Pergamon

CEMENT AND CONCRETE RESEARCH

Cement and Concrete Research 29 (1999) 611–614

Communication

Effects of artificial lightweight aggregate on autogenous shrinkage of concrete

K. Kohno *, T. Okamoto, Y. Isikawa, T. Sibata, H. Mori

Central Research Institute Kiyosumi, Taiheiyo Cement Corporation, 2-23, Kiyosumi 1-chome, Koto-ku, Tokyo, 135-8410, Japan

Manuscript received 22 September 1998; accepted manuscript 27 October 1998

Abstract

Factors influencing autogenous shrinkage of lightweight aggregate concrete, such as the type, moisture content, and unit quantity of artificial lightweight aggregate, have been studied experimentally. It was found that the autogenous shrinkage of concrete is reduced by using lightweight aggregate and that the autogenous shrinkage of lightweight aggregate concrete decreases with increasing moisture content and unit quantity of lightweight aggregate. These observations suggests that water lost internally by self-desiccation of cement paste is replaced by moisture from the lightweight aggregate.

Keywords: Autogenous shrinkage; Lightweight aggregate; Moisture content of aggregate; Self-dessication

In recent years, lightweight aggregate concretes with high strength or high workability have been widely developed [1,2]. This type of concrete has a low water-to-binder ratio or a large quantity of binder. The autogenous shrinkage of this concrete is expected to increase, because previous research on cement paste or normal aggregate concrete demonstrated that autogenous shrinkage increases with decreasing water-to-binder ratio and with increasing quantity of binder [3,4]. However, it is possible that the autogenous shrinkage of lightweight aggregate concrete is greatly influenced by moisture in the lightweight aggregate, because the water absorption of lightweight aggregate is larger than that of normal aggregate. The amount of moisture in lightweight aggregate varies, depending on storage, prewetting, and pumping. Hence, it is necessary to understand the relationship between the moisture content of aggregate and autogenous shrinkage of concrete.

Further, new types of artificial lightweight aggregate with superior water absorption properties have been developed [5,6]. These lightweight aggregates have created considerable interest in recent years, because their application improves the workability, strength, and resistance to freezing and thawing of lightweight aggregate concrete. In this study, the autogenous shrinkage of concrete containing this type of lightweight aggregate was chosen as one of the research topics.

Few studies have been carried out on the autogenous shrinkage of lightweight aggregate concrete. A comprehensive understanding of the effects of lightweight aggregate on autogenous shrinkage is still lacking. Hence, the objective of this study is to understand the effects of type, moisture content, and volume concentration of lightweight coarse aggregate on autogenous shrinkage.

1. Concrete materials

The concrete materials used for this study are as follows.

Cement (C): A Japanese high-early-strength Portland cement (with specific gravity of 3.15 and specific surface area of 4490 cm^2/g) was used.

Admixtures: A polycarbonate type of superplasticizer and a modified alkylcarbonate type of air-entraining agent were used.

Fine aggregate (S): Crushed sand (with specific gravity in saturated and surface-dry conditions of 2.62, water absorption of 1.63%, maximum size of 5.0 mm, and fineness modulus of 3.07) was used.

Coarse aggregates (G): Three different artificial lightweight aggregates and a crushed stone aggregate were used. The physical properties of these aggregates are given in Table 1. The first lightweight aggregate (LA) is a crushed and coated type made from expanded

*Corresponding author. Tel.: 81-3-3642-7171; Fax: 81-3-3643-2047; E-mail: katsuya_kouno@taiheiyo-cement.co.jp.

PII: S0008-8846(98)00202-6

Table 1
Physical properties of coarse aggregate used for this study

Type	LA	HLA1	HLA2	CS
Specific gravity in oven-dry condition	1.27	1.17	0.94	2.62
Water absorption (vol %)				
By immersing for 24 h	22.3	4.42	4.79	1.94
By boiling for 2 h	35.4	9.67	8.70	—
Maximum size (mm)	15	15	15	15
Fineness modulus	6.47	6.48	6.40	6.51

shale. This type of lightweight aggregate is the most commonly available in the Japanese market. The next two aggregates are high-performance lightweight aggregates (HLA), which we recently developed. These are pelletized and coated lightweight aggregates made from finely ground perlite powder, a binder, and a gas-forming agent. HLA was produced by thorough mixing of the powder materials, followed by dense pelletization using a granulating machine and heating in a rotary kiln (the pellets sinter at about 1000°C and then are expanded at about 1100° to 1200°C). The specific gravity of HLA can be freely controlled by the heating conditions. In this study, two types of HLA with different specific gravities were used. From Table 1, it can be noted that HLA has an extremely low water absorption. This is because the surface is coated perfectly and the interior consists of closed microcells.

2. Mixture proportions

The mixture proportions for the concrete are summarized in Table 2. In all of the concrete mixtures, the unit water content and unit cement content were fixed and the water-to-cement ratio was 32%. The factors influencing autogenous shrinkage were the type, moisture content, and unit quantity of coarse aggregate. Four different types of coarse aggregate were used with different moisture contents: dried absolutely, immersed for 24 h, and boiled for 2 h. The unit quantity of coarse aggregate was controlled at 320, 350, and 380 L/m^3. Slump was 15 ± 3 cm and air content was 5.0 % ± 1.0%. These were controlled by the dosages of superplasticizer and air-entraining agent.

Table 2
Mixture proportions

	G					
No.	Type	Moisture content (vol %)	Unit content (L/m^3)	s/a (%)	Slump (cm)	Air content (%)
1	LA	22.3 (Immersed)	350	43.3	17	5.5
2		0.00 (Oven dried)			15.5	4.6
3		35.4 (Boiled)			18	4.9
4	HLA1	4.42 (Immersed)	320	48.2	12	5.6
5			380	38.5	18	4.4
6			350	43.3	12.5	5.2
7		0.00 (Oven dried)			18	4.6
8		9.67 (Boiled)			12	4.8
9	HLA2	4.79 (Immersed)	350	43.3	14	5.7
10	CS	1.94 (Immersed)	350	43.3	12.5	4.1

32% w/c; 166 kg/m^3 water content; 518 kg/m^3 cement content.

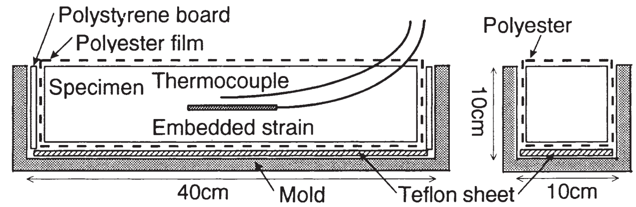

Fig. 1. Concrete specimen in the casting mold.

3. Measurement of autogenous shrinkage

3.1. Length change of specimen up to 24 h after casting

Fig. 1 shows the specimen in the casting mold. Polystyrene board and a polytetrafluoroethylene (Teflon) sheet were put on the inside surface of the steel mold (10 × 10 × 40 cm) so that movement of the specimen was free and unrestrained by the mold. The specimens were wrapped in polyester film to prevent water evaporation from the surface of the specimen. The specimens were stored at a room temperature of 20°C. After the initial setting time, the autogenous shrinkage was measured by a strain gauge (with a modulus of elasticity of 39 MPa and a length of 10 cm) and a thermocouple embedded in the specimen. The measurements were corrected for thermal strain due to hydration, by assuming that the coefficient of linear thermal expansion is 10×10^{-6}/°C.

3.2. Length change of specimen after removal of the mold at 24 h

All specimens were sealed by adhesive aluminum tape immediately after removal of the molds and stored in a room at a temperature of 20°C and a relative humidity of 60%. Changes in the length and mass of the specimens were measured. The mass changes of all specimens were less than ±0.01% during this test. This observation means that

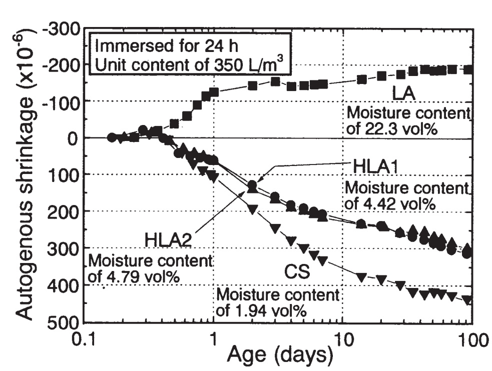

Fig. 2. Effect of type of coarse aggregate on autogenous shrinkage.

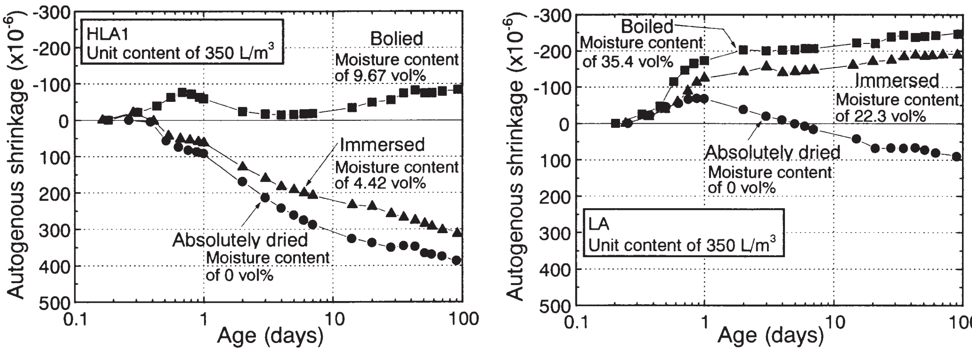

Fig. 3. Effect of lightweight aggregate moisture content on autogenous shrinkage for (*A*) HLA1 and (*B*) LA.

water hardly evaporated or permeated through the surface of specimen.

4. Results and discussion

4.1. Effect of type of coarse aggregate on autogenous shrinkage

The autogenous shrinkage of specimens using LA, HLA1, HLA2, and CS immersed in water for 24 h are shown in Fig. 2. The specimen containing LA (with a moisture content 22.3 vol%) swelled rapidly until the age of 1 day. The autogenous expansion then remained stable at about 180×10^{-6}. Two specimens containing HLA1 (with a moisture content of 4.42 vol%) and HLA2 (with a moisture content of 4.79 vol%) showed similar volume changes. The specific gravity of HLA has a very small influence on autogenous shrinkage. Using HLA, the autogenous shrinkage increased consistently with age and reached about 300×10^{-6} after 90 days. The autogenous shrinkage of CS concrete was about 430×10^{-6} after 90 days and was larger than that of all of the lightweight aggregate concretes.

4.2. Effect of lightweight aggregate moisture content on autogenous shrinkage

The autogenous shrinkage of specimens containing HLA1 and LA with varying moisture contents is shown in Fig. 3. The specimen containing boiled HLA1 (with a moisture content of 9.67 vol%) did not shrink at all. The autogenous expansion remained stable at about 50×10^{-6} until 90 days. Autogenous shrinkage was greatest for the specimen containing absolutely dry HLA1; greater than that for the specimen containing immersed HLA1 (with a moisture content of 4.42 vol%). In short, autogenous shrinkage decreases with increasing moisture content of HLA1. The specimen with absolutely dry LA, in contrast to the specimen with absolutely dry HLA1, swelled slightly during the early stages, but then begin to shrink after 5 days. The autogenous shrinkage reached about 100×10^{-6} after 90 days. The permeability of LA is higher than that of HLA, as shown in Table 1. When LA was absolutely dry at the time of mixing, it rapidly absorbed mixing water until the end of initial setting. This resulted in the slight expansion that was observed at an early age. However, when boiled or immersed LA was used, shrinkage was not observed. The amount of expansion up to 1 day was largest for boiled LA, but the volume change after 1 day was almost equivalent to that for using immersed LA. This result means that prewetting of LA (recently LA has scarcely been used without prewetting, because prewetting facilitates mixing and handling) has a major influence on autogenous expansion at the early age.

From Fig. 3, it can be noted that the autogenous shrinkage of LA concrete is generally smaller than that of HLA concrete. Autogenous volume change of lightweight aggregate concrete is related directly to the permeability and adsorption capacity of the aggregate. These properties of lightweight aggregate are dependent on the continuity of the aggregate pores.

4.3. Effect of unit quantity of lightweight aggregate on autogenous shrinkage

Fig. 4 shows the relationship between the unit quantity of HLA1 and autogenous shrinkage. For the specimen with a unit quantity of 320 L/m^3, shrinkage was observed at the end of initial setting. However, the specimens with unit contents of 350 and 380 L/m^3 swelled slightly during the early

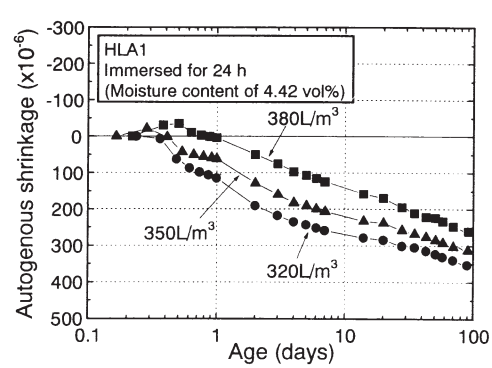

Fig. 4. Effect of unit quantity of lightweight aggregate on autogenous shrinkage.

stages. For the specimen with a unit content of 380 L/m^3, shrinkage did not occur until the specimen had aged for 1 day. With increasing unit quantity of HLA1, the autogenous shrinkage is observed at a later age and the amount of shrinkage after 60 days is decreased. From this observation, it was concluded that the autogenous shrinkage can be reduced by increasing the unit quantity of lightweight aggregate.

4.4. Autogenous shrinkage mechanism of lightweight aggregate concrete

The important findings in this study are that (1) the autogenous shrinkage of concrete is reduced by using lightweight aggregate, and (2) the autogenous shrinkage is dependent on type, moisture content, and unit quantity of lightweight aggregate. These points should be explained by the redistribution of water based on autogenous shrinkage mechanism.

The space originally occupied by cement particles and water is gradually replaced by the space filled by hydration products. The space not taken up by the solid components such as the unhydrated cement particles or the hydration products consists of capillary pores. At the early stage of hardening, most of the capillary pores and most of the lightweight aggregate particles are fully saturated with water. As the hydration reaction progresses, the capillary water is consumed to form new and fine capillary pores. However, the internal relative humidity in the capillary pores is not lowered due to a continuous supply of moisture from lightweight aggregate particles. As a result, the cement paste does not shrink. As Fig. 2 shows, the autogenous shrinkage of lightweight aggregate concrete is smaller than that of normal concrete. The reduction of autogenous shrinkage of lightweight aggregate concrete is because water lost internally by self-desiccation of the cement paste is immediately replaced by moisture from the lightweight aggregate. As Figs. 3 and 4 show, the autogenous shrinkage of lightweight aggregate concrete is observed at a later age and decreases with increasing moisture content and unit quantity of lightweight aggregate. This is because a larger amount of moisture is able to be supplied to the desiccated capillaries.

The results of this study suggest that an aggregate with a large absorption capacity, such as lightweight aggregate or recycled aggregate, can reduce the autogenous shrinkage.

5. Conclusions

The autogenous shrinkage of concrete using three different artificial lightweight aggregates has been measured. The main results obtained are as follows:

1. Autogenous shrinkage of lightweight aggregate concrete is smaller than that of normal concrete.
2. Autogenous shrinkage of lightweight aggregate concrete is related directly to the permeability and adsorption capacity of the aggregate.
3. Autogenous shrinkage of lightweight aggregate concrete decreases with increasing moisture content and unit quantity of lightweight aggregate.

References

[1] M.H. Zhang, O.E. Gjørv, ACI Mater J 88 (3) (1991) 240–247.
[2] T. Kawai, H. Ohno, K. Ozawa, T. Igi, Cem Concr (in Japanese) 552 (1993) 32–43.
[3] E. Tazawa, S. Miyazawa, Cem Concr Res 25 (8) (1995) 1633–1638.
[4] E. Tazawa, S. Miyazawa, Mag Concr Res 49 (178) (1997) 15–22.
[5] D. Tachibana, K. Kimura, K. Naitoh, J Mater Concr Struct Pavement (in Japanese) 24 (496) (1994) 89–98.
[6] T. Okamoto, H. Hayano, T. Sibata, Concr J (in Japanese) 36 (1) (1998) 48–52.