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Stress–strain relationship in axial compression for EPS concrete

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HIGHLIGHTS

- Stress–strain behavior of EPS concrete in uniaxial compression was observed.
- Effect of dry density and curing age on the mechanical properties was grasped.
- A stress–strain model for EPS concrete was proposed and its applicability was confirmed.

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ABSTRACT

Expanded polystyrene (EPS) concrete is an environment friendly lightweight material, which is widely used for building construction in recent years. In this study, EPS concrete with the dry density of 800–1200 kg/m^3 was made by replacing coarse aggregates with EPS beads, and its stress–strain behavior was investigated based on the axial compression tests. Then, the effect of dry density and curing age on the compressive strength as well as peak strain were observed. Finally, a stress–strain model for EPS concrete was proposed and its applicability was discussed. As a result of this study, EPS concrete showed higher compressive strength and peak strain with the increase of dry density and curing age. It was also indicated that the proposed stress–strain model agreed well with the test results and could be used for the structure analysis and design in the structural application of EPS concrete.

1. Introduction

Because of lightweight feature and good thermal properties, EPS concrete has been widely used in the construction of nonstructural and structural members, such as walls and slabs [1,2]. Especially, a new structure system named lightweight steel and lightweight concrete structure (LSLCS), which used EPS concrete as structural lightweight concrete, was proposed and applied to the building construction in China [3]. And the structural capacities of those LSLCS buildings were also evaluated based on the analytical research. Accordingly, it is necessary to clarify the material characteristic of EPS concrete such as the stress–strain relationship, since stress–strain relationship of the concrete is the foundation of structural analysis and design.

In recent years, some researchers have conducted the observation of mix proportion and basic properties for EPS concrete [4–11]. However, to the best of the authors' knowledge, little systematic studies has been conducted on the stress–strain relationship of EPS concrete. And compared with the normal concrete [12–18], almost no mathematic model was proposed for the stress–strain behavior of EPS concrete in previous researches, which is desirable for the structural analysis and design in structural applications of EPS concrete such as LSLCS buildings. Therefore, the main objective of this paper is to conduct a detailed experimental study on the stress–strain behavior and develop a stress–strain model for EPS concrete. According to the fib Model Code for Concrete Structures 2010 [12], lightweight aggregate concrete with a density under 800 kg/m^3 can usually not be used for structural applications. Hence, the stress–strain behaviors of EPS concrete with the dry density of 800–1200 kg/m^3, which were made by replacing coarse aggregates with EPS beads, were observed based on the axial compression tests. Then, the effect of dry density and curing age on the basic properties of EPS concrete was discussed. Finally, a stress–strain model for EPS concrete was proposed and its applicability was verified.

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2. Test program

2.1. Materials and mix proportions

ASTM Type I ordinary Portland cement (OPC) with a 28-day compressive strength of 42.5 MPa was used as cementitious material in the concrete mix. River sand with a fineness modulus of 2.6 was used as fine aggregate. The commercially available spherical expanded polystyrene (EPS) was used as lightweight aggregate (see Fig. 1(a)) in place of the normal coarse aggregate. Here, the grain diameter of EPS beads was mostly 3 mm and the bulk density was 16 kg/m^3. In order to obtain suitable workability, naphthalene water-reducing admixture was used.

The EPS concrete specimens were divided into six series with the parameters such as dry density (800 kg/m^3, 1000 kg/m^3 and 1200 kg/m^3) and curing age (28 days and 60 days). And there were four specimens in each series used for uniaxial compression test, three of them (test group) were used for the observation of basic properties and the proposal of stress–strain model, another one (check group) was used for the applicability verification of the proposed stress–strain model. Details of the specimen series and the mix proportions of EPS concrete are shown in Table 1.

2.2. Preparation of specimens

The fresh concrete (see Fig. 1(b)) was poured into steel molds and compacted by hand slightly. The specimens were demolded approximately 24 h later, then placed in a standard curing room at a temperature of 20 ± 2 °C and humidity of 95% until the testing age was reached. As shown in Fig. 1(c), EPS beads were distributed uniformly in the composite of EPS concrete.

According to the current Chinese National Standard GB/T50081-2002 [19] for test method of concrete, specimen size was fixed at 100 mm × 100 mm × 300 mm. In order to observe the difference of compressive strength between prism and cube, three cubes with dimension 100 mm × 100 mm × 100 mm were casted for each specimen group.

To determine the dry density of each specimen series, three test specimens were oven dried to a constant weight (60 h, 150 °C) after the test at curing age such as 28 days and 60 days. The measured dry density reported in Table 1 is the mean result of the three specimens (coefficient of variance: 0.012–0.043), and it shows a good agreement to the design dry density.

2.3. Test procedure

The stress–strain behavior was determinated by tests on the prism specimens, which were performed in a MTS electronic universal testing machine with a capacity of 300 kN. The load was controlled by displacement, and the loading rate was fixed at 0.003 mm/s. To facilitate the ball joint adjustment, the two strain gauges were attached on the middle surfaces of the two opposite sides and parallel to the longitudinal axis for every specimen. In order to ensure that the specimen was loaded uniaxially, the ball joint was adjusted until the strains recorded on the both sides were consistent. Due to the strain gauge experienced failure after specimen cracking, the strain of the full stress–strain curve was obtained by the displacement gauge.

3. Test results

3.1. Failure pattern

The failure patterns of specimens are shown in Fig. 2. The inclined cracks and vertical cracks appeared along the loading direction when approaching the peak stress. After the peak stress, the crack extended to the central section gradually with the increase of the strain. Finally, the specimen failed as the crack developed from micro to macroscopic and crossed throughout the entire specimen. It was indicated that the failure pattern was similar to those reported in previous studies [5,8]. As shown in Fig. 2, cracks of specimens at 60 days exhibited similar number and inclination angle as those of specimens at 28 days. That means curing age had little influence on the failure pattern of EPS concrete specimen.

3.2. Basic properties

The basic properties of EPS concrete are presented in Table 2, which are calculated as the mean values of the test group for each specimen series. The compressive strengths of prism and cube specimens are noted as f_c and f_{cu}, respectively. The ratio f_c/f_{cu} of EPS concrete is 0.83–0.95, and it is higher than that of the normal concrete 0.76 [18]. The reason for this difference can be considered that no coarse aggregate was used in EPS concrete and the properties of the two components (EPS beads and hardened cement paste) in the composite of EPS concrete showed weaker lateral restraint to the center of the specimen, which led to small strength increase for cube specimens compared with prism specimens.

The variations of the compressive strength and peak strain (the strain corresponding to the peak stress) with dry density are shown in Figs. 3 and 4, respectively. As it can be seen, the increases of density and curing days led to increases in the compressive strength and peak strain. Here, as shown in Table 2, for the same dry density, the peak strain of EPS concrete increased by 13.7–14.8% at 60 days compared with 28 days. In addition, for the same

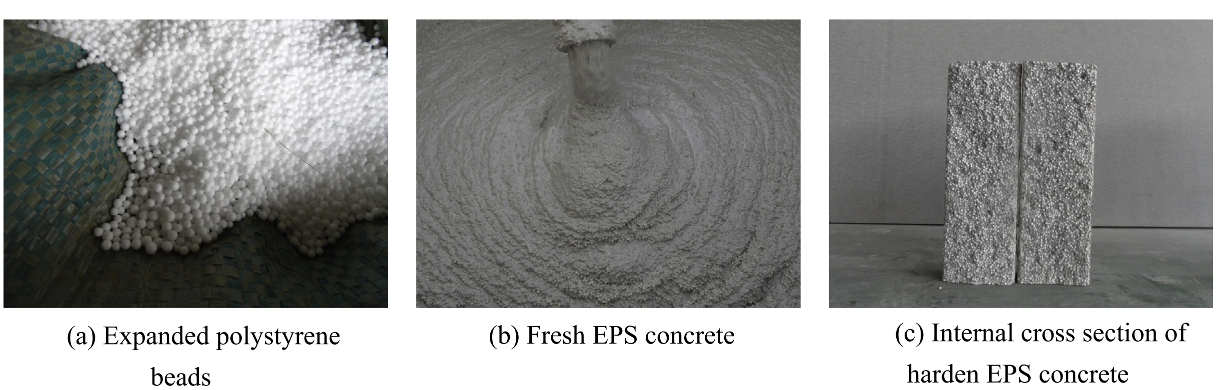

Fig. 1. Expanded polystyrene beads and EPS concrete.