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Effect of prewetting degree of ceramsite on the early-age autogenous shrinkage of lightweight aggregate concrete

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HIGHLIGHTS

- Three stages of early-age autogenous shrinkage of LWAC, namely liquid phase, skeleton-formational phase and hardening phase.
- Quantitatively study for the early-age autogenous shrinkage of LWAC with different prewetting degree ceramsite.
- Early age autogeneous shrinkage of LWAC decreases with the increase of prewetting degree of ceramsite.

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ABSTRACT

Lightweight aggregate (LWA) can provide internal curing to lightweight aggregate concrete (LWAC) due to the water absorption and desorption capability of ceramsite. Hence, the addition of ceramsite has a strong effect on the early age autogenous shrinkage of LWAC. In this paper, the early-age autogenous shrinkage of LWAC with different prewetting degree LWA was quantitatively studied when the same net water to cement ratio (NWC) or total water to cement ratio (TWC) was used. During the liquid phase and skeleton-formational phase, the positive effect of the 24 h prewetted ceramsite on the early-age autogeneous shrinkage of LWAC is obvious. During the hardening phase, the LWACs show small expansion strains. Therefore the early age autogeneous shrinkage of LWAC decreases with the increase of prewetting degree of ceramsite for the same NWC or TWC.

1. Introduction

The lightweight aggregate concrete (LWAC) has the properties of light weight, thermal insulation and environmental protection, which conforms to the trend of concrete development in the future [1]. The early-age shrinkage of concrete, occurring immediately after its casting, is important because the concrete at that time has only the lowest straining-resistant capacity and its shrinkage is most sensitive to the internal stresses, where the early-age is commonly defined as the first day when concrete has set and starts to harden [2]. Autogenous shrinkage of cement paste and concrete is defined as the macroscopic volume change occurred with no moisture transferred to the exterior surrounding environment, and is usually a concern in high-strength or high-performance concrete where there is a low water-to-cement (w/c) ratio [2]. According to the point of view of Tazawa and Miyazawa [3], the early-age autogenous shrinkage is more significant than the later age drying shrinkage when the w/c ratio is very low. If the early age shrinkage exceeds 1000 $\mu\varepsilon$ (1 mm/m), there is a high risk of cracking [4], which corresponds to a shrinkage of about 0.25–0.5 in. of movement in 20 ft (or 0.4–1.0 mm/m) according to the American Concrete Institute guidelines [5]. Due to this weak ability of concrete to resist deformation at the early age, the stress caused by the early age autogenous shrinkage has great influence on concrete structure, and there will be a high risk of cracking.

The early-age autogenous shrinkage of LWAC with non-prewetted LWA is also relatively large, easily leading to cracking of concrete structures in the early-age [6]. However, the prewetted lightweight aggregate can be used as an internal curing source, and its reservoir function can provide needed water to the hydration of cement [7], and autogenous shrinkage can be reduced effectively by this internal curing of the prewetted lightweight aggregate [6]. Cusson and Hoogeveen show that the concrete with prewetted ceramsite sand can reduce the autogenous shrinkage in the first day [8]. Bentur et al. show that replacement of some coarse aggregate by saturated surface-dry lightweight aggregate (for example, air-dry lightweight aggregate with 30 min of prewetting) can

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eliminate the autogenous shrinkage of concrete, and that the concrete will swell when the additional hydration takes place due to the supplied water from the saturated surface-dry lightweight aggregate [9].

Several researchers have explored the early age autogenous shrinkage of concrete, especially the first day after the casting of concrete [10–13]. To our knowledge, the effect of prewetting degree of lightweight coarse aggregate on the early-age autogenous shrinkage of concrete has not been reported. Based on corrugated tube method et al., this study is intended to quantitatively investigate the effect of prewetting degree of lightweight coarse aggregate on the early-age autogenous shrinkage of concrete within 1d, especially in three stages, namely liquid phase, skeleton-formational phase and hardening phase when the total water to cement ratio or net water to cement ratio is the same.

2. Experiment

2.1. Materials

All materials used in the experiments were produced in China. Grade 42.5R (Chinese cement grading system) Portland cement with apparent density of 3050 kg/m^3, manufactured in Fujian Province, China, was adopted.

Coarse aggregates include lightweight coarse aggregate and normal weight crushed stone (NCA). The lightweight aggregate is spherical shale ceramsite produced in Yi Chang City, Hubei province, China (YCS). The properties and gradation of YCS are listed in Tables 1 and 2, respectively. The properties and gradation of NCA are listed in Tables 3 and 4, respectively. A kind of natural Min river sand with a fineness modulus of 2.3, an apparent density of 2590 kg/m^3 and a bulk density of 1481 kg/m^3 was used as fine aggregate. The sand's gradation is shown in Table 5. A superplasticizer (SP) TW-4 (Sulfonated naphthalene formaldehyde type) with a water-reducing ratio of 25% was used in this study. The water is the tap water in Fuzhou municipal area.

2.2. Mixture proportions

The aggregate volume of concrete remains unchanged during the whole design of various mixture proportions so that the effect of aggregate content can be ignored. There are three variables in the mixture design shown in Table 6. The first is the replacement ratio of lightweight aggregate, 50%, 100%, respectively; the second is the prewetting degree of ceramsite, 0 h and 24 h, and the last one is the water to cement ratio (w/c). Herein, the total water content (TW) is the summation of the net water content and the amount of water pre-soaked by lightweight coarse aggregate; the net water content (NW) is referred to the water added during the mixing of LWAC.

The letter A indicates the shale ceramsite from Yi Chang (YCS). The first number after letter A is the replacement ratio of lightweight coarse aggregate to NCA, “1” means the replacement ratio is 100%, and “2” means the replacement ratio is 50%. The second number 1, 2 or 3 respectively stand for the LWAC with non-prewetted ceramsite (noted as group 1), the LWAC with ceramsite prewetted for 24 h and its total water to cement ratio (TWC) keeping the same as the group 1 (noted as group 2), as well as the LWAC with ceramsite prewetted for 24 h and its net water to cement ratio (NWC) keeping the same as the group 1 (noted as group 3).

2.3. Experiment and methodology

2.3.1. Application of maturity concept

The Arrhenius temperature function (Eq. (1)) is now widely accepted and adopted by ASTM and RILEM specification [14].

$$M(t) = \int_0^t \exp\left(\frac{E_a}{R}\left(\frac{1}{273+T_{ref}} - \frac{1}{273+T(t)}\right)\right)dt \tag{1}$$

Where T_{ref} is a reference temperature taken as 25 °C; $T(t)$ is the actual temperature; E_a is an activation energy (K J/mol) ; E_a/R is the universal gas constant, 8.314 (J/mol K). E_a/R is the activation energy factor.

Table 1
Properties of ceramsite.

Apparent density (kg/m^3)	Bulk density (kg/m^3)	Cylinder compressive strength (MPa)	Void fraction (%)	24 h water absorption (%)
1478	860	8.8	41.8	4.06

Table 2
Gradation of ceramsite (residue on each sieve) (%).

< 5 mm	5 mm	10 mm	16 mm	20 mm
0.1	85.4	14.5	0	0

Table 3
Technical indexes of NCA.

Apparent density (kg/m^3)	Bulk density (kg/m^3)	Void fraction (%)	Water absorption (%)	Crushing value (%)
2660	1532	42.4	0.2	8.45%

Table 4
Gradation of NCA (residue on each sieve) (%).

2.36 mm	4.75 mm	9.5 mm	16 mm	19 mm
0	8.36	82.9	8.74	0

Table 5
Gradation of fine aggregate (residue on each sieve) (%).

< 0.15 mm	0.15 mm	0.3 mm	0.6 mm	1.18 mm	2.36 mm	4.75 mm
0.5	5.1	45.1	46	2.8	0.5	0

Table 6
Mix proportions of LWAC.

No.	A11	A12	A13	A21	A22	A23
Ceramsite replacement ratio (%)	100	100	100	50	50	50
Prewetted Time (h)	0	24	24	0	24	24
Cement (kg/m^3)	476	476	476	476	476	476
Sand (kg/m^3)	698	698	698	698	698	698
Ceramsite (kg/m^3)	583	583	583	292	292	292
NCA	0	0	0	519	519	519
SP (kg/m^3)	8	8	8	8	8	8
TW (kg/m^3)	167	167	190	167	167	179
NW (kg/m^3)	167	144	167	167	155	167
TWC	0.35	0.35	0.40	0.35	0.35	0.38
NWC	0.35	0.30	0.35	0.35	0.32	0.35

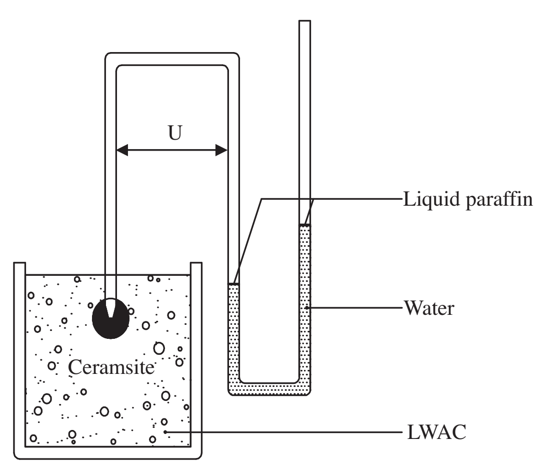

Fig. 1. U-tube micro pressure measurement setup.

In order to find a unique best-fit E_a/R factor for a given property, for example, the compressive strength, the tensile strength or the level of hydration, a Best-Fit Method was proposed [15]. This Best-Fit Method assumes that a given concrete, being cured under different temperature histories and developed to the same level of a certain property, will have the same maturity for that property. The activation