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Effect of shale ceramsite type on the tensile creep of lightweight aggregate concrete

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HIGHLIGHTS

- High water-absorption ceramsite LWC, low water-absorption ceramsite LWC, and normal-weight coarse aggregate NWC were researched.
- Tensile creep of these concretes was measured by using a newly developed shrinkage-restrained testing ring.
- Effect of shale ceramsite type on the tensile creep of lightweight aggregate concrete was investigated.

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ABSTRACT

High water absorption ceramsite (YAS), low water absorption ceramsite (YCS), and normal-weight coarse aggregate (NCA) were used as coarse aggregates in concrete. YCS, YAS and NCA were respectively presoaked for 24 h before their mixing into concrete. The net water/cement ratio of concrete with YCS, YAS and NCA was taken as 0.35. Mechanical properties and autogenous shrinkage of concrete made with the abovementioned coarse aggregates were determined. The tensile creep of these concrete was investigated by using a newly developed shrinkage-restrained testing ring. This study shows that the lightweight coarse aggregate concrete (LWAC) with YAS has the lower tensile creep than the LWAC with YCS, which has the similar tensile creep to the normal-weight coarse aggregate concrete (NC) with NCA.

1. Introduction

There is a worldwide environmental, economic, and technical impetus to encourage the structural use of lightweight aggregate concrete (LWAC) [1]. Due to the obvious advantages of LWAC in its lightweight, good thermal properties, fire resistance and seismic resistance as well as environmental friendliness, it has been widely applied in the construction of high-rise buildings, long span bridges and marine structures in harsh environments [2,3]. Taking its structural application for an example, a decreased density can reduce the structural self-weight, foundation size and construction cost [1,4].

A major drawback for LWAC is its vulnerability to cracking under restrained shrinkage condition. In another word, the restrained shrinkage is the basic reason for the cracking of cementitious materials [5], and the cracking occurs when the tensile stress caused by drying and autogenous shrinkages restrained by external or internal constraints in LWAC exceeds its threshold value (namely the tensile strength of LWAC) [6].

A significant feature in the cracking of LWAC is that its tensile creep that is able to partially relieve tensile stresses and then delay the occurrence of cracking [7]. Up to now, more research has been focusing on the compressive creep rather than the tensile creep of LWAC [8]. Nevertheless, research on tensile creep is one of key steps in understanding the cracking behavior of LWAC.

Recently the mechanical properties and durability of LWAC has been investigated [9,10]. However, little literature information is available about the tensile creep of LWAC made with different types of shale ceramsites [11]. The scope of this research lies in the effect investigation of different types of shale ceramsites with different water absorption on the tensile creep of LWAC. The results were also compared with that of the normal-weight coarse aggregate concrete (NC).

2. Experiment

2.1. Material

The compositions of ordinary Portland cement used in this study are presented in Table 1. The physical properties as well as the strength characteristics of the cement are given in Table 2. Three types of coarse aggregates (TCA) were employed as followings: (1) the lightweight expanded shale ceramsite with the shape of round-

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Table 1
Compositions of cement (%).

Clinker	Dihydrategypsum	Fly ash	Limestone	Slag
82.5	5.5	4.0	4.0	4.0

ness from Yi Chan city, Hubei province, China (YCS), namely low water absorption ceramsite, whose cylinder compressive strength was 8.8 MPa; (2) the lightweight expanded shale ceramsite with the shape of cylinder from Yong An city, Fujian province, China (YAS), namely high water absorption ceramsite, whose cylinder compressive strength was 5.2 MPa; (3) the normal-weight coarse aggregate (NCA) with the shape of angularity having a crushing value index of 8.45%. The properties and gradations of those three types of coarse aggregates are listed in Table 3 and shown in Fig. 1, respectively. The 24 h water absorption rates of YCS, YAS and NCA were 4.06%, 12.08% and 0.2% respectively. A kind of natural Min river sand with a fineness modulus of 2.3, an apparent density of 2630 kg/m^3 and a bulk density of 1630 kg/m^3 was used as fine aggregate; the sand's gradation is shown in Table 4. A superplasticizer (SP) TW-4 (sulfonated naphthalene formaldehyde type) with a water-reducing ratio of 25% was used in this study.

2.2. Three types of water/cement ratio

In LWAC, there exist three types of water/cement ratio, which are termed as total water/cement ratio (TWC), net water/cement ratio (NWC), and effective water/cement ratio (EWC). They are the weight ratios of total water content, net water content (namely, added water content) and effective water content to the cement content in LWAC. In the present study, the net water is referred to the water added during the mixing of LWAC, the total water is the summation of the net water and the amount of water soaked by shale ceramsites in different prewetting degrees. The effective water is the water remaining in hydrating cement paste (HCP), which is not absorbed by shale ceramsites during cement hydration process. Either the total water content or net water content is constant in LWAC, but the effective water content is varying during the water absorption and desorption process of the lightweight coarse aggregates, which means that the EWC varies during the cement hydration process of LWAC [6].

2.3. Mixture proportions

Three concrete mixtures, namely YC, YA and NC, were prepared and their mix proportions are listed in Table 5, respectively. There, three types of coarse aggregates (TCA), namely YCS, YAS and NCA, were pre-soaked for 24 h before the concrete mixing. The volume of YCS, YAS or NCA per cubic meter concrete mixture was approximately equal to 0.4 m^3.

The net water content in Table 5 excludes the water pre-soaked by the coarse aggregates and has a constant NWC of 0.35 in these three concrete mixtures. The total water content in Table 5 includes the water pre-soaked by coarse aggregates and increases with the increase of the water absorption rate of coarse aggregates. The TWC ranges from 0.36 for the concrete mixture NC to 0.40 for the concrete mixture YC, and 0.52 for the concrete mixture YA.

2.4. Mechanical test

According to the Chinese Code GB/T 50081-2002 [12], the 28 days cubic compressive strength and 7 days, 28 days Young's elastic modulus were measured on three samples sized of 150 mm × 150 mm × 150 mm for compressive test and 150 mm × 150 mm × 300 mm for Young's elastic modulus tests, respectively.

2.5. Autogenous shrinkage test

Three specimens of fresh concrete for each concrete mixture listed in Table 5 were cast in steel moulds sized of 100 mm × 100 mm × 400 mm. The moulds were stripped after 18 h in a curing room with a temperature of 20 ± 2 °C, and a humidity of 40%. Immediately after that, all the six faces of the specimens were sealed by wax and then wrapped by plastic films. Finally, the autogenous shrinkage of concretes was measured by micrometer gauges during a period of 28 days as shown in Fig. 2. However, autogenous shrinkage occurs when concrete is still in plastic stage.

Table 2
Physical properties and strength characteristics of cement.

Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)		Specific surface Blaine (m^2/kg)
Initial	Final	3 days	28 days	3 days	28 days	360
125	185	5.7	8.4	27.5	45	

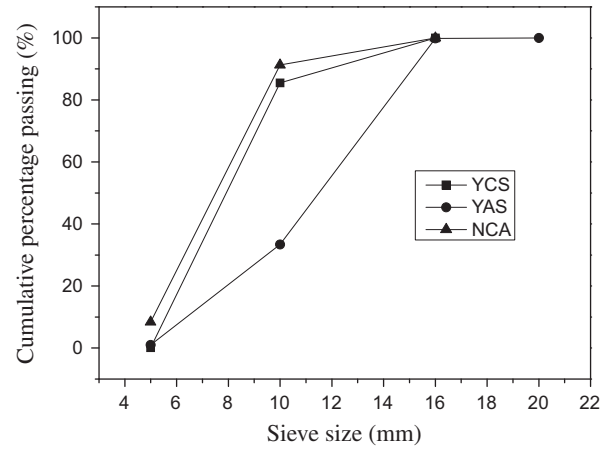

Fig. 1. Grain size distribution of coarse aggregates.

Table 3
Properties of coarse aggregates.

TCA	Apparent density (kg/m^3)	Bulk density (kg/m^3)	Void fraction (%)	24 h Water absorption (%)
YCS	1478	860	41.8	4.06
YAS	1683	880	47.8	12.08
NCA	2660	1532	42.4	0.20

A quite large portion of autogenous shrinkage in the curing age of 18 h was not accounted for the measurement because of the difficulty of test measurement. Further research in this aspect is needed.

2.6. Shrinkage-restrained ring

A shrinkage-restrained test ring with a piece of clapboard was firstly invented [13] as shown in Fig. 3 [6]. The purpose of using a piece of clapboard was to increase the circumferential tensile stress by reducing the concrete ring section area at the position of the clapboard, to create a stress concentration at the position of the clapboard, and to shorten the concrete cracking process. All the concrete rings had the same inner diameter of 315 mm and the same outer diameter of 395 mm. The wall thickness and height of the interior steel ring were 12 mm and 100 mm, respectively.

One strain gage (marked as No. 1) was attached on the inner surface of the interior steel ring at the half height position, and the other strain gage (marked as No. 2) was located opposite to the No. 1 gage. The strain data were collected at 20 min intervals by a computer.

Each concrete ring was cast in two layers, with each layer being vibrated for 15 s. The exterior steel ring and base plate were removed 1 day after casting. The top, bottom circumferential surfaces of the concrete rings were sealed with wax, so that both the tensile creep and cracking behavior of LWAC can be investigated. All the LWAC rings were tested in an environment with the temperature of 20 °C.

For the cracking behavior test, only one specimen for each kind of concrete mixture was tested. Of course, more specimens are needed for further research to obtain more statistical results.

3. Test results

3.1. Mechanical properties

The mechanical properties (compressive strength, splitting tensile strength and Young's elastic modulus) of concrete were tested and listed in Table 6. The table reveals that the YC group has higher 28 days compressive strength ($f_{cu}(28)$), splitting tensile strength

Table 4
Gradation of fine aggregates.

Sieve size (mm)	<0.15	0.15	0.30	0.60	1.18	2.36	4.75
Residue on each sieve (%)	1.0	4.4	60.2	31.4	2.4	0.6	0.0