# INFLUENCE OF COMPOSITE MINERAL ADMIXTURES ON EXPANSION AND CRACK DUE TO AAR

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## ABSTRACT

The effect and mechanism of the composite mineral admixtures (fly ash, zeolite and slag) on preventing the expansion and crack of concrete due to alkali-aggregate reaction (AAR) are described in this paper. The results showed that the expansion can be reduced, and the microstructure can be improved by adding the composite mineral admixtures. However, the composite mineral admixtures cannot absolutely diminish the alkali-aggregate reaction of mortar bars with lower-alkali cement and higher-reactivity aggregate, but the expansion values and deleterious expansions of mortar bar were reduced and further reduced with the increased amount of the composite mineral admixture. The fluidities of paste and strengths of mortar containing mineral admixture were also studied.

**Key words:** Composite mineral admixtures, alkali-aggregate reaction, expansion and crack

## 1. INTRODUCTION

In recent years, alkali aggregate reaction (AAR) that is usually a slow and quite complex chemical process has been one of the major factors affecting the durability of concrete structures. It is believed that siliceous materials, in the presence of the potassium or sodium hydroxides derived from cement, react to form an alkali silica complex that can expand by absorbing water. Alkali aggregate reaction has caused concrete losing its durability and large money consumption around the world in the past decades. Destruction of concrete structures caused by AAR has been found in China, such as Beijing, Shanghai, Shandong province, etc. As there has been no fundamental remedial method for the destruction caused by AAR to buildings, it is believed that adding mineral admixtures to concrete has been an effective measure to reduce AAR [1].

Up to now, the replacing part of cement by mineral admixtures, such as fly ash, slag or zeolite, when reactive aggregate used in concrete is an effective and economical measure to reduce AAR. It has been confirmed and widely accepted that a certain amount of fly ash can successfully reduce the AAR expansion. However, there still had some failure structures even with 20% to 25% fly ash. Zeolite can produce better reducing effect on AAR than fly ash and slag, due to its higher chemical reactivity. For an aggregate with high alkali reactivity, to suppress AAR efficiently, 30% natural zeolite powder with a specific surface area of 500~700 $m^2/kg$ is needed. However, if the natural zeolite powder with a specific surface area of 251 $m^2/kg$ is used, a content of 40% zeolite is required [2].

The practice that mineral admixtures or low-alkali cement are used to prevent AAR in concrete is well known. In those cases, more than 40% mineral admixtures would be added to concrete, which may cause the early strength losses and produce harmful effect on the properties of concrete. When 40% fly ash was added to the concrete, quite a lot of fly ash might float on the surface of concrete, which decrease the early strength and abrasion resistance of concrete. For zeolite with a strengthening and without dispersing effect on the concrete, and with a high demand for water, only 10%~15% is usually used in concrete. For 40% slag with dispersing and strengthening effects used in concrete, it may cause the water losses in concrete and bleeds. It is very difficult to use 40% fly ash, zeolite or slag solely in the design and construction of concrete structures. The applications of such amount of mineral admixture used in concrete are limited, and the AAR in concrete structures may only be reduced or delayed, but could not completely inhibit in practice [3] [4].

Most of the previous researches about mineral additives preventing AAR were focused on one of the mineral additives including fly ash, zeolite or slag. No research on the composite mineral admixtures consisting of fly ash, zeolite and slag for expansion and microstructure in AAR of concrete is found in the literatures. The suppression effects of composite mineral admixture on AAR were systematically studied in this paper.

## 2. EXPERIMENAL MATERIALS AND METHODS

### 2.1 Materials

The cement used in this study consisted of 96% clinker and 4% nature gypsum, from Nanjing cement plant, with specific surface area 400 $m^2/kg$. The zeolite was from Shandong Province, fineness 580 $m^2/kg$. The finenesses of blast furnace slag and fly ash were 630 $m^2/kg$ and 680 $m^2/kg$ respectively. The chemical compositions of these mineral materials are shown in Table 1. The superplasticizer was a dry naphthalene powder product from Tsinghua University, with a commercial name NF.

Two aggregates were used in the tests: reactive aggregate (silica glass sand) and non-reactive aggregate (quartz sand).

Table 1 Chemical composition of the raw materials

| Item | Chemical composition /% by weight | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Loss | $R_2O$ | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | Σ |
| Cement | 2.97 | 0.80 | 20.41 | 4.81 | 2.88 | 63.86 | 1.52 | 2.03 | 99.28 |
| Fly ash | 3.25 | 1.37 | 58.09 | 20.62 | 9.55 | 2.65 | 1.14 | 0.56 | 97.23 |
| Zeolite | 8.54 | 4.74 | 67.66 | 11.48 | 1.12 | 2.58 | 0.66 | 0.40 | 97.18 |
| Slag | 1.81 | 1.25 | 32.94 | 13.46 | 3.01 | 35.95 | 9.44 | 0.45 | 98.31 |

### 2.2 Methods

The mortar strength was measured according to China National Standard GB177-85. The dimensions of mortar specimens are 40 mm × 40 mm × 160 mm, w/c = 0.44, c/s = 2.5. The mortars were mixed and moulded by vibration. After being placed in a fog room (20℃, 90% RH) for 24 hours, the specimens were demoulded and then cured in water at 20 ± 3℃ for 3, 7 and 28 days. The fluidities of paste with composite materials were determined according to China National Standard GB2419-1981.

The alkali-aggregation reaction was examined according to reference [5][6]. The mortar was made of cement and non-reactive aggregate (quartz sand) or reactive aggregate (silica glass sand), size 0.15-0.63 mm. The specimens, with a size of 10 mm × 10 mm × 60 mm, w/c = 0.30, and a ratio of cement to aggregate = 10, were cured in a fog room (20℃, 90% RH) for 24 hours and then cured in 100 ℃ steam for 4 hours. After steam curing, the specimens were put in an autoclave with 10% KOH solution at 150℃ for 6 hours. The expansions of specimens due to AAR were calculated, the microstructure of mortar was observed by SEM.

## 3. RESULTS AND DISCUSSION

### 3.1 The fluidities of paste with mineral admixtures

Table 2 shows the fluidity values of pastes with or without mineral admixtures. It can be seen that for the paste with slag, the fluidity values show more change with time, the loss of fluidity values with slag are higher than that with fly ash and composite mineral material. When zeolite replacing 40% of cement, there is a significant drop in fluidity values compared to the control. When 40% of cement is replaced by fly ash or composite mineral material separately, there is little difference in fluidity values between them, but that values are much higher than that of the control.

Table 2 Fluidity results of paste /cm

| Item | Cement /g | Content of additive /g | NF /g | W/B | Fluidity | |
|---|---|---|---|---|---|---|
| | | | | | 0 h | 1.5 h |
| Control | 400 | 0 | 2.4 | 0.30 | 17.0 | 14.0 |
| Zeolite | 240 | 160 | 2.4 | 0.30 | 11.0 | 10.0 |
| Fly ash | 240 | 160 | 2.4 | 0.30 | 26.0 | 25.0 |
| Slag | 240 | 160 | 2.4 | 0.30 | 28.0 | 21.0 |
| Zeolite + Fly ash + Slag | 240 | 160 | 2.4 | 0.30 | 27.0 | 25.0 |

3.2 The compressive strengths of mortar with mineral admixtures

The formulation and the results of mortar strength with and without mineral admixtures are shown in Table 3. The item used as a control was Portland cement without blend materials.

Under same conditions such as water to binder ratio and curing condition, the early strength (3 days) and later strength (28days) of mortar with zeolite or fly ash are lower than that of the control, but those of mortar with slag or composite mineral material are higher than that of the control. From Table 2 and 3 results, it can be seen that the effect of composite mineral material to mortar in the fluidity values of pastes and strength of mortar is better than other materials only used.

Table 3 Strength results of mortars /MPa

| Item | Cement /g | Content of additive /g | Sand /g | NF /g | W/B | Compressive strength | |
|---|---|---|---|---|---|---|---|
| | | | | | | 3 d | 28 d |
| Control | 540 | 0 | 1350 | 3.24 | 0.44 | 41.2 | 64.0 |
| Zeolite | 324 | 216 | 1350 | 3.24 | 0.44 | 28.2 | 46.0 |
| Fly ash | 324 | 216 | 1350 | 3.24 | 0.44 | 26.0 | 48.0 |
| Slag | 324 | 216 | 1350 | 3.24 | 0.44 | 46.0 | 68.0 |
| Zeolite + Fly ash + Slag | 324 | 216 | 1350 | 3.24 | 0.44 | 43.2 | 65.0 |

3.3 Alkali-aggregate reaction

In order to determine the restriction ability of composite mineral material to alkali-aggregate reaction, reactive aggregates and non- reactive aggregates were used. The expansion values and alkali-aggregate reactions of mortar were measured and observed by a scanning electron microscopy.

The results in Table 4 shows that the both expansion of mortar bars made from mortar without and with 40% composite mineral material when containing non-reactive aggregates and autoclaved at 150 ℃ were very low, only 0.02%. By examination under a scanning electron microscopy, the alkali-aggregate reactions were not observed in either the mortar containing 40% composite mineral material or the control in case of non-reactive aggregate (Fig. 1a and 1b).

(1a) Without composite mineral material

(1b) With 40% composite mineral material

Fig 1. SEM photograph of mortar with non-reaction aggregate

When reactive aggregates were used in the mortar, significant expansions were observed after autoclave at 150℃, up to 0.28%. At the same time, the cracks typical for alkali-aggregate reactions appeared on the surface of mortar bar without mineral material, and were not founded obviously on the surface of mortar bars with 20% or 40% composite mineral material, but the micro-cracks cause by alkali-aggregate reaction on the mortar bars containing 40% composite mineral material have been observed by scanning electron microscopy, with the depth of 600 nm approximately (Fig. 2).

Table 4 Expansion of alkali-aggregate reaction (%)

| Item | No mineral material | 20% mineral material | 40% mineral material |
|---|---|---|---|
| Non-reactive aggregate | -0.03 | 0.02 | 0.01 |
| Reactive aggregate | 0.28 | 0.22 | 0.18 |

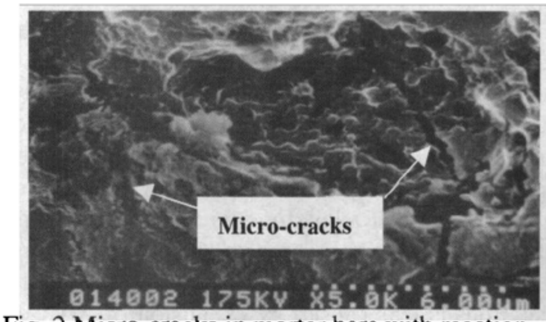
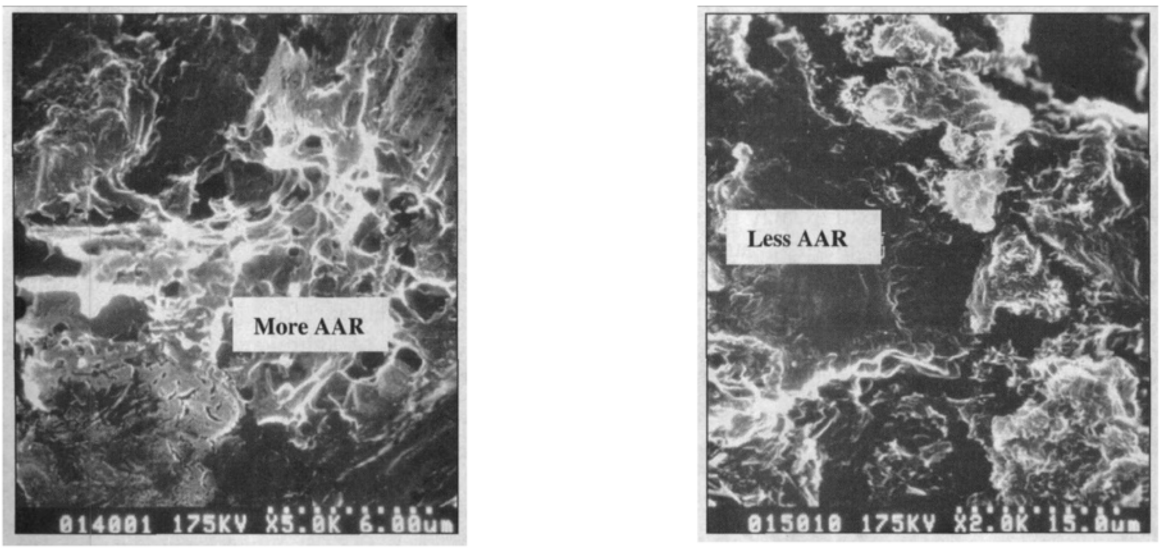


Fig. 2 Micro-cracks in mortar bars with reaction aggregate and 40% composite mineral material

When the cement replaced by composite mineral material, the expansion values of mortar were decreased. Analyzing the mortar bars with a scanning electron microscopy, alkali-aggregate reactions were founded in either mortar containing 40% composite mineral material or the control (Fig. 3b and 3a). More alkali-aggregate reactions occur in the mortar without mineral material (Fig. 3a), while less in the mortar containing 40% composite mineral material (Fig. 3b).



(3a) Without composite mineral material (3b) With 40% composite mineral material

Fig 3. SEM photograph of mortar with reaction aggregate

## 4. DISCUSSION

The mineral admixtures may reduce the alkali-aggregate reaction, but the preventive effects and mechanisms are different from each other. As has been discussed above, the mechanism of slag and fly ash reducing alkali-aggregate reaction are very similar. When slag and fly ash is hydrated, the alkali content that is inevitably released to the pore solution from cement may be decreased. For zeolite, due to the ions exchange of zeolite, the concentration of sodium and potassium ions in the mortar may be lowered, and the formation of gels and alkali-aggregate reaction can be suppressed.

Composite mineral admixtures replacing the same amount cement in mortar, through pozzolanic reaction and ions exchange of slag, fly ash and zeolite respectively, the basicity of mortars will be lowered [7]. The co-effects of composite mineral admixtures for preventing alkali-aggregate reaction are developed. More alkali may be retained in the hydration products, and the alkali-aggregate reaction is reduced. The more the composite mineral admixtures is used, the lower the basicity of mortar bars is, so the preventing AAR effect may be improved. Although the preventing effect of composite mineral admixtures is very good, owing to the alkali, reactive aggregate and water existing, the alkali-aggregate reaction may still occur, but the deleterious cracks caused by expansion of AAR on the surface of mortar bars are not be found after 40% composite mineral admixtures replacing the same amount of cement.

It should be noted that the above discussion centered on the study of the preventive AAR effect of the composite mineral admixtures is mainly based on the high reactive aggregate. Obviously, the composite mineral admixtures may change the physical structure and reduce the pore distribution of the mortars, so these factors may influence the expansion results and preventive alkali-aggregate reaction effects. Further works on these problems will be done in the future.

## 5. CONCLUSION

The composite mineral admixtures may decrease the expansion and crack of mortar caused by alkali-aggregate reaction, but cannot absolutely diminish the alkali-aggregate reaction of mortar containing reactive aggregate. The more the composite mineral admixtures replacing cement are used, the lower the alkali-aggregate reaction is.

When composite mineral admixtures replacing up to 40% of cement in paste or in mortar, the fluidities of paste or strengths of mortar may be suitable in use.

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