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Mechanical properties, drying shrinkage, and creep of concrete containing lithium slag

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HIGHLIGHTS

- Experimental result is presented on mechanical properties of concrete with lithium slag.
- Addition of lithium slag can improve the compressive strength of matured concrete.
- Addition of certain amount of lithium slag can reduce drying shrinkage and creep.
- Addition of about 20% lithium slag in binder gives the lowest specific creep.

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ABSTRACT

This paper presents an experimental study on the compressive strength, elastic modulus, drying shrinkage, and creep of concrete added with lithium slag as a supplementary cementitious material. The effects of the lithium slag on these mechanical properties were examined experimentally by using specimens with different lithium slag contents (0%, 10%, 20% and 30% of binder). In addition, mercury intrusion porosimetry and scanning electron microscope techniques were also used to investigate the pore microstructure of the concretes with different lithium slag contents to support the findings obtained from the mechanical property tests. It was shown that, the addition of lithium slag in concrete can improve the mechanical properties of matured concrete, including the compressive strength, elastic modulus, drying shrinkage and creep, if the right amount of lithium slag is used.

1. Introduction

Efforts have been made in recent decades to develop "green" concretes containing industrial waste [1–4]. It is well known that in such green concretes cement has been partially replaced by industrial and/or agricultural byproducts such as fly ash, ground granulated blast furnace slag, metakaolin, rice husk ash, etc., which are considered as supplementary cementitious materials (SCMs). The replacement of cement by using SCMs not only decreases the landfills of waste materials and their associated environmental impacts, but also reduces the carbon footprint of concrete. In general, SCMs can be used to improve the mechanical properties of concrete, either in fresh or hardened mixtures [5–8]. In addition, using SCMs can also decrease the cost of construction while providing "green" concrete with comparable mechanical properties. Therefore, SCMs are widely used in concrete either in blended cement or added separately in concrete mixtures [9–11]. The continuously increasing demand of SCMs used in concrete results in the great shortage of traditional SCMs. Therefore, there is a need to find new types of SCMs which can be used in concrete.

In China, a great amount of lithium slag (LS) is discharged as a byproduct in the process of the lithium carbonate using sulfuric acid method when the spodumene ore is calcined at high temperature of 1200 °C. The main formation process of LS is shown in Fig. 1.

According to the statistical analysis [12], about nine tons of LS are discharged when one ton lithium salt is produced in the production process of lithium carbonate. Today, about 8×10^5 tons of LS are discharged every year in China. The disposal of such large quantities of LS not only results in the shortage of landfills but also causes serious environmental pollution problem. Therefore an urgent task is to find an efficient way to recycle the disposed LS. Considering the grindability and certain pozzolanic reactivity because of the high content of active silicon dioxide and aluminium oxide, LS may be used as a SCM in cement and concrete.

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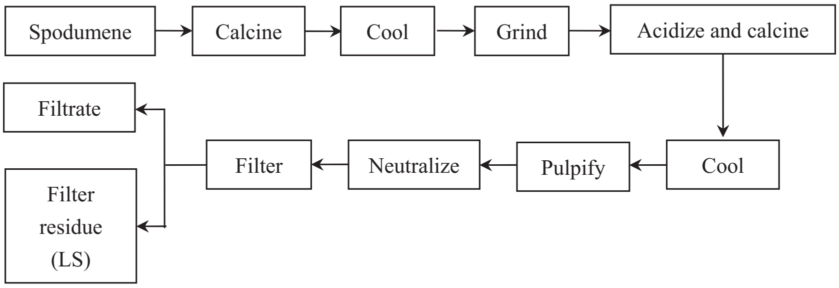

Fig. 1. Formation process of LS.

However, from a literature survey there are very limited references on the use of LS in concrete [13–15], and the effect of LS on the mechanical properties of concrete such as drying shrinkage and creep has not been discussed.

In this paper, an experimental study on the mechanical properties, drying shrinkage, and creep of concrete containing LS as a SCM is presented. The effects of LS on the compressive strength, elastic modulus, drying shrinkage, and creep of the concrete containing LS were examined using an experimental method. The mercury intrusion porosimetry (MIP) and scanning electron microscope (SEM) techniques were also used to investigate the pore microstructure of the mixed concrete to support the findings obtained from the experiments.

2. Experimental

2.1. Materials

The cement used in the present study was ordinary Portland cement of Grade P·O42.5 according to common Portland cement (Chinese GB 175-2007). The LS used was supplied by Sichuan lithium salt plant in China, whose appearance is shown in Fig. 2. It can be seen from the figure that the appearance of LS is earthy yellow.

Table 1 gives the chemical properties of the cement and LS used, which shows that the LS has far more SiO_2 and Al_2O_3, but much less CaO than the cement does. In addition, the content of SO_3 of the LS is also more than that of the cement.

The particle size distributions of the cement and LS were determined by laser particle analysis using BT-9300 Laser Particle Analyzer, which are shown in Fig. 3. It can be seen from the figure that the size range of LS particles is narrower than that of cement particles. However, in terms of the average size, LS particle is smaller than cement particle, which is demonstrated in the grading curves of cement and LS shown in Fig. 4.

Fig. 2. Appearance of LS.

The specific gravities of cement and LS are about 2910 and 2450 kg/m^3, respectively, which were determined according to the standard test method for cement density (Chinese GB/T208-2014) using the small pycnometer method. The specific surface area is about 360 m^2/kg for cement and 440 m^2/kg for LS, respectively, which were determined based on the nitrogen adsorption method. In addition, LS particles were found to be irregular in shape, which can be demonstrated in the SEM image shown in Fig. 5.

River sand was used for fine aggregates, which has a fineness modulus of 2.5 and a specific gravity of 2550 kg/m^3. Crushed limestone was used for coarse aggregates, which has a size range from 5.0 mm to 25 mm, and a specific gravity of 2660 kg/m^3. The specific gravity and the sieve analysis for both fine and coarse aggregates were done as specified in the standard for technical requirements and test method of sand and crushed stone (or gravel) for ordinary concrete (Chinese JGJ 52-2006). The polycarboxylic superplasticizer admixture with a specific gravity of 1200 kg/m^3 was used, which allows a water reduction up to 25%.

2.2. The concrete mixture proportioning

Mixture proportioning was carried out according to specification for mix proportion design of ordinary concrete (Chinese JGJ 55-2011). The targeted compressive strength was 50 MPa for the control mixture.

Four types of concrete mixtures of different LS contents (0%, 10%, 20% and 30% of binder) were used in the experiments. In all types of mixtures the binder to aggregate ratio, fine aggregate to aggregate ratio, and water to binder ratio were kept as constants, which are 0.25, 0.41, and 0.35, respectively. The superplasticizer content was adjusted to maintain a slump of 150–180 mm for all mixtures. Table 2 shows the details of the relative weight of each component used in each type of mixtures.

2.3. Test methods

Four groups of specimens were casted for each mixture. One is for the compressive strength test, in which the dimensions of the specimens are 150 mm × 150 mm × 150 mm. One is for the elastic modulus test, in which the dimensions of the specimens are 150 mm × 150 mm × 300 mm. One is for the drying shrinkage test, in which the dimensions of the specimens are 100 mm × 100 mm × 300 mm. One is for the creep test, in which the dimensions of the specimens are same with those in the drying shrinkage test.

For the compressive strength and elastic modulus tests, after mixing and casting, the specimens were kept in moulds for about 24 h at room temperature (20 ± 5) °C. After that, they were demoulded and placed in a standard curing room of controlled