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Experimental study on early cracking sensitivity of lightweight aggregate concrete

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HIGHLIGHTS

- Lightweight aggregate concrete (LWAC) has a lower cracking sensitivity than normal-weight concrete.
- Prewetted ceramsite and expansive agent can minimize early cracks.
- Partial replacement of aggregates by ceramsite reduces cracking sensitivity.
- A model is presented for the relationship between the moisture content of ceramsite and the restraining stress.

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ABSTRACT

In this study, experimental investigations are reported on the effects of the moisture content of ceramsite, the replacement rate of aggregates, and the use of expansive agent on the early cracking sensitivity of lightweight aggregate concrete. Three kinds of commercially available lightweight aggregates (clay ceramsite, shale ceramsite, fly ash-clay ceramsite) were used in the experiment. The cracking sensitivity of concrete was investigated via splitting tensile test, plate cracking test and temperature-stress test. The results showed that the cracking sensitivity of concrete decreased with the increases in the moisture content and the replacement rate of aggregates. A model describing the relationship between the moisture content of ceramsite and the restraining stress was presented.

1. Introduction

Early cracking is one of the main quality problems of concrete, especially for high-strength concrete [1]. High-strength concrete usually has significant temperature deformation [2] and self-desiccation [3,4] due to the use of low water/cement ratio (w/c) and fine supplementary cementitious materials [5], which are the main causes of early cracking [4]. In order to avoid such early cracking risk of concrete, it is necessary to prevent the decrease in internal relative humidity [6]. Although external water curing is normally adopted, the cracking of high-strength concrete still exists because of the slow penetration of water in concrete [7,8].

Ceramsite with high water absorption capacity is an efficient material to reduce the cracking potential of concrete in its early ages [6,9]. Water in saturated lightweight aggregates can be supplied to cement paste [10,11] to prevent the decrease in internal relative humidity. ICC2003-RILEM TC [12] defined this behavior as internal curing. Concrete with internal curing exhibited smaller autogenous shrinkage and creep than the normal concrete [13,14]. Desorption of ceramsite in concrete can strengthen the interfacial structure between ceramsite and cement paste matrix [4,15], thus substantially increasing the potential robustness of materials in early ages with respect to temperature changes [16,17]. Partial replacement of aggregates by lightweight aggregate can also significantly reduce self-drying and delay cracking [5,18]. Meanwhile, some valuable researches also show that the single incorporation of expansive agent can mitigate the risk of cracking induced by shrinkage [19].

However, different types of ceramsite have different moisture contents and water absorption/desorption processes [20], which will lead to different curing degrees and different cracking behaviors at early ages. The combined effects of desorption of lightweight aggregate and addition of expansive agent are also unclear. In this study, 30 groups of mixing proportions were used in splitting tensile test and plate cracking test to quantify the effects of moisture content, replacement ratio of aggregates and expansive agent on the early age cracking behavior of concrete.

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Temperature-stress experiments were also conducted to explore the development patterns of temperature and restraining stress of concrete with different mixing proportions at early ages. The effects of different ceramsite, replacement rates of aggregates and expansive agent on the cracking sensitivity of lightweight aggregate concrete, as well as the effect of moisture content of aggregates in concrete (1 m^3) on tensile stress (72 h) due to restraint were discussed.

2. Experimental scheme

2.1. Materials

Three kinds of ceramsite used in this study were Nantong ceramsite (namely, N fly ash-clay ceramsite, as shown in Fig. 1), Yichang ceramsite (namely, Y shale ceramsite, as shown in Fig. 2), and Zhengzhou ceramsite (namely, Z clay ceramsite, as shown in Fig. 3). All aggregates were prewetted for 24 h before the test. Portland cement (P·II 42.5R) from Guangzhou Zhujiang Cement Co. Ltd. and Polycarboxylate superplasticizer (SP) were adopted. The expansive agent used in the experiment was the SY-G type agent. Its restraint expansion rate in water (7 d) and in air (21 d) are 0.027 and 0.010, respectively.

2.2. Mixing proportions

All specimens were designed to have an identical water (including water presoaked by ceramsite)/cement ratio of 0.39 so that the effect of w/c ratio can be ignored. An appropriate amount of SP of around 7.29 kg/m^3 was added to obtain the desired workability. Partial normal-weight coarse aggregate was replaced by ceramsite according to different replacement ratios of coarse aggregates (100%, 70%, 50%, 30%, and 0%) to obtain various mixtures (L100, L70G30, L50G50, L30G70, and G100). The concrete without expansive agent was used as the reference specimen and the concrete with 10% expansive agent is used as the control one. The mixing proportions of the concrete are listed in Tables 1–3.

2.3. Experimental methodology

2.3.1. Test of material properties

To examine the cracking sensitivity of concrete more accurately, it is necessary to understand the basic properties of aggregates. In the present study, the compressive cylindrical strength, apparent density, packing density, and the 1 h/24 h water absorption rate of three kinds of ceramsite were tested based on China National Standard (GB/T 17431.2-2010) [21]. The apparent density of the stone was also measured in accordance with the code. Some details of the experiment are as follows:

Fig. 1. Ceramsite N.

Fig. 2. Ceramsite Y.

Fig. 3. Ceramsite Z.

1. The compressive cylindrical strength of ceramsite N, Y and Z. First, sieved the ceramsite samples of 10 mm–20 mm for 5L; then loaded up the samples in a tube and vibrated on a vibration table; next, mounted on a guide tube and a loading head (Fig. 4), the load was applied at a uniform speed 400 N/s. Finally, record the pressure value when the head ran into a depth of 20 mm (reached the first scale line). The universal testing machine WAW-1000 by Shaoxing Kent Mechanical & Electrical Co., Ltd was used.

The compressive cylindrical strength f (MPa) of ceramsite was calculated by

$$f = \frac{p_1 + p_2}{F} \quad (1)$$

where p_1 is the pressure value when the loading head ran into 20 mm (N); p_2 is the weight of the loading head 2.377 kg × 9.8 N/kg (N); F is the pressure area of the loading head 10,000 mm^2. The test was carried out 3 times and the average values were obtained. The coefficients of variation were 0.67%, 6.14% and