Comparison of the Effectiveness of Four Mineral Admixtures to Counteract Alkali-Aggregate Reaction

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ABSTRACT

Two fly ashes, one silica fume and one granulated slag were used as admixtures to test the effectiveness of these pozzolans in reducing expansion of concrete due to alkali-aggregate reaction. Standard mortar bar (ASTM C-227) and concrete prism (CSA.A23.2-14A) expansion tests were used to show the effects. Three type of aggregate were used, to represent the best known alkali-aggregate reactions:

1) Trois-Rivières siliceous limestone--alkali-silica reactive;
2) Kingston dolomitic limestone--alkali-carbonate reactive;
3) Lady Evelyn Lake argillite--alkali-silica/silicate reactive.

Other experimental work included the measurement of $Ca(OH)_2$ content in the cement pastes, and microstructural examination of the pastes by scanning electron microscopy.

The effectiveness of the mineral admixtures in reducing expansion was different for each of the three aggregates. $Ca(OH)_2$ measurements and scanning electron microscopy revealed important differences related to the type of mineral admixture used and its replacement levels.

INTRODUCTION

In this investigation, four Canadian mineral admixtures were tested to determine their effect on the reactions between alkalies and three Canadian aggregates that produce the best known alkali-aggregate reactions:

1- Siliceous limestone from Trois-Rivières, Que., representing the alkali-silica reaction;
2- Dolomitic limestone from Kingston, Ont., representing the alkali-carbonate reaction; and
3- Argillite from a dam site at Lady Evelyn Lake, Ont., representing the alkali-silica/silicate reaction.

The four selected mineral admixtures were:

1- Granulated slag from the St.Catharines (Ont.) blast furnace;
2- Silica fume from the Becancour (Que.) Fe-Si plant;
3- Fly ash from the Lingan (N.S.) thermal plant; and
4- Fly ash from the Thunder Bay (Ont.) thermal plant.

Table 1 - Physical and chemical data on the mineral admixtures and cement.

	Thunder Bay Fly Ash (Ont.)	Lingan Fly Ash (N.S.)	St. Catharines Slag (Ont.)	Becancour Silica Fume (Que.)	Cement (Type 10)
SiO_2	41.8	44.9	38.9	95.4	21.0
Al_2O_3	22.7	25.8	6.6	0.1	4.3
Fe_2O_3	3.9	19.1	1.1	-	2.4
CaO	12.9	1.4	34.2	0.3	63.2
MgO	-	0.9	12.4	0.7	2.5
Na_2O	3.1	0.5	0.3	0.02	0.3
K_2O	6.3	3.2	0.5	0.7	1.0
SO_3	0.8	0.7	3.3	0.24	2.93
Mn_2O_3	7.8	0.8	1.5	-	-
L.O.I.	0.8	2.9	-.38	1.8	2.1
TOTAL	100.0	100.2	98.3	99.4	99.7
Total Alkali	6.8	2.6	0.6	0.5	1.0
Soluble Alkali	2.3	0.07	0.01	0.12	0.61
Carbon Content	4.3	2.5	0.8	-	-
Blaine (cm^2/g)	6120	3190	4280	43,750	-
% Passing 325 mesh	96.7	85.5	82.9	98.3	-
Pozzolanic Activity with cement	141	94	93	119	-

TEST MATERIALS

Description of the aggregates

The Trois-Rivières aggregate is from the St-Casimir member of the Middle Ordovician Neuville Formation (Trenton Group). It is a fine-grained, slightly argillaceous limestone with some rich fossil zones. Most fossils are calcite, but some are silicified. Silica is also finely disseminated in a microspar matrix. The HCl-insoluble residue of the aggregate is between 4% and 12% (mostly illite, also quartz, silicified fossils, dissemenated silica, feldpars, chlorite, and pyrite). The petrographic equivalent of this limestone is widespread in Quebec, and many cases of alkali-reactivity have been attributed to limestone aggregates similar to the one from the Trois-Rivières area [1-4].

The Kingston aggregate is from the Middle Ordovician Gull River Formation, equivalent to the Black River Formation. It is an argillaceous dolomitic limestone, fine-grained and slightly fossiliferous. Small dolomite rhombs are scattered in a calcitic mud containing clay, quartz and feldspars (55% calcite, 27% dolomite and 18% insoluble residue). Alkali-carbonate reaction in Canada is limited to the province of Ontario, but many cases have been reported elsewhere [Swenson and Legget 1960, Hadley 1961].

The Lady Evelyn Lake aggregate is a Proterozoic rock from the Cobalt Group (Huronian) of the Canadian Shield. It is a slightly metamorphosed and slightly calcareous argillite consisting of alterning silty and clayey beds intersected by small veins of calcite and chlorite. The most abundant minerals are illite, quartz, feldspars and chlorite [Dolar-Mantuani 1985].

Description of the mineral admixtures

The physical and chemical characteristics of the four mineral admixtures are given in Table 1. Two facts should be emphasized: 1) the Becancour silica fume has a high SiO_2 content and a high specific surface area, and 2) Lingan fly ash has a relatively low soluble alkali content whereas the Thunder Bay fly ash has an alkali content higher than that of the cement.

Experimental work

The Trois-Rivières and Lady Evelyn Lake aggregates were subjected to mortar bar expansion tests (ASTM C-227), whereas the Kingston aggregate was subjected to concrete prism expansion tests (CSA.A23.2-14A). Other experimental work included measuring the $Ca(OH)_2$ content by thermogravimetric analysis, and studying the micromorphology of pastes containing mineral admixtures. The samples were pastes of cement + mineral admixture made with the same water-cement ratio (w/c=.48) used for the ASTM C-227 expansion tests.

The micromorphology studies were done with a scanning electron microscope on mortar pastes having the same characteristics as the ASTM C-227 mortar bars containing the Lady Evelyn Lake aggregate.

Curing conditions of the samples used for thermogravimetric analyses and micromorphology studies were 37^oC and 95% R.H. Samples were 7 months old when the experiments were done.

RESULTS

Expansion tests

Figure 1 shows all the results from the expansion tests. The Y-axis shows the percent change of length of samples with mineral admixtures compared with the control samples, the X-axis shows the different mineral admixtures and their level of replacement. The effectiveness of the mineral admixtures in reducing expansion was different for each of the three aggregates.

With the Trois-Rivières limestone, Thunder Bay fly ash reduced expansion the most- 100% reduction at 6 months with a replacement level of 30%. In decreasing order of efficiency are the Becancour silica fume, the Lingan fly ash and, lastly, the St.Catharines granulated slag.

With Kingston dolomitic limestone, the St.Catharines granulated slag was the most efficient - 78% reduction at 3 months with replacement levels of 50% and 65%. The Lingan fly ash, the Becancour silica fume and the Thunder Bay fly ash follow in decreasing order of efficiency. Thunder Bay fly ash actually increased expansion compared to the control samples - 82% increase at 3 months with replacement levels of 20% and 30%.

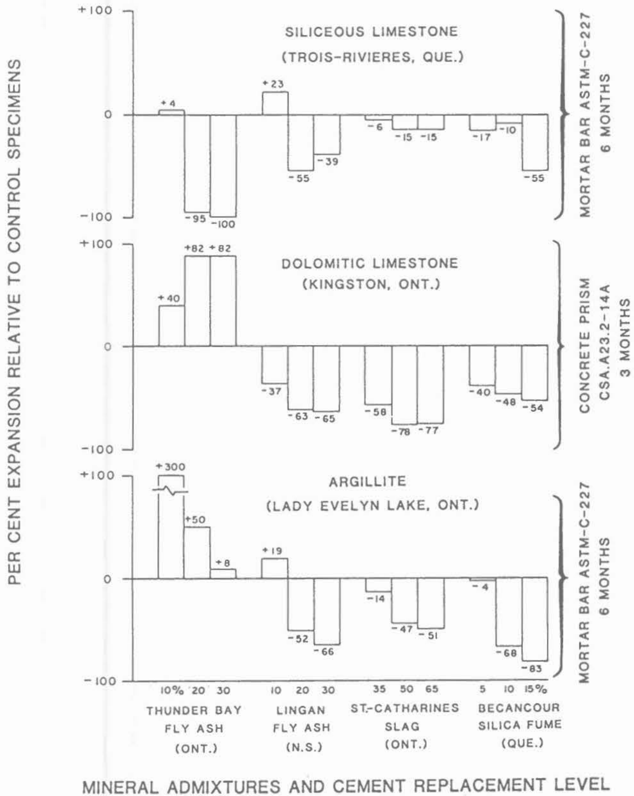

Fig. 1 - Results of the expansion tests.

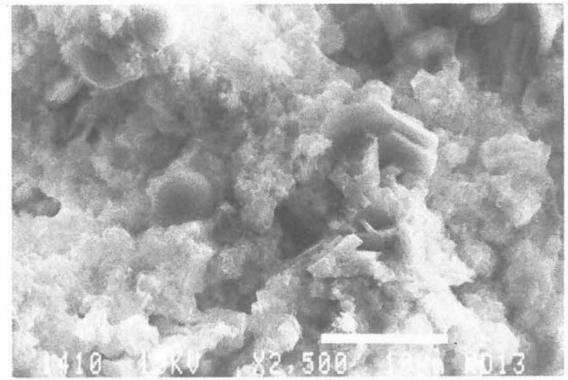

Fig. 3 - 30% Thunder Bay fly ash paste.

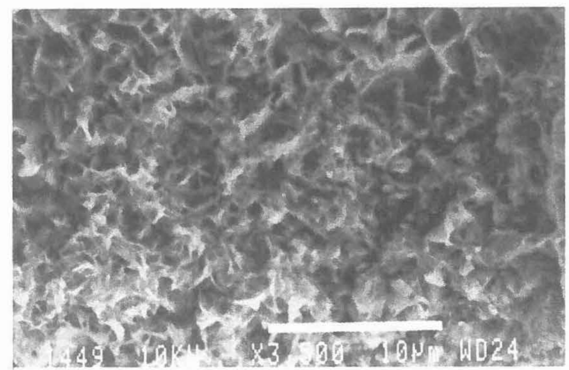

Fig. 4 - 15% Becancour silica fume paste.

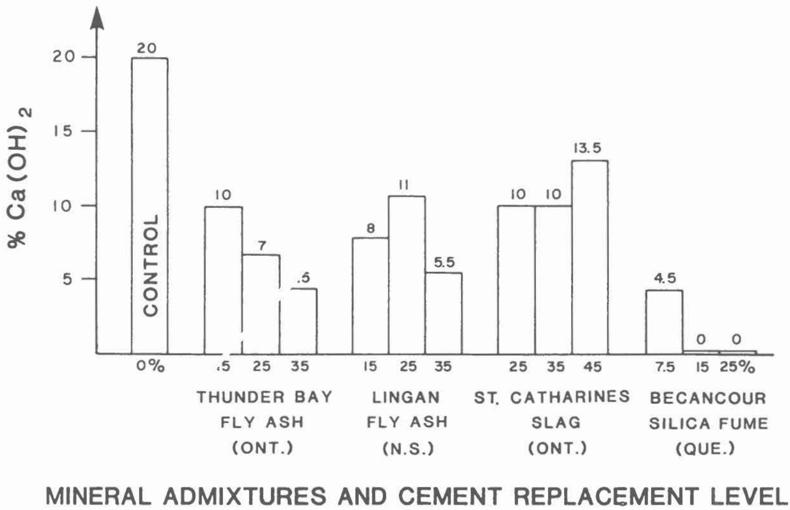

Fig. 2 - $Ca(OH)_2$ content of the mixes.

With Lady Evelyn Lake argillite, the Becancour silica fume reduced expansion the most - 85% reduction at 6 months with a replacement level of 15%. The Lingan fly ash, the St-Catharines granulated slag and, lastly, the Thunder Bay fly ash follow in decreasing order of efficiency.

$Ca(OH)_2$ measurements

Figure 2 shows $Ca(OH)_2$ analyses of samples 7 months old. The $Ca(OH)_2$ content of the sample without mineral admixture is 20% whereas it is consistently lower with mineral admixtures. The Becancour silica fume was the only additive to consume all of the $Ca(OH)_2$ produced by hydration of the portland cement, at a replacement level of 15% or more.

Micromorphology studies

Figures 3 and 4 show photomicrographs of some samples selected to represent the main characteristics of the mortar pastes with the different mineral admixtures. Of all the pastes examined, the one with Becancour silica fume, especially at 15% cement replacement, appears the most dense.

Supplementary observations of the pore contents of the same samples revealed the presence of silica gel in the pores of samples containing Thunder Bay and Lingan fly ashes at 15% replacement levels.

Finally, $Ca(OH)_2$ crystals are generally observed in the pores of all samples. For those containing 15% or more of Becancour silica fume, the crystals appear to be only pseudomorphs of $Ca(OH)_2$ crystals, because X-ray fluorescence analyses reveal the presence of silicon in addition to calcium.

DISCUSSION AND CONCLUSION

According to the results of the expansion tests, the characteristic alkali-carbonate reaction observed with the Kingston dolomitic limestone is caused mainly by the soluble or available alkalies of the cement + mineral admixtures. Thus, the main factor in controlling the alkali-carbonate reaction is either the dilution or the concentration of the cement alkalies by the mineral admixtures.

For the Trois-Rivières siliceous limestone and the Lady Evelyn Lake argillite, the results of expansion are less definitive and it seems that a combination of factors, instead of one predominent factor, should be taken into account. The soluble or available alkali content of the mixes could play a prominent role, but other factors such as the amount of $Ca(OH)_2$ available, the permeability of the pastes and the nature of the alkali-aggregate reaction involved should also be considered.

An important conclusion arising from this study is that the role and the efficiency of mineral admixtures vary according to the type of alkali-aggregate reaction involved. A mineral admixture that efficiently counter-acts a type of alkali-aggregate reaction could be quite inefficient for reducing another type of alkali-aggregate reaction.

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