DURABILITY OF LOW STRENGTH CONCRETE WITH HIGH VOLUME FLY ASH SUBJECTED TO SULFATE ATTACK

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Abstract

Based on the simulating actual sulphate ambient, experiments were carried out to investigate the variations of compressive strength, dynamic elastic modulus and mass of low strength concrete with high volume fly ash under immersing into sodium sulfate solution. And the related mechanisms were discussed. Results indicate that the compressive strength, dynamic elastic modulus and the mass change of low strength concrete were influenced greatly by sulfate solution immersion condition, water to binder, fly ash to cement ratio. Compared with immersion in pure water condition, the compressive strength and dynamic elastic modulus of concrete at corresponding ages is larger under immersion in sodium sulfate solution. The mass of concrete sample increased with the increasing immersion age in investigated age. It follows that low strength concrete with high volume fly ash under sulfate solution immersion condition is durable.

1. INTRODUCTION

Low strength concrete is increasingly used as groundwork of great engineering structure, such as high speed railway, passenger transport special railway line and large-scale reinforcement concrete structure and etc., which can improve effectively the load-bearing capability of foundation[1]. For the sake of economics consideration, a high volume by-product such as fly ash is added into this low strength concrete. For example, cement fly ash gravel mixture denoted as CFG, a typical low concrete, is usually applied to strengthen the foundation of great project[2~3]. These foundations usually serve in deleterious ambient including groundwater with sulfate salt, carbonate salt and etc. Especially in Southwest and Northwest of China, there is a wide range of sulfate salt contaminated environment where exists a relative high concentration sulfate ion in groundwater. It is well known that sulfate salt has a bad effect on cement-based materials [4~6]. However little information was reported on the degradation of underground low strength cement-based materials groundwork serving in ambient with sulfate salt. It is indispensable to investigate the durability of low strength with high volume fly ash subjected to sulfate attack.
2. EXPERIMENTAL DETAILS

2.1 Raw materials

ASTM Type CEM I Portland cement used, denoted as P.O 32.5 according to Chinese National Standard, was from XiangXiang Cement Plant of Hunan Province. Graded II fly ash (FA) produced by Xiangtan Power Plant was used. The specific area of fly ash is 480 m²/kg. The chemical properties and compositions of cement and fly ash was listed in Table 1. The crushed stone with a size of 5mm~31.5mm was used as coarse aggregate of concrete. The packing density and apparent density of crushed stone is 1550 kg/m³ and 2700kg/m³, respectively. Limestone chippings with a size of 0.08~5mm and a fineness modulus of 3.58 was used as fine aggregate. The content of particles with a size of less 0.15mm is 4.3%. The apparent density of limestone chippings is 2680kg/m³.

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<th>Table 1 the chemical compositions of cement and fly ash / % by mass</th>
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<td>Fly ash</td>
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2.2 Sample preparation and testing method

The low strength concretes with different fly ash content and different water to binder(cement and fly ash) ratios were designed and prepared by experiments. The mix proportions of concrete samples was listed in Table 2.

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<th>Table 2 mix proportions of concrete samples</th>
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Mixture was mixed in a forcible mixer. And the fresh mixture was molded into a size of 100mm×100mm×100mm and 100mm×100mm×300mm by use of stainlessness steel mold. The sample was demolded at about 48 hours. Then the initial weight, transverse basic frequency and dimensions of sample with a size of 100mm×100mm ×300 mm was measured by apparatus at 2 day age. And finally the sample was placed into a container with sodium sulfate solution of a concentration of 5% and pH= 5 and pH=7, respectively. And the...
weight, basic frequency and dimension of sample was measured again at interval specified immersion age. The dynamic elastic modulus of sample was calculated according to Chinese National Standard GBJ82-85. The compressive strength of sample with a size of 100mm × 100mm × 100mm was tested in terms of Standard of experimental method of mechanical properties for ordinary concrete (GB/T50081-2002).

In order to simulate the actual ambient with sulfate media, two sodium sulfate solutions, 5% concentration by mass and pH=5 and 5% concentration and pH=7, were prepared respectively by use of pure Na₂SO₄ and H₂SO₄ agent and distilled water. The sulfate solution was filled into a plastic container. The container was placed in a room with 20±3°C temperature and covered with plastic film.

3 RESULTS AND DISCUSSION

3.1 Changes of strength and dynamic elastic modulus under different conditions

3.1.1 Effects of water to binders

Figure 1 gave the result of variation of compressive strength of sample with water to binder ratio (w/b) under different immersion conditions at 28d age, serial A1~A3 in Table 2 is the corresponding mix proportions of samples.

![Figure 1: effects of w/b on compressive strength and dynamic elastic modulus of sample under different condition](image)

The result shown in Figure 1a indicates that the compressive strength of sample decreases with the reducing w/b under three immersion conditions. It is obvious that the porosity of concrete increases with the increasing water to binder ratio. And thus the strength of sample decrease. In addition, the most noteworthy that the compressive strength of sample immersing in sodium sulfate solution with a concentration of 5% and pH=5.0 is higher compared with that of samples immersing the other two solutions. The may be the activation effect of acidity sulfate solution on fly ash and thus improve the strength of sample [7].

The results given in Figure 1b shows that the dynamic elastic modulus for three concretes increase with the increasing immersion age under sodium sulfate solution with a concentration of 5% and pH=7 condition. And the dynamic elastic modulus of sample...
increases rapidly within 14 days immersion ages and then increases slightly with the increasing ages. Moreover, the dynamic elastic modulus of samples increases with the decreasing w/b.

3.1.2 Effects of fly ash to cement ratio

The results of fly ash to cement ratio affecting the compressive strength and dynamic elastic modulus of specimens under different immersion conditions were shown in Figure 2, the mix proportions for corresponding samples was listed in Table 1 as serial B1~B4.

One can see that, from the results given in Figure 2, the compressive strength and dynamic elastic modulus of samples decrease with the increasing fly ash to cement ratio (F/C) under two immersion solutions conditions at 28 day immersion age. And the dynamic elastic modulus of sample slight decrease with increasing F/C ratio when F/C is less 1.1. However, the immersion solution condition has a remarkable effect on compressive strength. The compressive strength of sample immersing into sulfate solution with a concentration of 5% and pH=7 is more than that of sample immersing in pure water. Under two immersing solution condition the dynamic elastic modulus of samples with different F/C ratio is almost the same at 28 day age.

Figure 2: Effects of fly ash to cement ratio on compressive strength and dynamic elastic modulus of samples at 28 day immersion ages

3.1.3 Effect of solution type on dynamic elastic modulus of sample

Figure 3 was the variation of dynamic elastic modulus of serial A2 specimen under three type immersion solutions conditions at different ages, the initial dynamic elastic modulus of sample was measured at 2 days. From the experimental results given in Figure 3, it can be found that under three immersion solutions conditions, the increasing rate of dynamic elastic modulus of sample increases rapidly within 14 day immersion age and then the increases slightly when the immersion age further extended. Compared with the initial dynamic elastic modulus at 2 day age, the increasing rate of dynamic elastic modulus of sample is up to about 100% when the immersion age reached about 14 day. In addition, the dynamic elastic modulus of sample was affected greatly by immersion solutions condition. Among the three immersion solutions, under pure water immersion condition the dynamic elastic modulus of
sample is smallest and is largest under sodium sulfate with a concentration of 5% and pH=5 for all investigated ages.

![Figure 3: Effects of immersion solution type on dynamic elastic modulus of serial A2 sample under different immersing ages](image)

3.2 Mass change of sample under different conditions

3.2.1 Effects of water to binder ratio

Figure 4 gave the mass change of specimens with different w/b ratios under Na$_2$SO$_4$ solution with a concentration of 5% and pH=7 condition. One can see that from the results given in Figure4, the mass of samples increase rapidly within 14 day immersion ages and then increases slowly with the extending age. Obviously, the mass increase of sample mainly results from the ingress of water and ion into interior of sample from solution. Furthermore the water to binder ratio affects obviously the increasing rate of mass of different samples. The higher the water to binder ratio is, especially for water to binder ratio of 0.7, the larger the increasing rate of mass of specimen is. High porosity of sample with high water to binder ratio may be responsible for the large increasing rate of mass.

![Figure 4: effect of water to binder on mass change rate of sample](image)
3.2.2 Effects of fly ash to cement ratio (F/C)

Figure 5 gave the results of mass change of samples with different fly ash to cement (F/C) ratio under immersing in 5% Na$_2$SO$_4$ solution condition. The results shown in Figure 5 indicates that the mass of all samples increase rapidly with the increasing age within 14 days immersing age and then almost keep constant when immersing age extends continually. And increasing rate of mass of sample decreases with the increasing F/C ratio within investigated immersion ages. However, the increasing rate of mass for all samples only ranges from 1% to 2% under tested conditions.

![Figure 5: effect of fly ash to cement (F/C) ratio on change rate of mass of samples](image)

3.2.3 Effects of immersion solution type

The effect of immersion solutions condition on change of mass of serial A2 sample was shown in Figure 6.

![Figure 6: effect of immersion solution type on change rate of mass of serial A2 sample](image)

From the results given in Figure 6, it can be found that there exists a similar tendency related to the mass change of sample with immersion age under three immersion solution
conditions. However, the increasing rate of mass of sample differs from each other under three immersion solutions conditions. Under immersing into sodium sulfate with a concentration of 5% and pH=7 the increasing rate of mass is largest among the investigated three immersion solutions. The increasing rate of mass of sample immersing in pure water is about the same as that immersing in sulfate solution with a concentration of 5% and pH=5.

Above results shows that the mechanical properties and the mass of low strength concrete with high volume fly ash samples are influenced comparatively by sodium sulfate solution. Compared with pure water immersion condition, the compressive strength and dynamic elastic modulus of concrete with high volume fly ash as well as the mass of sample increases under immersing into sodium sulfate solution conditions. Related reasons are discussed as followings.

3.3 Mechanisms
For the low strength concrete with high volume fly ash, its strength results from the cement hydration and the secondary hydration between fly ash and calcium hydroxide in mixture. The strength increases with the increasing age due to the hydration reaction extension. Under different curing condition, the hydration process of cement and fly ash are different. And the physicochemical action between sample and ion media in ambient also changes. When the sample is immersed into ambient solution such as sulfate solution, complicated physicochemical role between sample and solution occurs. Firstly, dynamic substance exchanges between concrete and solution occurs due to the concentration gradient of ions and other media. The hydration products such as CH will dissolve into solution if the concentration of CH in solution is not enough, the sulfate ion and water in solution will transport into concrete through capillary pore. This will result in a change of mass of sample. The ingress of sulfate ion and water into concrete is rapid because of high porosity of low concrete and thus the mass of sample increases fastly within a relative short immersion age. Secondly, hydration reaction between cement hydration products, fly ash and sulfate ion and etc. can be formed. New hydration products such as thaumasite, AFT and gypsum can be produced[4]. In addition, the sulfate can also accelerate the reactive of fly ash[7] and therefore the microstructure and mechanical properties of sample are changed. However, under pure water immersion, only water enters into concrete, the disjoining pressure of water molecule between harden cement paste will reduce the strength of concrete. Immersion in pure water the pozzolanic effect of fly ash is limited compared with that of immersing in sodium sulfate solution. The SEM photo for the microstructure of serial A2 concrete under immersing into pure water and sodium sulfate with a concentration of 5% and pH=7 are given in Figure 7. From the results given in Figure 7, one can see that, compared with immersion in pure water, the hydration products and the reaction degree of fly ash in concrete sample under immersion in 5% sulfate solution is larger. And thus the strength of concrete is higher. This experiments indicate that no obvious deterioration of low strength concrete with high volume fly ash is observed under immersing sulfate solution condition. It follows that under sulfate solution immersion condition the low strength concrete with high volume fly ash is durable.

4. CONCLUSION
1) Compared with pure water immersion condition, the compressive strength and dynamic elastic modulus of concrete with high volume fly ash immersing into sodium sulfate solution
with a concentration of 5% and pH=5 or pH=7 are larger. The compressive strength and dynamic elastic modulus of concrete decrease with the increasing water to binder ratio or with the increasing fly ash to cement ratio under three immersion condition.

2) The dynamic elastic modulus of low strength concrete with high volume fly ash under immersing in pure water or sulfate solution condition increases rapidly within 14 day immersion ages and then increases slowly with the age continuous extension. The mass of samples increases with the increasing immersing age.

3) Under sulfate solution immersion condition, no deterioration of low strength concrete with high volume fly ash is observed in investigated area.

![SEM photos](image1)

**Figure 7: SEM photo of serial A2 concrete immersing in two solutions**

**REFERENCE**


