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Axial compressive stress-strain relation and Poisson effect of structural lightweight aggregate concrete

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HIGHLIGHTS

- The strength and modulus of elasticity of LWAC was investigated.
- LWAC exhibits more significant lateral expansion than common concrete.
- The peak strains of LWAC increase with volume fraction of LWA.
- A numerical model for stress-strain curve of LWAC is proposed.

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ABSTRACT

Compared with the traditional concrete, the concrete fully made with the lightweight aggregate exhibits remarkable reduction in mechanical properties and is not suitable for the structural elements. To improve the performance of concrete, a hybrid aggregate system is usually used through partially substituting the natural crushed stone by the artificial lightweight aggregate. Using the expanded shale as the artificial lightweight aggregate, the stress-strain relation and Poisson effect of concrete were studied in the present study. Four different volume contents of shale aggregate were used in the experiment, and the effect of the volume content of shale on the mechanical properties of concrete was investigated. The reduction of peak stress and modulus of elasticity was observed with increase of the volume fraction of shale aggregate. However, the axial and lateral strains corresponding to the peak stress increase with the volume fraction of the shale aggregate. From the ratio of the lateral strain to the axial strain, a more significant Poisson effect was viewed for the concrete with higher content of the shale aggregate. Using the volume content of lightweight aggregate as the model parameter, a numerical formula was finally proposed to describe the stress-strain relation of lightweight concrete.

1. Introduction

Concrete is by far the most important construction material, and more than 10 billion tons are produced each year. But this popularity accompanies with an enormous impact on the environment, and vast amounts of natural resources are consumed [1]. Especially, ten to eleven billion tons of aggregate are being used each year all over the world, and the sources of good quality natural aggregates are considerably declining. To meet the pressure of the environment protection and sustainable development, the artificial aggregate is widely used as the substitute of the natural crushed stone to produce the concrete [2–9].

Owing to its porous structure, the lightweight aggregate (LWA) has less strength and is more deformable than the natural aggregate. Therefore, fully using LWA as the aggregates shall significantly reduce the mechanical properties of concrete at all aspects. To improve the performance of concrete, a hybrid aggregate system combining the natural crushed stone and the artificial aggregate is usually used. The previous studies have revealed that the strength and content of LWA have crucial impact on the mechanical behaviors of the concrete [10–12]. For the low-strength LWA, it is generally agreed that LWA is the weakest component of concrete and the content of LWA influences unfavorably on the mechanical behaviors of lightweight aggregate concrete (LWAC) [13]. However, when the strength of LWA is higher than that of mortar matrix, it has been shown that LWA is not an absolutely negative factor for the mechanical properties of concrete [14,15].

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Since the mechanical behaviors of LWAC differ from those of common concrete distinctly, the stress-strain relation model is crucially essential for the structural nonlinear analysis and design. Cui et al. investigate the pre-peak stress-strain relation of LWAC experimentally, and an analytical model concerning the effect of volume fraction of LWA was proposed [14].

For the concrete subjected to axial compression, the lateral Poisson effect has been revealed to be an important mechanism for concrete failure [16]. Especially, for the concrete confined by the steel tube or FRP, the expansion of concrete shall lead lateral pressure acted on the concrete, which results in significant improvement of the strength and ductility of concrete [17–20]. However, comparably rare work has been carried on the Poisson effect of LWAC. A comprehensive insight about this topic may be beneficial for the rational design of LWAC structure.

In this research, the expanded shale is chosen as the experimental material for LWA. With four different volume contents of LWA, the influences of volume fraction of LWA on mechanical performance of LWAC are examined. Though testing the axial and lateral stress-strain relations of concrete, the Poisson effect of LWAC is investigated. To fit the axial stress-strain curve of LWAC, a modified Sazen model was introduced. In Sazen model, three parameters, i.e., the initial tangential modulus of elasticity, the peak secant modulus of elasticity, and the peak strain, are used [16]. Based on the experimental results, the functions of those three parameters to the volume content of LWA are fitted.

2. Experimental study

2.1. Materials and mix proportion

The normal Portland cement (42.5 MPa) confirming to Chinese standard specification GB175-2007 [21] was used. The manufactured sand was used as the fine aggregate. The natural coarse aggregate was the crushed granite with size of 5–20 mm and water absorption capacity of 0.8%. The artificial LWA was the expanded shale with cylinder compressive strength of 8.5 Mpa, size of 5–20 mm and water absorption capacity of 5%. The expanded shale was immersed in the water for 12 h to avoid change of water-to-cement ratio due to water absorption of shale during mixing, and then is drained until the surface moisture reaches constant. An aphthalene-based superplasticizer was used to obtain a better workability. The apparent density or bulk density of all solid materials are listed in Table 1. The mix proportion is designed following Chinese specification JGJ 55-2011 [22]. Four different volume contents of expanded shale, i.e., 0, 20%, 40% and 60% were used in the experiment, and a summary about the mix proportion is given in Table 2.

For each group of concrete, three prism specimens (150 mm × 150 mm × 300 mm) and three cube specimens (150 mm × 150 mm × 150 mm) were cast. All the specimens were tested at age of 28 days.

Table 1
Density of raw materials (kg/m^3).

Raw materials	Apparent density	Bulk Density
Cement	3100	–
Crushed granite	2669	1606
Expanded shale	–	882
Sand	2657	–

2.2. Test procedure

Compressive test was carried out using a hydraulic 2000 kN press with constant stress rate as illustrated in Fig. 1. Following Chinese specification GB/T 50081-2002 [23], the cube specimens were used to test the cubic compressive strength of concrete, and the prism specimens were used for the stress-strain relation test. The prism specimens undergone three loading-unloading cycles from 0.5 MPa to the third of the ultimate strength estimated from the cubic compressive strength before the formal test. The axial and lateral strains were measured by the strain gauges, and Fig. 2 gives the arrangement of strain gauges. The initial tangential elastic modulus of the LWAC was computed from the original slope of the stress-strain curve.

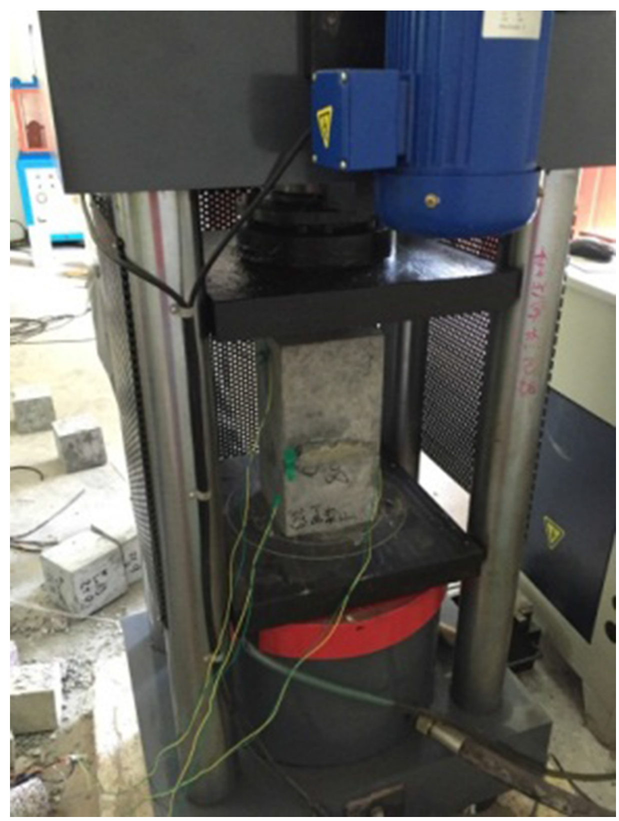

Fig. 1. Test equipment.

Table 2
Mixture proportion of concrete (kg/m^3).

Groups*	Cement	Sand	Crushed granite	Shale	Water	Superplasticizer
CC	439.29	740.16	1110.24	0.00	153.75	4.39
LWAC-20	439.29	740.16	888.19	116.14	153.75	4.39
LWAC-40	439.29	740.16	666.14	232.28	153.75	4.39
LWAC-60	439.29	740.16	444.10	348.42	153.75	4.39

* CC represents the common concrete. In the expression of LWAC-XX, XX is the volume fraction of LWA.