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Influence of aggregate size and aggregate size grading on ASR expansion

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Abstract

The influences of aggregate size and aggregate size grading on ASR expansion in the Chinese autoclave test were studied. The result shows that the effect of the addition of coarse aggregate on the expansion of mortar is complex. It may be inhibiting expansion, may have no effect, or may be promoting expansion. Moreover, its effect will change with age. By theoretic analysis of micromechanics, it is shown that the effect of coarse aggregate on the expansion of mortar depends on the relation between the free expansion of coarse aggregate ε_a and mortar ε_s. From the results of experimental and theoretic analyses, the authors suggest that for the evaluation of the alkali-reactivity of aggregate, single-size aggregate grading might be more reasonable.

Keywords: Aggregate size; Aggregate size grading; Alkali-aggregate reaction; Expansion; Chinese autoclave method

1. Introduction

It is well known that ASR expansion is related to the aggregate size. Some researches have shown that the expansion of the mortar bar with reactive siliceous aggregate increases as the reactive particle size is reduced, but the expansion doesn't increase continuously when the particle is smaller than 20 μm [1,2]. In tests using opaline silica as the reactive aggregate, Diamond and Thaulow [3] found that the expansion is delayed when larger aggregates are used. Nishibayashi and Yamura's research [4] showed that the expansion of concrete containing only reactive fine aggregate grows primarily in the early period. It becomes constant at a rather early stage. On the other hand, the expansion of concrete containing only reactive coarse aggregate grows slowly, but continues for a long period.

The influence of the aggregate size grading on ASR expansion has had very little research. An important finding in Nishibayashi and Yamura's research is that in specimens containing both reactive coarse and fine aggregate, the expansion is rather small and becomes constant in the early stage. It means that the aggregate size grading could influence the value of ASR expansion.

In the methods evaluating the aggregate-alkali reactivity, some use single-size aggregate grading, and others use multisize aggregate grading. Which is more reasonable? The influence of the aggregate size grading on ASR expansion is explored in this paper.

2. Experimental details

2.1. Materials

The tested aggregates included: (1) quartz glass (QG) and (2) the reactive gravel from Beijing (BJ). All aggregate were crushed and sieved. For QG, the aggregates of four size ranges are obtained: 0.15–0.80, 0.80–1.25, 1.25–2.5, and 2.5–5 mm. For BJ, the aggregates of two size ranges are obtained: 0.15–0.80 and 5–10 mm.

The cement was Portland cement, and its alkali content was 0.66% in terms of equivalent Na_2O. In the experiment, the alkali content was adjusted to 1.5% by adding KOH to the mixing water.

2.2. Experimental process

The Chinese autoclave method was used in the experiment. The water-cement ratio of the mixture was 0.3 and the specimen size was 20 × 20 × 60 mm. The specimens were removed from the molds at 1 day after they were cast, and

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their initial lengths were measured. The specimens were cured at 100°C for 4 h in steam, then were autoclaved at 150°C for 6 h in the solution containing 10% KOH. The length change was measured and the expansion was calculated.

3. Results

Fig. 1 shows the relationship of the expansion to the aggregate size for QG. It can be seen that the expansion decreases with the increase of the aggregate size. Moreover, this difference is more marked when the aggregate content is larger.

The relationship between the expansion and cement/aggregate (c/a) is shown in Fig. 2. For the 0.15–0.80-mm range, the c/a maximum expansion was 8, but for the 2.5–5-mm range, the expansion increased with the increase of aggregate content until c/a maximum expansion was 4. It indicates that the c/a causing maximum expansion decreases when the reactive aggregate size is increased.

Table 1 shows the results of testing with BJ. It is obvious that the expansion of the specimen with the large aggregate is less than the specimen with the small aggregate.

For the influence of the aggregate size grading, two kinds of aggregate were used. The aggregate of the 0.15–0.80-mm range is a fine aggregate, and that of the 5–10-mm range is a coarse one. Under the condition that the property of mortar is constant, the different amount of coarse aggregate was added and the expansion was observed.

The experimental result using BJ aggregate is shown in Fig. 3. After autoclaving for 6 h, the expansion of the specimen decreased as the content of coarse increased, regardless of the ratio of cement to fine aggregate (c/s), but with smaller c/s, the effect of coarse aggregate is larger. It is obvious that the expansion is different if the c/s is not same. This difference is larger when there is coarse aggregate, but it will decrease as coarse aggregate is added. When a/(c + s) is larger than 0.5, the influence of c/s will be less, and the expansion depends mainly on the amount of coarse aggregate.

With prolonged autoclave time, the effect of coarse aggregate will be changed. When autoclave time is 12 h, adding

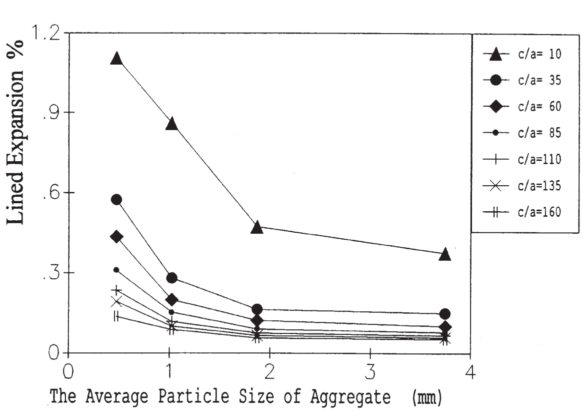

Fig. 1. The relationship between the expansion of mortar and the average aggregate particle size (QG).

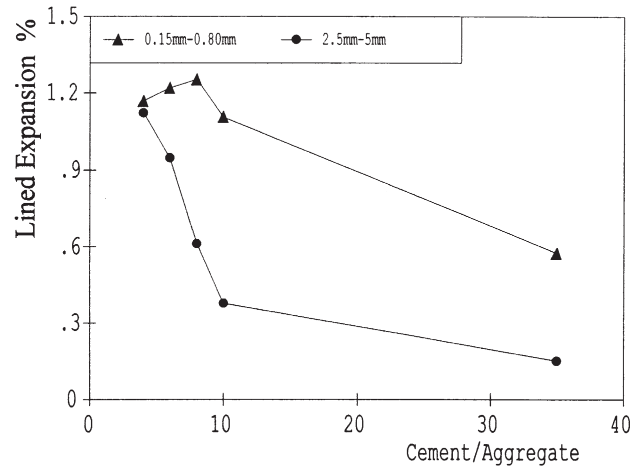

Fig. 2. The relationship between the expansion and cement/aggregate.

coarse aggregate reduces the expansion for the mortar when c/s equals 3 or 6, but does not influence the expansion for the mortar when c/s is 9. When autoclave time is 18 h, adding coarse aggregate reduces the expansion for the mortar when c/s is 3, is constant when c/s is 6, and raises when c/s is 9.

4. Discussion

Some authors deduced the relationship between the deformation of the composite materials and the deformation of both matrix phase and particle phase by micromechanical method [5]. It takes the form shown in Eq. (1):

$$\varepsilon = \varepsilon_m + (\varepsilon_p - \varepsilon_m) f\left(\frac{v_p}{v}\right) \quad (1)$$

$f\left(\frac{v_p}{v}\right)$ is a monotone, raising function of $\frac{v_p}{v}$, and $\left(f\frac{v_p}{v}>\right)0$

where: ε is the deformation of the composite materials (%);
ε_m is the free deformation of the matrix phase (%);
ε_p is the free deformation of the particle phase (%); and
$\frac{v_p}{v}$ is the volume fraction of the particle phase.

It is obvious that the effect of the particle phase on the expansion depends on $\varepsilon_p - \varepsilon_m$. If $\varepsilon_p < \varepsilon_m$, $\varepsilon_p - \varepsilon_m < 0$, and the expansion of composite materials decreases with the increase of the content of particle phase. If $\varepsilon_p = \varepsilon_m$, $\varepsilon_p - \varepsilon_m = 0$, and the expansion of composite materials is irrelative to the content of particle phase. If $\varepsilon_p > \varepsilon_m$, $\varepsilon_p - \varepsilon_m > 0$, and the expansion of composite materials increases with the content of particle phase.

For concrete, mortar may be regarded as the matrix phase, and coarse aggregate may be regarded as the particle phase. The expansion of mortar is relative to the c/s ratio. In general, the smaller the c/s, the greater the expansion of mortar. For siliceous aggregate, the reaction of coarse aggregate to alkali is slower. Thus, in early age, ε_p is smaller

Table 1
The result of testing with BJ aggregate

Autoclave time (h)	Particle size of aggregate (mm)	Cement/aggregate						
		2	3	6	7	8	9	10
6	0.15–0.80	0.124	0.119	0.099	0.095	0.092	0.082	0.080
	5–10	0.053	0.049	0.045	0.043	0.037	0.034	0.031
12	0.15–0.80	0.175	0.163	0.116	0.114	0.111	0.104	0.087
	5–10	0.062	0.059	0.054	0.050	0.047	0.042	0.037
18	0.15–0.80	0.305	0.247	0.166	0.137	0.120	0.110	0.100
	5–10	0.090	0.076	0.064	0.058	0.049	0.048	0.046

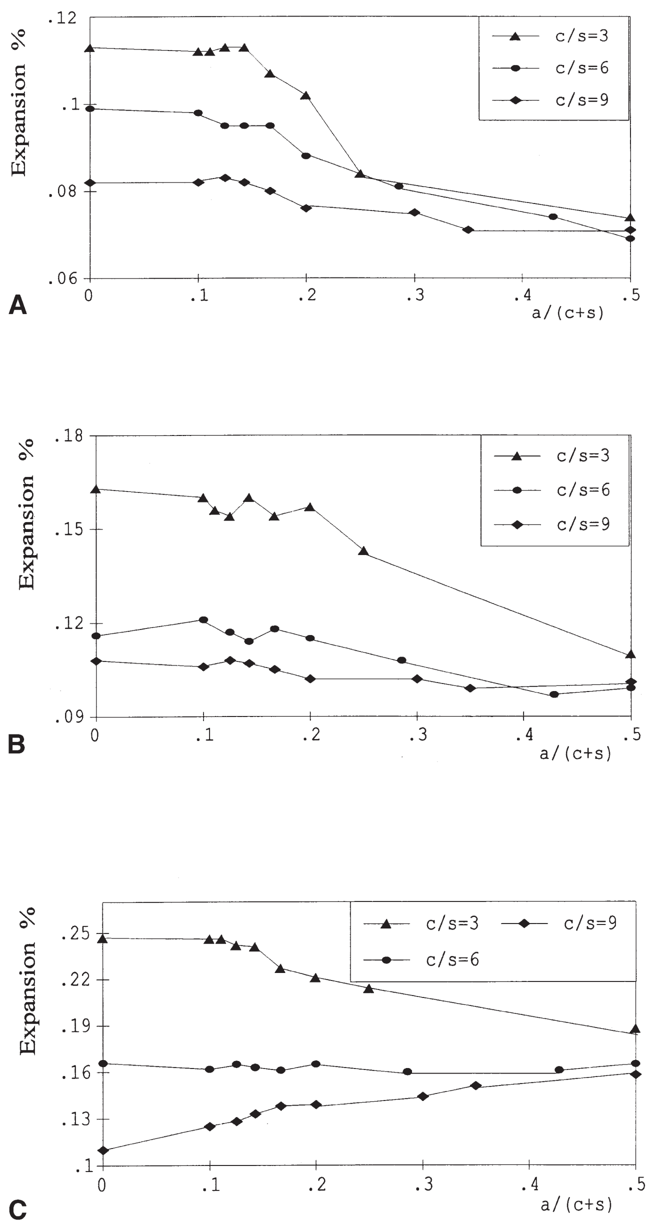

Fig. 3. The influence of the coarse aggregate on the expansion of mortar bar (BJ). (a) Autoclaved for 6 hours at 150°C; (b) Autoclaved for 12 hours at 150°C; (c) Autoclaved for 18 hours at 150°C.

than ε_m, and the addition of coarse aggregate makes the expansion decrease. However, the relation between ε_p and ε_m will be exchanged with time, and the coarse aggregate will have different effect for different mortar.

Table 2 shows the free expansion of coarse aggregate and the expansion of every mortar at different autoclave times. It confirms experimentally the relationship of the effect of coarse aggregate on the expansion to ε_p and ε_m.

It must be noted that the coarse aggregate can make the expansion decrease, but it is transient and the expansion will be increased when the test is prolonged.

In ASTM C227, five sizes of aggregate grading is used. There are some coarser particles among these aggregates, which makes the expansion slow. For some aggregates, it often gives an erroneous conclusion.

5. Conclusions

According to the experimental results and the analyses, some conclusions can be obtained concerning the effect of particle size on expansion in the Chinese autoclave test:

1. For siliceous aggregate, the smaller the size, the greater the expansion of ASR is when the aggregate size is within the range of 0.15–10 mm.
2. For siliceous aggregate, the cement/aggregate ratio that reaches the maximum expansion decreases as the aggregate size is increased.
3. The aggregate size grading can effect markedly the expansion of ASR. When there are bigger aggregates in the specimen, the expansion is smaller at an early age, but will increase continuously at later ages.
4. Because bigger aggregate makes the expansion slow, it is reasonable that single-size aggregate grading is used for the evaluation of the aggregate-alkali reactivity.

Table 2
The free expansion of particle phase and the expansion of matrix phase

Type of aggregate	Autoclave time (h)	ε_p	ε_m		
			c/s = 3	c/s = 6	c/s = 9
BJ	12	0.106	0.163	0.116	0.104
	18	0.188	0.247	0.166	0.110

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