EVALUATING THE EFFECTIVENESS OF NATURAL ZEOLITE IN PREVENTING EXPANSION DUE TO ASR BY ACCELERATED TEST

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ABSTRACT

An accelerated mortar bar test based on ASTM C441-89 was used to evaluate the suppressing effect of natural zeolite, fly ash and blast-furnace slag on the expansion due to alkali-silica reaction. The test can indicate the difference of the performance obtained by these mineral admixtures. However the results need some new interpretation as the experiment conditions have been changed. Then natural zeolite and other mineral admixtures were used to prevent the expansion of a reactive natural aggregate from Beijing by mortar bar test according to ASTM C1260-94. The results confirm the effectiveness of natural zeolite in preventing ASR, which was found by traditional methods.

Keywords: Alkali-silica reaction, natural zeolite, accelerated method, suppressing effect, mineral admixtures

INTRODUCTION

The alkali-aggregate reaction (AAR) involves chemical interaction between alkali hydroxides usually derived from cement and reactive components in the aggregate particles. Three kinds of AAR have been reported: alkali-silica reaction (ASR), alkali-carbonate reaction and alkali-silicate reaction. The first one is the most popular reaction that has been a severe problem to the durability of concrete structure in many parts of the world. In order to reduce the risk of ASR, the use of low alkali cement as well as non-reactive aggregate are recommended. But these materials are not always available so the most practical way in field is using mineral admixtures like blast-furnace slag (BFS) and fly ash (FA) in preventing excessive expansion of concrete due to ASR.

In 1940, Stanton was the first to explain the possibility of reducing the expansion due to ASR by using pozzolanic cement containing finely ground 'Monterrey Shale' or by replacement of 25% high-alkali cement with pozzolana (Stanton 1940). Now several hundreds of papers dealing with this subject has been published and most of them discussed the effectiveness of BFS, FA, and silica fume. Since 1980s, we have been concerning the role of natural zeolite in cement and concrete. The effectiveness of this pozzolanic material in reducing the expansion due to ASR had been tested by traditional methods: ASTM C289, C227 and C441(Feng 1992, 1997, 1998).

Though these methods, such as ASTM C227 Mortar Bar Test, have been widely used, it may require a year or more for completion and the suitability of the methods have been questioned by many researchers (Swamy 1992, Wigum 1997). At the same time, the accelerated mortar bars tests, most of which center on the procedure published by Oberholster and Davies (1986), have been developed quickly. The version of the NBRI test is now adopted as ASTM C1260-94, which is similar to the European ASR test method recommended by RILEM TC-106. In China, a lot of work need to be done to deal with the accelerated methods for testing ASR.

The major object of this paper is to evaluate the effectiveness of natural zeolite in preventing expansion due to ASR by accelerated methods. First, ASTM C441-89 was modified to compare the effectiveness of mineral admixtures in a short time. Second, natural zeolite, BFS and FA are used to depress the expansion of a reactive aggregate from Beijing by mortar bar test according to ASTM C1260-94.

MATERIALS AND EXPERIMENTAL METHODS

Materials

Cement-- Ordinary portland cement with high alkali content (see Table 1) , was used throughout the investigation. The specific surface area of the cement is about 3150 cm^2/g.

Natural zeolite-- Two kinds of natural zeolite powders were used. One is named Z-A whose mean size is 13.4 μm; the other is named Z-B of which has two fineness: Z-B-1 and Z-B-2. The mean size of the two powder is 18.2 μm and 4.5 μm respectively. The XRD pattern of the two kinds of natural zeolite are shown in Fig. 1. The zeolites belong to clinoptilolite, whose formula of typical unit cell is $Na_6[(AlO_2)_6(SiO_2)_{30}]\cdot 24H_2O$.

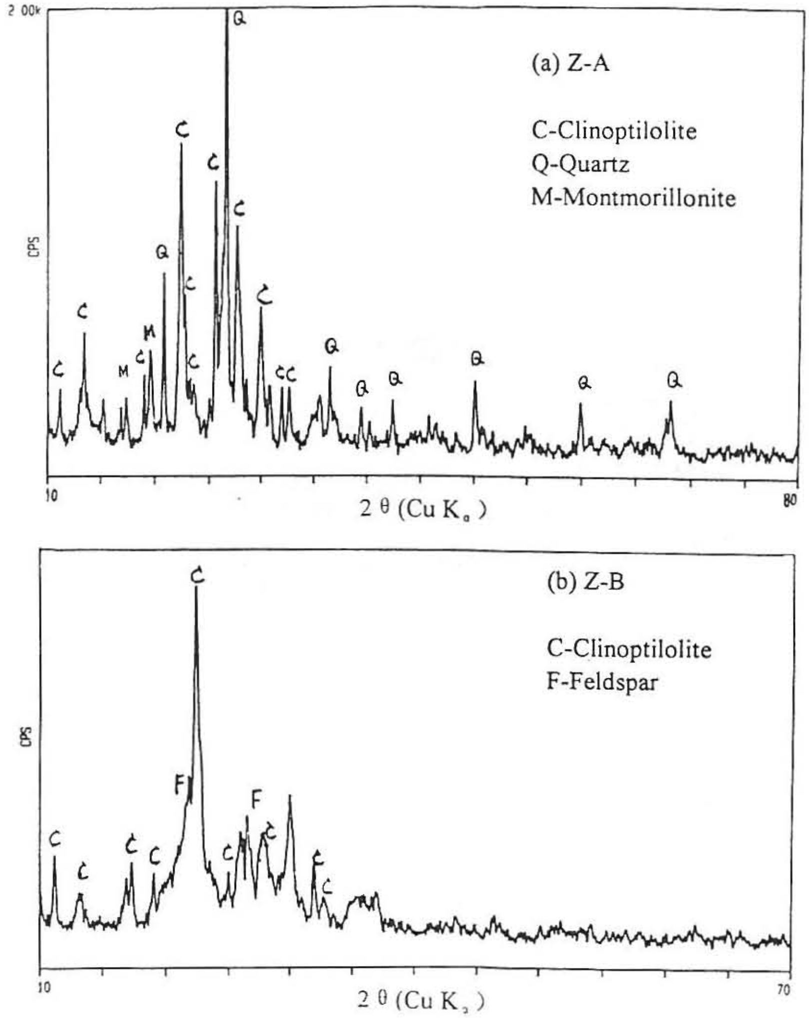

Fig. 1: XRD pattern of (a) Z-A and (b) Z-B

Fly ash-- FA from Beijing Thermal Power Plant was used, it has a specific surface area of 3600 cm^2/g.

Blast-furnace slag--BFS from Beijing was ground to powder of different particle size. C-BFS has a specific surface area of 3500 cm^2/g, and that of F-BFS is 5000 cm^2/g.

The chemical analysis of OPC, NZ, BFS and FA are summarized in Table 1.

TABLE 1: Chemical Analysis of OPC and Pozzolanic Materials

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	K_2O	Na_2O	CaO	MgO	L.O.I
OPC	22.17	5.43	3.16	0.25	1.10	0.07	60.87	1.67	4.18
Z-A	70.26	12.16	1.18	0.12	1.40	1.91	2.83	0.91	8.98
Z-B	70.84	12.32	1.31	0.14	2.30	0.80	2.41	1.23	8.17
FA	50.87	34.71	3.53	-	0.62	0.25	3.23	0.77	2.88
BFS	33.27	12.10	1.63	-	0.75	0.5	38.39	11.18	0.01

Aggregate--(1) The Chinese standard sand, which mainly consists of quartz, was used as a non-reactive aggregate. (2) A kind of siliceous limestone, named YD, was crashed to make sand with size fraction of 0.3-0.6 mm. Fig. 2 shows the chalcedony in YD. (3) Fused silica is used as highly reactive aggregate. It is made up of 99.99% non-crystalline SiO_2. The size fraction of the fused silica is 2.5～5 mm.

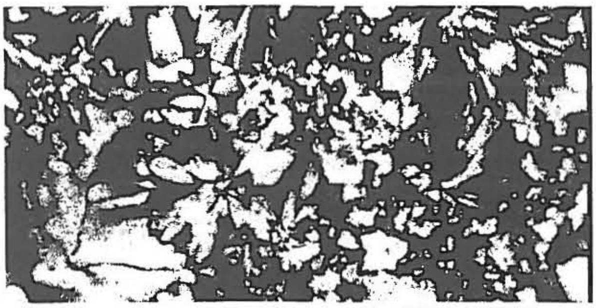

Fig. 2: Petrography photograph of YD (×200)

Experiment details

In modified C441-89 method, the Pyrex glass is replaced by the combination of Chinese standard sand (95%) and fused silica (5%). A quarter of cement was replaced by the mineral admixtures having an absolute volume equal to the absolute volume of the 25 percent cement. The size of the specimen is 30×30×285 mm and two stainless studs were embeded to the specimen. Another important change is the curing condition. Instead of the 38±2℃, the specimen were put into the 1M NaOH solution in 80℃ vessel.

The length of the bars was periodically measured using a comparator with a sensitivity of 0.001 mm. The reduction of mortar expansion Re was calculated in accordance with the ASTM C441-89.

When specimens prepared with YD , the mortars were cast and stored in accordance with the ASTM C1260-94 procedure. Of all the mortars, the water/binder ratio is 0.47.

effective. The effective order is Z-B-2>Z-A>Z-B-1>FA>C-BFS≈F-BFS. The failure of BFS to suppress the expansion is not surprising because the amount of BFS was not as high as 50% of cement as specified in ASTM C441-89.

TABLE 2: Reduction of Mortars Expansion (Re) at Different Ages

Admixtures / Age (days)	Z-A	Z-B-1	Z-B-2	FA	C-BFS	F-BFS
7	87	67	95	66	15	17
14	71	58	81	51	9	10
28	61	54	64	46	10	8

The replacement level is the key to explain the results. Since the density of zeolite, fly ash and blast-furnace slag are 2.16, 2.08 and 2.91 respectively, the corresponding mass replacement level is 19%, 18% and 24% when their absolute volume is the same. While the suggested replacement level of FA and BFS is 25-40% and 40-60% respectively. So these pozzolans can not reduce expansion of mortar bars effectively. The proposed level of natural zeolite used is 30% (Feng 1997) which is also higher than the usage in this investigation.

For natural zeolite, the influence of fineness is important. The suppressing effect of Z-B-2 is greater than Z-B-1 due to the fact that Z-B-2 is finer than Z-B-1. From Table 2, another fact can be found that different kinds of natural zeolite show the various suppressing effect. The suppressing effect of Z-B-1 is less than Z-A though they have a similar size. This may results from the different alkali content in these two kinds of zeolite. Further researches will give more information.

Using ASTM C1260-94 to Assess the Performance of natural zeolite against ASR

Influence of reactive aggregate content on the expansion of mortar bars--The maximum expansion due to alkali-silica reaction depends on a certain proportion of the reactive material in the aggregate known as 'pessimum' content. This proportion may be as low as 3-5% in the case of 'opal' or much higher, even up to 100% , with less reactive materials (Awal 1997). In order to obtain pessimum content of YD, mortar bars with six different mixes of 0, 5, 10, 20, 50, and 100% YD with Chinese standard sand as fine aggregate, were tested; the 14-day expansion are shown in Fig. 4.

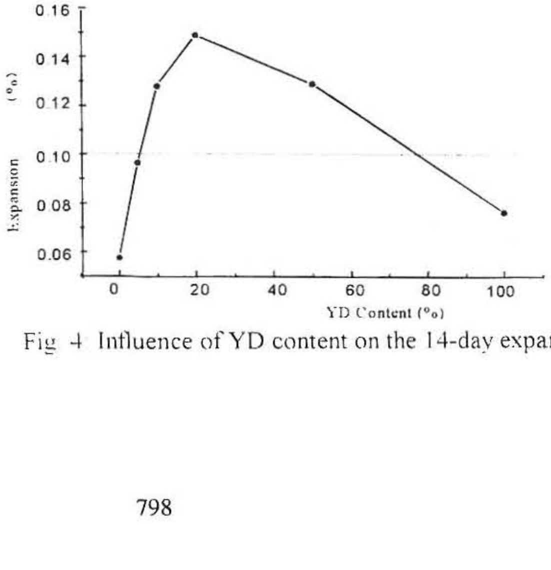

Fig. 4 Influence of YD content on the 14-day expansion

TEST RESULTS AND DISCUSSION

Evaluating Mineral Admixtures by Modified ASTM C441-89

Fig. 3 shows the effect of replacing a quarter of cement by various kinds of mineral admixtures on the expansion of mortar bars incorporating 5% fused silica at varying times of immersion in NaOH bath.

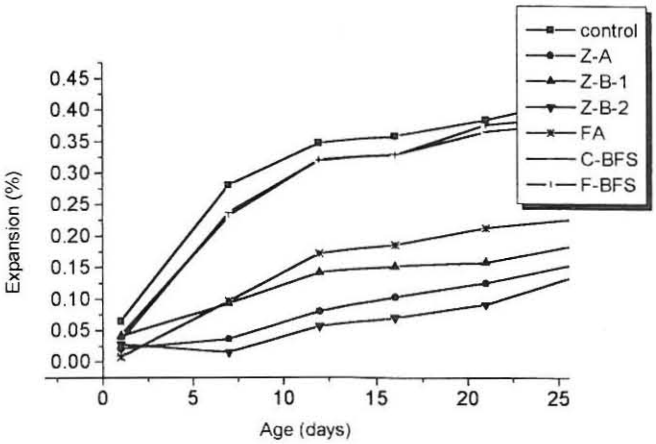

Fig. 3 Expansion curves of mortar bars in 1N NaOH solution in 80℃ vessel

As expected, in the control specimens, mortar bars incorporating fused silica showed 12-day expansion above 0.35%. The addition of zeolite or FA always reduce the expansion of mortar bars but BFS addition has little influence in reducing the expansion. All specimens show a continuous expansion through 28 days and have no sign of stopping expansion. The development of expansion is not uniform: the mortar bars expand faster in 1-14 days than in later age.

In ASTM C441-89, minimum values for the reduction of mortar expansion (Re) have been selected for use in specifications as a basis for acceptance of pozzolans proposed for use in combination with high-alkali cement and an aggregate known to be potentially alkali reactive. Table 2 show the (Re) at various time.

According to ASTM C441-89, test specimens made from the control mixture shall have a 14-day increase in length of at least 0.25% and a pozzolan is regarded as effective when the mortars containing this pozzolan show a Re greater than 75%. But this standard is specified in an environment of 40℃ and the aggregate are all Pyrex glass. In this investigation, the last specification is no longer satisfactory. From Figure 3, it can be seen that for the control, 7 days was enough to obtain an expansion greater than 0.25%. At that time, only two pozzolans induce a Re value greater than 75% (See Table 2). The Re values decrease with aging. If 50% of Re is acceptable, then Z-A, Z-B and FA can be regarded

Obviously, the pessimum content of YD is 20% when the expansion is 0.15%. It takes 14 days to finish this procedure to get the same conclusion which need 6 months by using traditional ASTM C227 method.

The suppressing effect of natural zeolite ,fly ash and blast-furnace slag--Fig. 5 shows the expansion curve of mortar bars containing pozzolans with recommended replacement level (Malhotra 1995, Feng 1992, Ramachandran 1998). The control bars with 20% YD show a 14-day expansion above the proposed boundary (0.10%). Dosage of about 30% for zeolite, 50% for BFS and 40% for FA are sufficient to reduce the expansion level below 0.10%. BFS or FA is less effective than zeolite, whose effectiveness is influenced by its fineness.

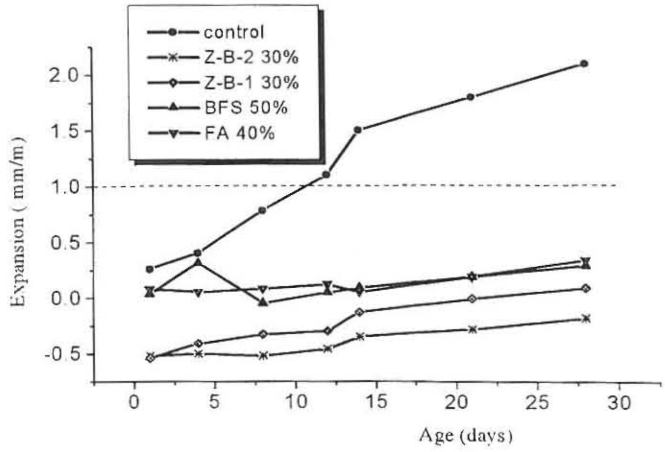

Fig. 5: Expansion of mortars mixed with or without mineral admixtures

The results is consistent with the early research using traditional methods (Feng 1997, 1998). It seems that the storage conditions of the test are suitable to accelerate the pozzolanic reactions of pozzolans such as natural zeolite, fly ash and blast-furnace slag (Berra 1996). This also reveals the potential of the accelerated method as a means for test the alkali reactive aggregate and for evaluating the effectiveness of mineral admixtures against ASR.

CONCLUSIONS

1. No other research findings on the use of modified ASTM C441-89 in evaluating the effectiveness of mineral admixtures on suppressing ASR are yet available to compare with the performance date obtained in this investigation. However, the test can discriminate the effect of natural zeolite, fly ash and blast-furnace slag.

2. Natural zeolite is more effective than fly ash or blast-furnace slag in suppressing

expansion of mortar bars due to alkali-silica reaction. The effect of zeolite is influenced by the fineness and the sources of the natural zeolite rock.

3. Accelerated test (NaOH bath method at 80℃) is suitable to detect the alkali reactive aggregate and can be used to evaluate the effectiveness of mineral admixtures against alkali-silica reaction.

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