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Effects of sulfate attack and dry-wet circulation on creep of fly-ash slag concrete

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HIGHLIGHTS

- A new test apparatus was developed using the guidelines provided by GB/T 50082-2009.
- An concrete creep test considering dry-wet circulation and sulfate attack was presented.
- A new model to predict the concrete creep under dry-wet circulation and sulfate attack was proposed.
- The stress level and dry-wet situation have most influence on the standard deviation of creep.

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ABSTRACT

Creep and sulfate erosion resistance of concrete are very important in terms of performance of concrete. It is of great interests to combine these two effects together to make a comprehensive investigation of the long-term performance of concrete. However, the research of the concrete creep under both dry-wet circulation and sulfate attack condition has rarely been reported. This paper firstly conducted experiments on the creep of concrete subjected to dry-wet cycle and sulfate attack. The test factors considered in this study include load stress level, sulfate solution concentration, immersion ways including long-term immersion (LM) and dry-wet cycle (DW). Then a creep model of concrete under sulfate corrosion was proposed considering concrete damage by mechanics theory, the prediction from the modified creep model is in good agreement with the test data. Taking into account the dry-wet cycles effects in the BP-KX model of concrete creep, the paper presented a model to predict the creep of concrete under dry-wet circulation and sulfate attack based on the creep model of concrete under sulfate corrosion. Finally, the calculated results from this new model were compared with the test data and the characteristics, shortage and applicability of this new model were also discussed.

1. Introduction

Environmental relative humidity is a main factor influencing drying creep of concrete [1]. In the aspect of concrete creep under variable environment humidity, researchers have conducted lots of studies on concrete creep under invariable humidity condition, but insufficient studies on that under dry-wet cycle.

In 1958, Hansen [2] observed that the concrete creep under the alternating ambient relative humidity is higher than that at a constant humidity. Later the test of Hansen [3] in 1960 shows that the mortar exposed to relative humidity alternating between 50 and 70 percent gives creep most as large as that at a constant relative humidity of 50 percent, but much larger than that at the average constant humidity of 60 percent. The test result indicates that creep increases when concrete is exposed to variations in relative humidity only if the load is applied prior to first drying out, and it is only the first drying that increases creep. Glucklich and Ishai [4] also concluded that creep is obviously higher under dry-wet cycle than that in normal condition. Bernhardt [5] in 1967 tested the creep of concrete specimens subjected to alternating storage in water and in dry air for varying periods between the ages of 10 and 120 days. Two features can be observed from his test results. First, after about 60 days under load, stabilization of creep can be observed. Second, in all cases where the total length of the cycle is seven days, the creep is sensibly the same regardless of the length of the wet period. Test of Al-Alusi et al. [6] in 1978 demonstrates that the increase in creep is mainly due to the first drying. Tubular specimens were used in their test and were subjected to alternating relative humidity cycles of 100 and 50 percent. After

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the third cycle of humidity change (50 days after loading), the increase in creep is negligible. In uniaxial compression, the increase in creep at the end of the first drying cycle is 7 times and 13 times the creep occurring under a constant relative humidity of 50 and 100 percent, respectively. In the aspect of theoretical research, Bazant et al. [7], based on the BP model, proposed the BP-KX creep model which describes the physical mechanism of creep under wet-dry cycle condition more rationally.

The concrete resistance to sulfate attack has been widely concerned among concrete engineering community. Sulfate attack is an important issue of the concrete durability research which involves the diffusion and transmission of environment sulfate in concrete [8,9], the reaction between sulfuric acid ion and chemical components of concrete [10], concrete damage [11] and so on. Especially for the part of concrete structures constructed in splash, tidal range and fluctuation zone which suffer from the compound effect of sulfate attack and dry-wet circulation is more serious than that soaked in sulfate solution [12].

There are few researches on the creep of concrete in corrosive solution. In the 1960s and 1970s, some researchers studied the creep of cement-based materials in different medium solutions. The mortar in mineral oil has much smaller creep deformation than that in water [13]. Hannant [14] concluded that methanol liquid has some influence on the specimen creep, but benzene liquid has not. This is because the methanol and water molecules have roughly the same diameter and medium molecular diameter is a factor that affects the concrete creep. Maxson and Achenbach [15] conducted creep test with concrete specimens placed in oil, pentane and seawater and lasted nearly 200 days. The test results show that the creep of the concrete specimens in hydrocarbons (oil and pentane) is bigger than that in seawater, due to the less free water in hydrocarbon probably. In addition, Parrott [16] carried out a creep test on cement paste in carbonization environment, the results show that the creep of cement paste suffered carbonization is 1.7 times as great as that in natural conditions after a 49 days sustained loading. Schneider and Piasta [17,18] studied the long-term deformation of concrete members loaded by axial compression in sodium sulfate solution, considering factors of stress level, sulfate solution concentration and specimen dimension. The test results presented that at the same age, the creep of concrete increases with the increasing stress level and sulfate solution concentration, and decreases with the increasing effective section size. Torrenti et al. [19] performed a test on the creep of concrete axial compression member in ammonia nitrate solution, in which the compressive stress level is 25% and the concentration of ammonia nitrate solution is 6 Mol. The test results show that the ammonia nitrate solution erosion accelerates the development of concrete damage and the creep deformation. Additionally, he proposed an empirical model for the creep of concrete in nitrate ion erosion and discussed the prediction of concrete creep in practice.

Through the above analysis, we can see that the long-term performances of concrete, different from those of the concrete in standard laboratory environment, change with sulfate erosion age. The joint action of different loading levels promotes or delays this effect. Although in practice the problems caused by creep can be found everywhere, creep prediction models have not yet considered the mutual influence of erosion ion and dry-wet circulation.

This paper firstly implemented experimental researches on the creep of concrete subjected to dry-wet cycle and sulfate attack. The test factors considered in this study include load stress level, sulfate solution concentration, immersion ways including long-term immersion (LM) and dry-wet cycle (DW). Based on the experiment, a creep model of concrete under sulfate erosion will be proposed by nonlinear regression of test data, considering concrete damage by mechanics theory. Taking into account the dry-wet cycle effect on the BP-KX model, the paper presented a model to predict the creep of concrete under dry-wet circulation and sulfate attack based on the creep model of concrete under sulfate corrosion. Finally, the calculated results from this new model were compared with the test data and the characteristics, shortage and applicability of this new model were also discussed.

2. Experimental program

In order to deeply understand the creep performance of concrete structure under the dry-wet circulation sulfate erosion environment, this paper conducted experimental study on the concrete creep under different experimental conditions, providing the basis for proposing a concrete creep calculation model considering dry-wet circulation and sulfate erosion.

2.1. Material properties

A Portland cement with a specific density of 3.1 g/cm^3 was used. The fineness modulus of the fine aggregates used in this study is 2.6. The coarse aggregates were natural crushed limestone, with size of 5–25 mm. The used FA is classified as low calcium Class II. Specific gravity of the FA is 2.4 t/m^3. The ground granulated blast furnace slag (GGBS) with the fraction passing 100 lm sieve was used in this study. Water reducer used in this investigation with a dosage of 2.0% from the total cement materials weight. The design of mixture for the concrete specimen is shown in Table 1.

Due to the testing concrete mixed with fly ash and slag, after curing for 28 d, the concrete strength will still increase. In order to weaken the effect of the strength increase on the test results, this study took the concrete specimens with 90-day curing.

2.2. Experimental parameters

The concrete creep test was designed according to Standard for Test Methods of Long-term Performance and Durability of Ordinary Concrete (GB/T50082-2009) [20]. The test factors considered in this study include load stress level (0,15% and 30%), sulfate solution concentration (1%, 5% and 10%), immersion ways: long-term immersion (LM) and wet-dry cycle (DW), so a total of 12 groups of specimens, in each group there were three specimens used to measure the concrete creep deformation. The sulfate corrosion and dry-wet circulation in actual engineering environment are slower than that in the laboratory, a total of 15 days as one dry wet circulation in this paper, that is 8 days firstly soaked in sulfate solution, then empty sulfate solution and 7 days dried in the container.

In order to present the test results clearly, the test parameters are abbreviated. For example, Compressive stress level is 15%, under long-term immersion, sulfate solution concentration is 5%, and corrosion time is 360 days, which can be represented as LM-S15-C5-D360.

2.3. Test apparatus and procedure

A new test apparatus was developed based on the guidelines provided by GB/T 50082-2009 [20]. which is shown in Fig. 1. In this study 100 × 100 × 300 mm prismatic specimen was used.

Table 1
Design of the concrete specimen mixtures.

Cement (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)	Water (kg/m^3)	Fly ash (kg/m^3)	Slag (kg/m^3)	Water reducer (kg/m^3)
296	729	1050	172	81	63	8.80