

**EFFECTIVENESS OF MINERAL ADMIXTURES IN CONTROLLING
ASR EXPANSION**

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1. INTRODUCTION

Alkali silica reaction (ASR) is now known to be capable of causing considerable damage to concrete structures, which may sometimes even lead to their failure. Although the occurrence of such reaction is limited when one considers the large number of concrete structures built, the reaction can cause serious problems of serviceability when it does occur. It is therefore important to consider at the design stage the possible damages arising from ASR, and to minimise the risk of its occurrence by choice of suitable materials, and appropriate design.

The most practical and beneficial means of controlling ASR expansion is probably through part replacement of cement by mineral admixtures such as fly ash, ground granulated blastfurnace slag and silica fume. A number of studies on the use of these and other natural and artificial pozzolans to control ASR expansion have been reported in literature. In spite of much detailed research, there are several aspects of the role of mineral admixtures in ASR that are not yet fully understood. For example, there appears to be no single explanation on the mechanism of pozzolanic reactions and control of ASR expansion. Further, the effect of pozzolanic additions on ASR is highly variable, and the effectiveness very much depends on the type of reactive aggregate, the type of mineral admixture, the method of replacement etc. Whilst there is a lot of evidence on mortar bar tests to show that pozzolans can reduce or even eliminate ASR expansion, there is also test data to show that materials judged as effective pozzolans by ASTM tests, sometimes even increase ASR expansion.

In this paper, some test data are presented to evaluate the effectiveness of fly ash, slag and silica fume in controlling and/or reducing ASR expansion in concrete.

2. EXPERIMENTAL DETAILS

Normal portland cement of ASTM Type 1 with a high alkali content of about 1% sodium oxide equivalent was used in these tests. The fine aggregate was a washed and dried natural sand, while the coarse aggregate consisted of a mixture of rounded and crushed gravel with 10 mm maximum size. Two types of

reactive aggregate were used - Beltane opal as partial replacement of fine aggregate or a synthetic reactive mineral, an amorphous fused silica, again replacing part of the fine aggregate. [1]

Only one type of low calcium Type F fly ash, slag and silica fume were used. The fly ash had acid soluble alkali of 3.47% sodium oxide equivalent; the slag had a relatively lower alkali, 0.65% sod. oxide eq., and the silica fume had a very low alkalinity, less than 0.31% sod. oxide eq. The mineral admixtures were used as partial but direct replacement of cement, weight for weight. The mixes were designed to develop nearly the same rate of strength with age as concrete without the admixture. A superplasticizer was used to achieve this; it was also known that the superplasticizer will make some contribution to the alkali content.

3. EFFECTIVENESS OF FLY ASH

The effectiveness of fly ash was monitored on reinforced concrete beams, 75 x 100 x 800 mm, containing both tension steel and links in the outer middle third shear spans. The concrete mix had a high cement content of 520 kg/m³, and opal was used as reactive aggregate. 30% and 50% cement replacements were used in these tests. The beams were cured at 20°C and 96% RH. Various measurements were taken on the beams, but only the concrete strains at the compression face (unrestrained by steel) are reported here. The results are shown in Table 1, where the concrete alkalinity is based on the portland cement alone.

Table 1. Test results on fly ash concrete

Mix	Cement kg/m ³	Fly ash kg/m ³	Alkali kg/m ³	Cube st MPa	Expansion μs
1	520	-	5.20	60.0	12,900
2	364	156	3.64	60.0	4,370
3	260	260	2.60	60.9	500

The results show that at 30% fly ash replacement level, although the concrete strength is restored, the fly ash is not adequate to prevent detrimental disruption of concrete due to ASR. Although the maximum concrete strain was reduced by nearly 70%, residual strains of about 4400 μs still remained. At 50% replacement level, there was a dramatic reduction of concrete expansion, but even then expansive strains of 500 μs remained. In a well designed beam such expansions should not induce serious cracking; nevertheless, compatible strains and stresses will be induced in the tension steel, and this would have to be superimposed on load induced stresses.

The question now arises as to whether the alkalinity in the fly ash and superplasticizer contribute to the expansion of concrete. To assess this, the alkalinity of the cement, fly ash and superplasticizer have been combined, and the results are presented in Table 2. Also shown in the Table are the measured (or estimated) strains from plain concrete control prisms having

cement alkalinity alone. The data clearly show that the expansions recorded in the RC beams in no way represent the effect of the total alkalinity of the mixes shown in Table 2.

Table 2. Expansion related to total alkalinity

Mix	Cement kg/m ³	Ash + sp kg/m ³	Total alkali kg/m ³	Expansion, μs	
				Prisms *	Beams
1	5.20	-	5.20	16,500	12,800
2	3.64	5.71	9.35	3,400 ⁺	4,370
3	2.60	9.52	12.12	800	500

* Measured or estimated⁺ strains due to cement alkalinity alone i. e. for 5.20, 3.64 and 2.60 kg/m³ sod. oxide eq. at 20° C and 96% RH.

It is thus quite clear, and safe to conclude, that the alkali bound in the ash and superplasticizer do not contribute to the total alkali in the concrete, and its expansion. On the other hand, PFA exercises a distinct control on the expansion of concrete affected by ASR. Although the expansion is not completely eliminated, a substantial reduction in expansion occurs. It is clear that the alkali bound in the ash is not released during the chemical reaction between alkali in the cement and the reactive aggregate.

4. ROLE OF EXTERNAL ALKALIES

Real life structures are different from laboratory tests and laboratory specimens. They often receive alkalis from outside sources such as deicing salts and ground water. They are also often exposed to different rates of sunshine and rain so that moisture evaporation and moisture gradients will be different locally. In real life situations there is thus nearly always a concentration gradient of alkalis; and locally, the alkali salt concentration may exceed the assumed minimum value in design. Thus, ASR expansion could occur locally even if all other conditions in terms of material combinations and environment, may be favourable for the prevention of deleterious expansion.

To illustrate this, some test data are presented below where external alkalis are introduced in the presence of mineral admixtures. The results may not be readily comparable in terms of the effectiveness of these admixtures: rather, they are presented to highlight the complex issues involved with ASR.

4.1 Tests With Fly Ash

The concrete mix used in these tests had 300 kg/m³ cement content, 50% of the cement was replaced with fly ash. The alkali content of the concrete was then adjusted to 3.0, 4.0 and 6.0 kg/m³ (excluding the alkalis in the ash and superplasticizer) by adding dissolved sodium hydroxide pellets in the mix water. A synthetic reactive aggregate, fused silica, was used in these tests [1].

The test specimens were exposed to water environment at 38-40°C at 1 day. The one year expansion results are shown in Table 3.

Table 3. Fly ash : one year expansion results

Alkali content - kg/m ³			Expansion %
Cement	Added	Total	
3.0	0	3.0	0.288
1.5	1.5	3.0	0.170
1.5	2.5	4.0	0.180
1.5	4.5	6.0	0.164

The results show similar amounts of expansion when high levels of alkali are added to the concrete. This indicates that under certain conditions there may be an upper alkali limit at which the pore solution reaches a saturation limit. At high levels of PFA replacement, a critical limit of alkalies could thus exist. Beyond this limit, any alkali contribution from any source has little or no effect. These results are consistent with the findings reported earlier by the authors [1] where it was found for concrete without fly ash that there is an upper alkali limit beyond which any additional external alkali is not fully effective in creating further expansion. Thus, it seems there is an upper alkali limit for both concretes without and with fly ash. It may be that at high alkali contents, the gel may become more fluid and dissipate itself harmlessly in the paste matrix [2].

4.2. Tests With Slag

The same portland cement and the same concrete mix as for fly ash tests were used, with 300 kg/m³ cement content. 50% of the cement was replaced with slag. The alkali content of the concrete was then increased to 3.0, 4.0 and 6.0 kg/m³ (excluding the alkalies in the slag) by dissolving sodium hydroxide pellets in the mixing water. As before, a synthetic reactive aggregate, fused silica, was used [1]. All the test specimens were cured in water at 38-40°C at 1 day. The expansion data at one year are shown in Table 4.

Table 4. Slag : one year expansion results

Alkali content - kg/m ³			Expansion %
Cement	Added	Total	
3.0	0	3.0	0.288
1.5	0	1.5	0.126
1.5	1.5	3.0	0.382
1.5	2.5	4.0	0.553
1.5	4.5	6.0	0.657

The results show that with no external alkali present, 50% slag replacement of cement reduced the expansion by about 55%; it should be borne in mind that no or very low expansion would be expected at 1.5 kg/m³ sod. ox. eq. However, when additional external alkalies were introduced into this slag concrete

mix to enhance the total alkali content to 3.0, 4.0 and 6.0 kg/m³, substantial increases in expansion of about 200% to 420% were measured.

Although the data presented here are limited, they form part of a more extensive study which space restrictions preclude from reporting. Nevertheless, these data raise several aspects on the role and effectiveness of slag in controlling ASR expansion. It may well be that slag at this level of replacement is inadequate to control deleterious ASR expansion. On the other hand, there is also evidence that slag aggravates expansion at low alkali levels while reducing expansion at high alkali levels [3]. Thus there is possibly a pessimum alkali content for slag also. Equally, the high temperature and the presence of moisture may favour the decomposition of the slag [3].

4.3 Tests with Silica Fume

The concrete mix used for these tests was identical to that used with fly ash and slag with 300 kg/m³ cement content and concrete alkali content of 3.0 kg/m³. The same reactive aggregate, fused silica, was used. The silica fume had acid soluble alkali content less than 0.31 sod. ox. eq. Two cement replacement levels were used : 10% and 30%. The alkali content of the concrete was increased as before to 3.0 and 6.0 kg/m³ (excluding alkalis in the silica fume) by externally added alkalis in the mixing water. All the concrete specimens were demoulded at one day, wrapped in polythene and cured initially in the laboratory for 7 days, and then exposed to water storage at 38-40°C.

The data on expansion with 10% silica fume replacement are not reported here. The results, however, showed that 10% silica fume was not adequate enough to control ASR expansion; in fact, it had only a slight effect on expansion without external alkalis. With the presence of additional available alkalis, the presence of silica fume at this level produced higher expansions compared to concrete without silica fume.

At 30% replacement level, however, silica fume achieved substantial reductions in ASR expansion as shown in Table 5. However, it was also clear that this level of replacement is necessary to ensure that damage does not result from ASR at any alkali level. The results also showed that the reduction in expansion was not proportional to the percentage of silica fume replacement.

Table 5. Silica fume:expansion at 210 days

Alkali content, kg/m ³			Expansion %
Cement	Added	Total	
3.0	0	3.0	0.284
2.1	0	2.1	0.020
2.1	0.9	3.0	0.028
2.1	3.9	6.0	0.012

5. CONCLUSIONS

The data presented here form part of more extensive studies not reported here. In spite of difficulties in interpretation, these studies indicate that cement replacement materials can give useful protection against ASR expansion, provided they are used in sufficiently large enough quantities. The reduction in expansion is generally not proportional to the percentage of cement replacement. At low replacement levels, the presence of additional free alkalis has a significant effect on expansion; at higher replacement levels their effect is only slight or negligible. The rate of reactivity, the type of mineral admixture, the replacement level, the method of replacement and the environment have all a profound influence on the protection against ASR afforded by mineral admixtures.

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