workability
With 20% fly ash (C)	0.55	160	No bleeding, good flowability, poor cohesiveness
With 30% S75 slag (E)	0.60	150	No segregation, no bleeding, good workability
With 20% S75 slag (D)	0.60	175	Slight segregation, good flowability, poor cohesiveness
With 30% S95 slag (F)	0.65	190	No segregation, no bleeding, good flowability, poor cohesiveness

TABLE 4 BASIC PROPERTY OF C45 ORDINARY PORTLAND CONCRETE

Type	Amount of water reducer/%	Slump/ mm	Performance
Ordinary concrete (A)	0.60	150	No bleeding, no segregation, good workability
With 10% fly ash (B)	0.55	150	No bleeding, no segregation, good workability
With 20% fly ash (C)	0.55	160	Slight segregation, poor cohesiveness
With 30% S75 slag (E)	0.60	150	Slight segregation, poor cohesiveness
With 20% S75 slag (D)	0.60	175	Slight segregation, bleeding, good flowability, poor cohesiveness
With 30% S95 slag (F)	0.65	190	Slight segregation, bleeding, good flowability, poor cohesiveness

TABLE 5 PERFORMANCE OF CONCRETE UNDER DIFFERENT STRENGTH GRADE (FLY ASH CONTENT IS 40%)

Type	Slump/mm	Performance
C20 Fly ash content 40%	180	Good workability
C30 Fly ash content 40%	200	Slight segregation, bleeding
C30 Fly ash content 20%, Mineral powder content 20%	200	Good workability
C35 Fly ash content 40%	210	Good workability
C40 Fly ash content 40%	200	Good workability

strength grade, more fly ash dosage can also meet performance requirements (Table 5).

3.2. BRITTLENESS COEFFICIENT OF CONCRETE

The mixture of slag and fly ash makes brittleness coefficient of cement mortar significantly reduced, and with the dosage increased, brittleness coefficient has the trend of decrease which is in favor of reducing the tendency of mortar and concrete crack. The brittleness coefficient of cement mortar with slag – dosage relation is shown as Fig.1. The brittleness coefficient of cement mortar with fly ash – dosage relation is shown as Fig.2.

3.3 ANTI-SULFATE CORROSION TEST OF CONCRETE

All obtained in accordance with the above principles each proportion of mixture concrete 28d compressive strength result and 150 times wetting-drying cycles sulfate attack compressive strength result are shown in Table 6 to Table 9, while 150 times sulfate attack strength and 28d strength ratio are provided (shown in percentage).

Table 6 to Table 9 show the compressive strength and the strength degradation trends of different strength grade concrete that are mixed with different fly ash or mineral powder, and are through 150d sulfate wetting-drying cycles.

3.4. STRENGTH COMPARISON OF PORTLAND CEMENT AND SLAG FLY ASH CEMENT EXPOSURE IN DIFFERENT ACID SOLUTION

It can be discovered from the test that Portland cement and slag fly ash cement are insensitive to mineral acids such as hydrochloric acid, nitric acid, sulfuric acid, etc., and the results are shown in Figs.3 and 4.

As can be seen, for fly ash, the mixed 10% fly ash can meet the sulfate resistance index of each strength grade of the concrete. When the fly ash content in concrete increased to 20%, specimen strength of C30, C35 and C40 after 150 times sulfate attack is in line with the durability design requirements.

However, when fly ash content of C45 specimen is 20%, its strength after 150 times sulfate wetting-drying cycles is greatly declined, failed to meet the standard requirements. For S95 mineral powder, in high-strength concrete (C40, C45) content of 30%, still can meet the sulfate resistance performance indicators of concrete. However, in lower strength concrete (C30, C35), specimen strength after 150 times sulfate attack has been less than 70%, failed to meet the standard requirements. For S75 mineral powder, dosage more than 10%, specimen strength after 150 times sulfate attack has been less than 70%, failed to meet the requirements, and is not recommended.

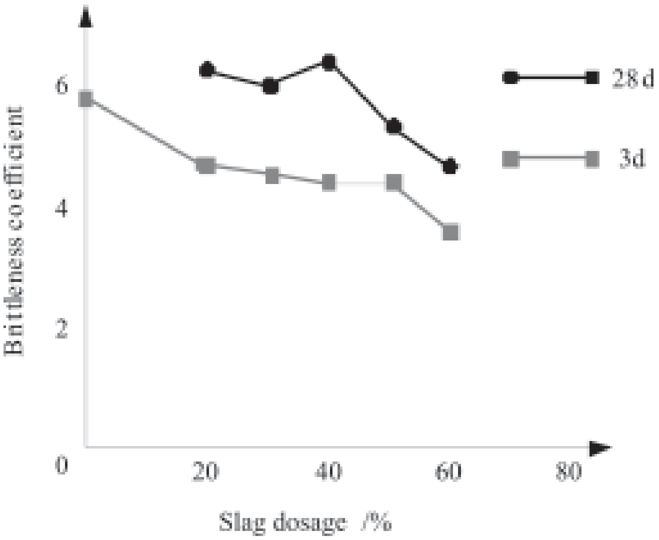

Fig.1 Brittleness coefficient of cement mortar with slag – dosage relation

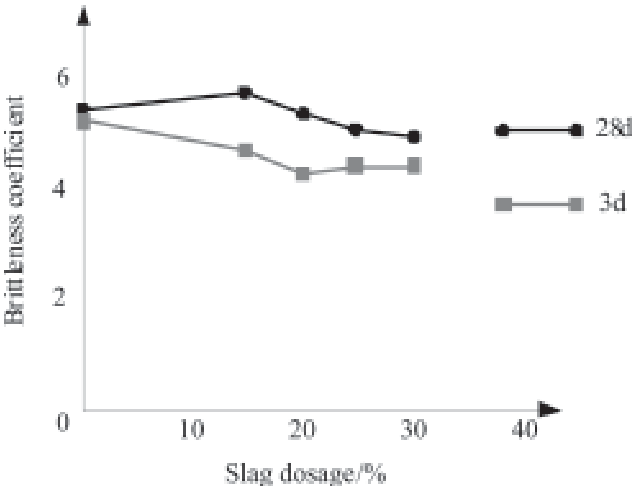

Fig.2 Brittleness coefficient of cement mortar with fly ash – dosage relation

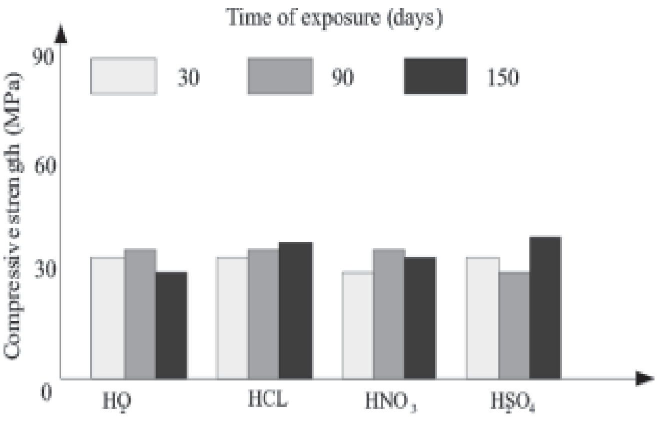

Fig.3 Strength of Portland cement after exposure in mineral acid solution (pH = 3)

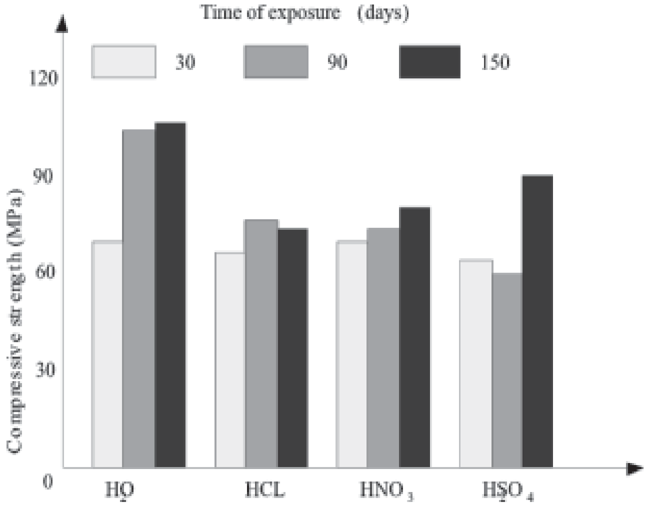

Fig.4. Strength of alkali activated slag cement after exposure in mineral acid solution (pH = 3)

In addition, in the proportion of mixture of each strength grade, the sulfate resistance of concrete with fly ash is much better than the one with mineral powder. But with the increase of admixture content, the sulfate resistance of specimen decreased slightly. For anti-sulfate, the sequence of optimizing mineral admixtures is: fly ash> S95 slag > S75 slag.

Based on the above results, the author believes that for the area with serious sulfate attack, fly ash content of concrete should be limited to 20%, S95 slag should not exceed 30%, S75 slag has great impact on concrete sulfate resistance, so it is recommended to avoid using or use a smaller dosage.

4. Conclusion

According to the test results, the following conclusions can be made:

(1) The sulfate attack damage of concrete with mineral admixtures is mainly expansive destruction caused by SO_4^{2-}.

(2) Concrete mixed with a certain amount of fly ash is still able to meet the mechanical properties and durability. Mixed with 10%, 20%, 30% fly ash can meet the sulfate resistance index of each strength grade concrete, that is, the specimen strength after 150 times sulfate attack are in line with the durability design requirements.

(3) In the proportion of mixture of each strength grade, the sulfate resistance of concrete with fly ash is much better than the one with mineral powder. But with the increase of admixture content, the sulfate resistance of specimen decreased slightly.

(4) For anti-sulfate, the sequence of optimizing mineral admixtures is: fly ash> S95 slag > S75 slag. For the area with serious sulfate attack, fly ash content of concrete should be limited to 20%, S95 slag should not exceed 30%, and S75 slag has great impact on concrete sulfate resistance, so it is recommended to avoid using or use a smaller dosage.

TABLE 6 COMPRESSIVE STRENGTH OF C30 CONCRETE AFTER SULFATE ATTACK

Test piece name	28d Compressive strength/ MPa	Compressive strength after 150 times sulfate attacks/MPa	MPa intensity ratio of after 150 times sulfate attacks and 28d/%
C30 doping	55.08	-	-
C30 Fly ash content 10%	55.21	-	-
C30 Fly ash content 20%	47.56	37.15	78.1
C30S75 Mineral powder content 10%	53.17	34.63	65.1
C30S75 Mineral powder content 30%	50.76	27.40	54.0
C30S95 Mineral powder content 30%	54.46	33.17	60.9

TABLE 7 COMPRESSIVE STRENGTH OF C35 CONCRETE AFTER SULFATE ATTACK

Test piece name	28d Compressive strength/ MPa	Compressive strength after 150 times sulfate attacks/MPa	MPa intensity ratio of after 150 times sulfate attacks and 28d/%
C35 doping	59.77	-	-
C35 Fly ash content 10%	57.50	-	-
C35 Fly ash content 20%	56.10	41.76	74.4
C35 S75 Mineral powder content 10%	56.17	39.00	69.4
C35 S75 Mineral powder content 30%	52.33	29.12	55.6
C35 S95 Mineral powder content 30%	55.17	35.22	63.8

TABLE 8 COMPRESSIVE STRENGTH OF C40 CONCRETE AFTER SULFATE ATTACK

Test piece name	28d Compressive strength/ MPa	Compressive strength after 150 times sulfate attacks/MPa	MPa intensity ratio of after 150 times sulfate attacks and 28d/%
C40 doping	66.37	-	-
C40 Fly ash content 10%	64.63	-	-
C40 Fly ash content 20%	55.33	45.85	82.9
C40 S75 Mineral powder content 10%	63.00	42.28	67.1
C40 S75 Mineral powder content 30%	53.10	40.79	76.8
C40 S95 Mineral powder content 30%	53.03	43.12	81.3

TABLE 9 COMPRESSIVE STRENGTH OF C45 CONCRETE AFTER SULFATE ATTACK

Test piece name	28d Compressive strength/ MPa	Compressive strength after 150 times sulfate attacks/MPa	MPa intensity ratio of after 150 times sulfate attacks and 28d/%
C45 doping	69.35	-	-
C45 Fly ash content 10%	63.98	-	-
C45 Fly ash content 20%	61.61	46.89	76.1
C45 S75 Mineral powder content 10%	64.66	41.01	63.4
C45 S75 Mineral powder content 30%	61.32	38.43	62.7
C45 S95 Mineral powder content 30%	56.09	42.43	75.6

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