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Experimental Research on the Effect of Ground Slag on Basic Tensile Creep of Early-age Concrete

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Abstract: Tensile creep of concrete at early ages is one of the important factors that affect the stress of restrained and partly restrained concrete. But only few data are available on tensile creep of concrete. The effect of ground slag on tensile creep was studied using lever-type tensile creep tester. Early age tensile basic creep of concrete loaded at the age of 3 days was researched. Results show that concrete exhibits large creep deformation when loaded at the age of 3 days. And the addition of ground slag decreases the early age tensile creep of concrete and tensile creep of concrete decreases with the increase of the content of ground slag. But the basic rule of the development of basic tensile creep in concrete has not been changed.

Keywords: Basic tensile creep, ground slag, specific creep, concrete.

1. INTRODUCTION

Ground slag is obtained from ground melt generated in blast furnace iron making. It contains chemical components such as SiO_2, CaO, Al_2O_3, Fe_2O_3 and MnO with higher activity, which can react with cement hydration product of $Ca(OH)_2$ to generate C-S-H gel under certain condition [1]. Concrete mixed with ground slag can reduce its hydration heat and improve its strength. Currently, ground slag has been an important part of modern concrete and particularly plays a key role for the preparation of concrete and mass concrete with high strength and high performance [2]. However, with the development of concrete towards high strength and high performance, larger autogenous shrinkage will occur at early age. In case of external restraint condition, greater tensile stress will be occurred inside the concrete. The magnitude of tensile stress is related to tensile creep, autogenous shrinkage, elasticity modulus and thermal expansively of concrete [3]. When the tensile stress caused by the free shrinkage exceeds the tensile strength, the concrete will crack. The deformation capacity of tensile creep must be studied so as to analyze the cracking sensitivity of early-age concrete. However, the current research on the effect of ground slag on tensile creep of early-age concrete is less and imperfect. Therefore, this paper will mainly research on the effect of ground slag on tensile creep of concrete at early age.

2. EXPERIMENTAL RESEARCH

2.1. Raw Materials

In this paper, well-graded P·O 42.5 ordinary Portland cement produced by Jiangsu Pangu Cement Factory. Coarse aggregate is adopted with the gravel of 5 ~ 25mm, silt content is 0.2% and apparent density is 2,700kg/m³. Its grain composition is shown in Table **1**. The fine aggregate used is natural river sand with fineness modulus of 3.0, silt content is 1.2% and apparent density is 2650kg/m^3. The test results of its sieve analysis are shown in Table **2**. Polycarboxylate superplasticizer JM-PCA produced by Jiangsu Bote New Materials Co. Ltd. with water-reduction rate of over 20%, S95 ground slag produced in Nanjing is used.

2.2. Mix Proportion

The maximum content of S95 ground slag in concrete is 50% by weight of binding material in accordance with the requirements of technical regulations DG/TJ08-501-1999 for the application of granulated blast furnace slag powder in cement concrete [4]. Therefore, four mix proportions of 10%, 20%, 30% and 50% of cement are used to replace the same amount of ground slag in this paper. In order to prevent other factors from affecting the property of concrete tensile creep, an equal amount of ground slag is used to replace cement by means of fixing aggregate content, sand ratio, total cementing materials and water/binder ratio in the course of determining the mix proportions of concrete. The composition of concrete mixes is shown in Table **3**.

2.3. Experimental Device

The experiment of tensile creep was performed on a lever-type tensile creep device by which axial tensile stress is applied on the concrete specimens. The fabrication and assembly diagram for the device is shown in Fig. (**1**). Its design idea is that the load applied at A can be amplified 10 times at CD on the pull rod through the lever ABC of the beam, and then the force on the pull rod can be amplified 3 times again at the two-force rod of DEF, so the load transmitted to the concrete specimen is 30 times of the weight of the balance weight at A [5]. The lever-type tensile creep device is characterized by simple structure, stress with larger amplification coefficient and stable load.

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Table 1. Test results of coarse aggregate sieve analysis.

Mesh Size（mm）	26.5	19	16	13.2	9.5	4.75
Grader retained percentage (%)	0	7.9	20.1	39.4	30	2.4
Accumulated retained percentage (%)	0	7.9	27.8	67.4	97.4	99.8

Table 2. Test results of fine aggregate sieve analysis.

Mesh Size（mm）	5	2.5	1.25	0.63	0.315	0.15
Grader retained percentage (%)	9	16.4	20.4	11	35	7
Accumulated retained percentage (%)	9	25.4	45.8	56.8	91.8	98.8

Table 3. Composition of concrete mixes.

Test No.	Composition of Concrete Mixes（kg/m^3）						w/b Ratio
	Water	Cement	River Sand	Gravel	Slag	Water Reducer	
RC	195	488	601	1116	0	1.952	0.40
A	195	439.2	601	1116	48.8	1.952	0.40
B	195	390.4	601	1116	97.6	1.952	0.40
C	195	341.6	601	1116	146.4	1.952	0.40
D	195	244	601	1116	244	1.952	0.40

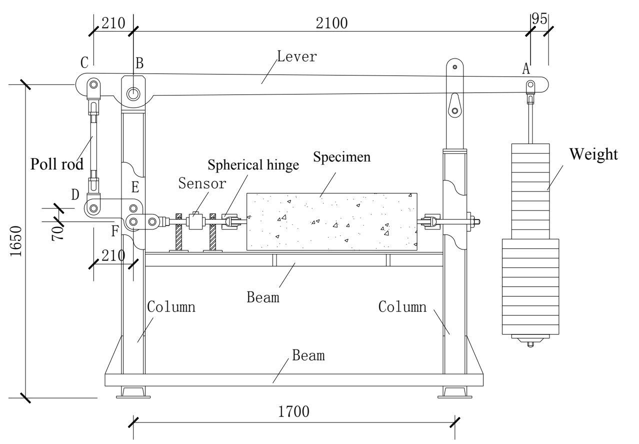

Fig. (1). Schematic diagram for lever-type device for tensile creep experiment.

2.4. Fabrication of Tensile Creep Specimen and Experimental Method

The size of concrete specimen for tensile creep is 100mm × 100mm × 515mm. Pull rods are embedded at both ends of the specimen for applying tensile force. The deformation is measured by contact displacement meter. Before pouring concrete, the pull rods and the deformation measuring stents are embedded to fix on the testing molds with the distance of 200mm between deformation measuring stents. The concrete specimens are immediately covered with polyethylene film after vibrated and compacted. And then these specimens were placed in curing room until mold removal at the age of 1 day. To prevent water from exchanging with outside, the specimens will be immediately sealed after test molds removal so that it will be in the state without moisture exchange with outside. Autogenous shrinkage was also occurred besides tensile basic creep whiles the concrete is under external tensile force. Therefore, in order to obtain accurate values of basic tensile creep, the free deformation of shrinkage-compensating specimen must be considered. Method of preparation of autogenous shrinkage specimens was same as the tensile creep specimens. The mold-removal specimen is immediately placed in the creep test room at the temperature of 20±2□ after being sealed for measuring free shrinkage deformation. The splitting tensile strength is tested at the age of 3 days to determine the applied load on the specimen of concrete creep, and the stress applied on the tensile creep specimen is about 0.4 times of splitting tensile strength. The size of concrete specimen of splitting tensile strength is 150mm×150mm×150mm. The specimens are covered with polyethylene film after pouring then placed in a curing room at standard temperature for curing, and splitting tensile strength is tested at the age of 3 days. The displacement meter is installed after the creep specimens are mounted in the lever-type tensile creep tester and the tensile stress is applied on the tensile creep specimens for 7 days. During the experiment, the applied load as well as the readings of displacement meter are recorded before and after loading, recorded them at 1h, 6h, 12h and 24h after loading, and then recorded every 12h from 2 days until the end of the experiment. The deformation of shrinkage-compensating specimen is also observed while observing the deformation of creep specimen.

3. EXPERIMENTAL RESULTS

3.1. Effect of Ground Slag on Splitting Tensile Strength

At the age of 3 days, the splitting tensile strength of concrete specimen is tested on the compression-testing machine. The splitting tensile strength of concrete with different ground slag content at the age of 3 days is shown in Fig. (**2**). As can be seen from Fig. (**2**), the strength of mix A～D at the age of 3 days is less than that of reference concrete. This is because the activity of ground slag is less than that of cement, so the initial reaction rate of concrete mixed with ground slag is less than reference concrete, and the splitting tensile strength of concrete gradually decreases with the increase in the mixing amount of ground slag at the age of 3 days.

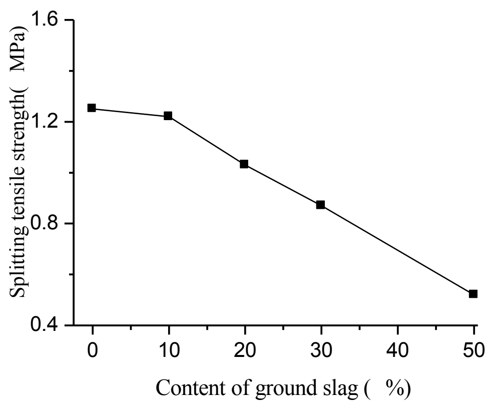

Fig. (2). Effect of ground slag on splitting tensile strength of concrete.

3.2. Effect of Ground Slag on Elasticity Modulus of Concrete

The tensile modulus of elasticity of early-age concrete is obtained from the early elastic stage of tensile creep test. Fig. (**3**) shows the elasticity modulus of concrete with different ground slag content at the age of 3 days. As can be seen from Fig. (**3**), the elasticity modulus of concrete gradually decreases with the increase of the content of ground slag at the age of 3 days. The elasticity modulus of concrete with mix A～D is 97.3%, 95.0%, 90.7% and 77.3% of reference concrete respectively. This is because the activity of ground slag is lower, and only a few ground slag participates in the hydration reaction before 3 days, which slows down the hydration process of cementing materials. Therefore, the hydration products in the concrete per unit volume is less, the structure of hardened cement is relatively loose, so that the elasticity modulus of concrete is significantly reduced.

3.3. Effect of Ground Slag on Autogenous Shrinkage of Concrete

The deformation of shrinkage-compensating concrete is measured on the condition that no humidity exchanges with outside, which includes autogenous shrinkage deformation and temperature deformation. However, the internal temperature of the concrete with age greater than 24h is basically unchanged due to a smaller cross-sectional size of concrete specimens. Additionally, the experiment is conducted at the temperature of 20±2°C, so the deformation of shrinkage concrete specimens measured under sealed condition after 1 days can be regarded as autogenous shrinkage deformation. The effect of ground slag on autogenous shrinkage of concrete within the ages of 1~ 10 days is shown in Fig. (**4**). It can be seen from Fig. (**4**) that the values of autogenous shrinkage of concrete mixed with ground slag are greater than that of reference concrete, and autogenous shrinkage gradually increases with the increase of content of ground slag. The values of autogenous shrinkage of concrete with mix A～D within 1~10 days are increased by 5%, 11.2%, 16.6% and 24.9% of reference concrete respectively. This can be explained by that chemical reduction rate of pozzolanic reaction of ground slag is greater than the reaction of cement hydration after 1 day, meanwhile, the pozzolanic activity of ground slag promotes the consumption of water under sealed conditions, so the internal self-drying process can be accelerated and the pore radius is decreased. Therefore, the autogenous shrinkage of concrete gradually increases with the increase of the content of ground slag.

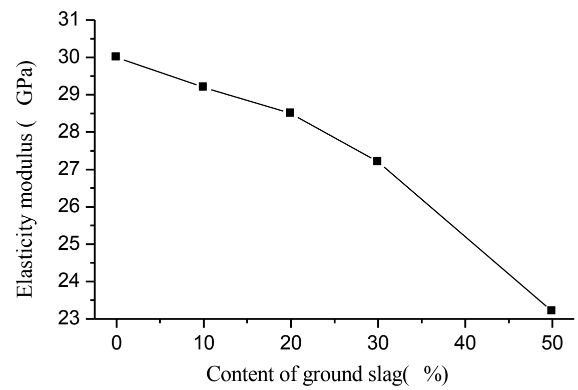

Fig. (3). Effect of ground slag on elasticity modulus of concrete.

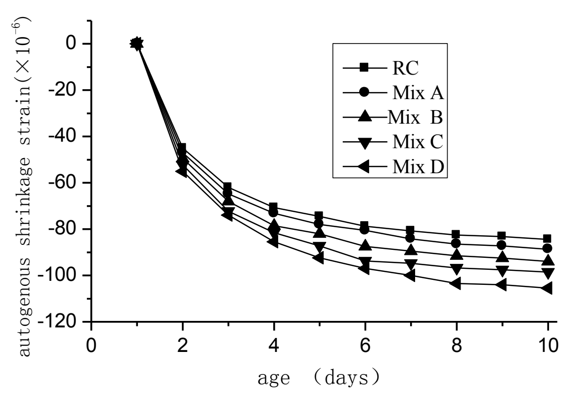

Fig. (4). Effect of ground slag on autogenous shrinkage of concrete.

3.4. Effect of Ground Slag on Tensile Creep of Concrete

According to the results of splitting tensile strength, the average stress applied on concrete with ground slag content of 0%, 10%, 20%, 30% and 50% is 0.931MPa, 0.921MPa, 0.743 MPa, 0.75 MPa and 0.65 MPa respectively, which is equivalent to 39.0%, 40.8%, 38.9%, 41.9 % and 40.4% of splitting tensile strength at the age of 3 days.

Fig. (**5**) shows the effects of ground slag on specific creep of concrete.

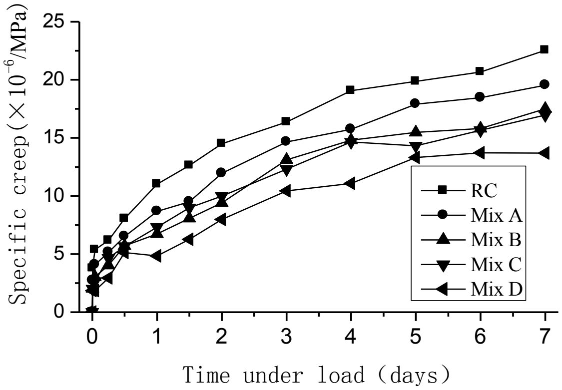

Fig. (5). Effect of ground slag on specific creep.

The following conclusions can be drawn from Fig. (**5**): (a) the specific creep of concrete with different ground slag content is characterized by faster development within 12h after loading and gradually slows down after 12h, which indicates that the mixing of ground slag does not change the basic rule of the development of concrete specific creep; (b) although the specific creep of concrete with ground slag content of 20% in the initial loading is less than that of concrete with ground slag content of 30%, after the load is applied for 3 days, the specific creep of concrete with ground slag content of 20% is greater than that of concrete with ground slag content of 30%, which may be due to an unexplained error in the experiment. So it can be said that the specific creep of concrete gradually decreases with the increase of the content of ground slag. The specific creep of concrete with ground slag content of 10%, 20%, 30% and 50% after continuous loading for 7d is 86.8%, 77.6%, 75.3% and 60.7% of reference concrete respectively.

4. MECHANISM ANALYSIS OF THE EFFECT OF GROUND SLAG ON TENSILE CREEP OF CONCRETE

The creep theory of micro-crack holds that the deformation of concrete creep is caused by the development of micro-cracks [6]. Micro-cracks are likely to appear on the surface of aggregate due to aggregate settlement, precipitation of mixing water and stress generated by drying shrinkage in the hardening process of concrete before load is applied on it. In the effect of tensile stress, micro-cracks may occur in the initial imperfection when the stress-strength ratio is 0.2 or less. The tensile stress field is unstable, so the development of crack size is inversely proportional to the number and length of cracks in the concrete. Since ground slag has higher specific surface area and good water retention, so it can significantly improve the cohesiveness and bleeding of concrete [7]. At the same times it can improve the mechanical performance of the interfacial transition zone between cement paste and aggregate and reduce the initial micro-cracks in the concrete as well as the length of the initial micro-cracks. Therefore, concrete mixed with ground slag can reduce its basic tensile creep based on the micro-crack mechanism.

The creep theory of interlayer slippage considers that concrete creep is caused by the slippage between cement gel. Cement gel has layered structure similar to that of tobermorite. Each particle of cement gel is bound by interactional molecular force, and most of absorbed water and bound water are contained in the gel. When shear stress is applied on the concrete specimens, slippage may occur between the adjacent C-S-H layers. The difficulty degree of the slippage depends on the Van der Waals force between the particles as shown in Fig. (**6**). SiO_2 and Al_2O_3 with pozzolanic characteristic in ground slag react with $Ca(OH)_2$, stable hydrated calcium silicate and hydrated calcium aluminate are produced, and the concentration of $Ca(OH)_2$ and the formation of large lattice of $Ca(OH)_2$ are decreased. Meanwhile, the ground slag absorbs a lot of $Ca(OH)_2$ crystals in the second hydration reaction, so the number and size of $Ca(OH)_2$ crystals in the interface of concrete are reduced, which can improve the bonding strength of interface between cement paste and aggregate [8] and increase the Van der Waals force between each particle of cement gel in the concrete. The particles of C-S-H gel are not easy to move, thereby the tensile creep of concrete decreases with the increasing of ground slag content.

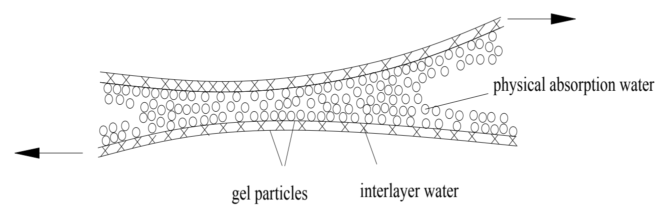

Fig. (6). Schematic diagram for interlayer slippage theory.

CONCLUSION

The splitting tensile strength and tensile elasticity modulus of concrete gradually decrease with the increasing of ground slag content at the age of 3 days, but the autogenous shrinkage of concrete within 1~10 days gradually increases with the increasing of the content of ground slag. The mixing of ground slag can reduce the tensile basic creep of concrete, and the tensile creep gradually decreases with the increase of ground slag content, but the basic rule of the development of basic tensile creep in concrete has not been changed.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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