The Effectiveness of Twelve Canadian Fly Ashes in Suppressing Expansion Due to Alkali-Silica Reaction

C. Perry
Structures Department
Southern Alberta Institute of Technology
Calgary, Alberta, Canada

R.L. Day, R.C. Joshi, B.W. Langan and J.E. Gillott
Department of Civil Engineering
The University of Calgary
Calgary, Alberta, Canada

ABSTRACT

Fly ashes with wide ranges of physical and chemical properties were obtained from twelve sources across Canada. They were used to replace 20%-40% by weight of cement in mortar bars containing reactive opal and expansions were monitored for a period of 12 months. The quantity of fly ash required to reduce expansion to below a limit of 0.1% at six months varied from less than 20% to more than 40%. The reduction in expansion at 12 months ranged from 5% to 81% at 20% replacement, 34% to 89% at 30% replacement, and 47% to 92% at 40% replacement. Regression analyses were carried out to relate performance to a number of physical and chemical properties of the fly ashes. Some reasonable correlations were found; however, more fundamental work is required to identify the principal characteristics responsible for the range in performance of the fly ashes.

INTRODUCTION

An accepted method of limiting the expansion of concrete due to alkali-silica reaction is the use of fly ash as a partial cement replacement. The amount required depends on the source of the fly ash and can vary from 20% to more than 40% by weight of Portland cement. The characteristics of fly ash that determine its effectiveness are largely unknown, and the mechanism by which expansion is reduced has not been definitely established.

An extensive program of research is currently underway at the University of Calgary aimed at increasing the utilization of fly ash in concrete. Physical and chemical characteristics of 12 fly ashes from across Canada have been studied in detail, and in this paper, an attempt is made to relate these properties to the effectiveness of the various fly ashes in reducing expansion due to alkali-silica reaction.

EXPERIMENTAL WORK

A modification of ASTM C227 (ASTM, 1983) was used in which longterm expansion data were obtained for mortar bars containing reactive opal and each of the 12 fly ashes added at cement replacement levels of 20%, 30% and 40% by weight. The opal was obtained from Ward's Natural Science Establishment (Source: Virgin Valley, Nevada, USA), and was blended with a non-reactive limestone aggregate at the "pessimum" amount (4%). Both the opal and the limestone was graded according to the requirements of ASTM C227. A water/cement ratio of 0.47 was used in all mixes regardless of flow and the mix volume was kept constant by adjusting the amount of the #50-#100 limestone size fraction to allow for the different cement and fly ash densities. Sodium hydroxide was added to the mix water to boost the alkali content of all mixes to 1.0% (equiv. Na_2O) by weight of cementitious material. The amount required in each case was calculated using the acid soluble value for the cement (0.42%, equiv. Na_2O) and the water soluble value for each of the fly ashes determined by the method of ASTM C114 (ASTM, 1982). Control specimens were cast containing either no fly ash or 30% fly ash and no opal. All mixes were prepared in duplicate. The mortar bars were stored at 23°C and 100% RH and length change data were obtained for a period of 12 months.

RESULTS AND DISCUSSION

Expansion data and relevant physical and chemical properties are summarized in Table 1 where the fly ashes are ranked in order of decreasing effectiveness. Ability to suppress expansion varied considerably and Fig. 1 compares the behaviour of three widely differing fly ashes.

Table 1. Expansion Data and Properties of 12 Canadian Fly Ashes (at age of 12 months)

FLY ASH SOURCE	EXPANSION (%) Replacement			PRINCIPAL OXIDES (percent)				ALKALIS (eq. Na_2O)		BLAINE	N_2 ADS.	RTD 45µm	LOI	PAI		WATER SOLUBLE SILICA
	20%	30%	40%	CaO	SiO_2	Al_2O_3	Fe_2O_3	Acid	H_2O	(cm²/g)	(m²/g)	(%)	(%)	PC (%)	LIME (%)	µg/g
POPLAR RIVER Sask. (LIG)*	.069	.039	.029	16.5	52.6	24.0	4.5	1.8	0.07	4990	1.14	2.8	0.5	166.4	13.0	195
DALHOUSIE I N.B. (BIT.)	.111	.077	.035	4.3	41.5	18.4	26.5	1.0	0.04	3100	2.68	21.4	5.1	93.6	6.4	195
WABAMUN Alta. (S.B.)	.127	.105	.041	10.3	58.8	22.2	3.9	0.8	0.01	4150	1.52	32.0	0.4	77.7	7.0	660
DALHOUSIE II N.B. (BIT.)	.143	.066	.043	2.7	35.5	14.4	38.6	1.8	0.04	1800	0.43	26.4	0.3	79.5	3.8	130
BOUNDARY DAM Sask. (LIG)	.147	.081	.041	15.3	44.3	21.1	3.8	4.8	0.06	1740	1.20	44.8	1.9	54.1	3.2	330
SUNDANCE Alta. (S.B.)	.155	.127	.089	9.9	57.8	23.0	3.5	2.9	0.02	4590	1.61	26.0	0.5	85.2	6.0	500
Q. ELISABETHA Sask. (S.B.)	.159	.077	.049	7.5	53.9	20.4	4.7	1.8	0.01	2180	6.70	20.4	11.9	61.1	5.1	285
NANTICOKE Ont. (BIT.)	.162	.103	.057	5.4	46.8	22.8	12.7	1.2	0.03	2510	3.28	27.0	5.7	100.0	6.9	265
LAKEVIEW Ont. (BIT.)	.164	.092	.045	4.0	43.6	22.0	14.7	2.1	0.06	2800	0.55	24.0	8.4	95.8	7.0	275
TRENTON N.S. (BIT.)	.184	.114	.059	1.9	43.8	17.2	30.0	2.0	0.02	3570	0.85	28.2	2.3	95.1	6.5	50
FORESTBURG Alta. (S.B.)	.278	.217	.140	9.0	56.3	21.7	4.9	4.5	0.06	4280	1.98	22.0	0.4	85.9	7.2	200
GENISEE Alta. (S.B.)	.342	.238	.190	7.4	56.5	23.0	5.3	3.4	0.05	5900	1.64	9.8	0.4	60.9	8.6	440

*LIG. = Lignite BIT. = Bituminous S.B. = Sub-bituminous

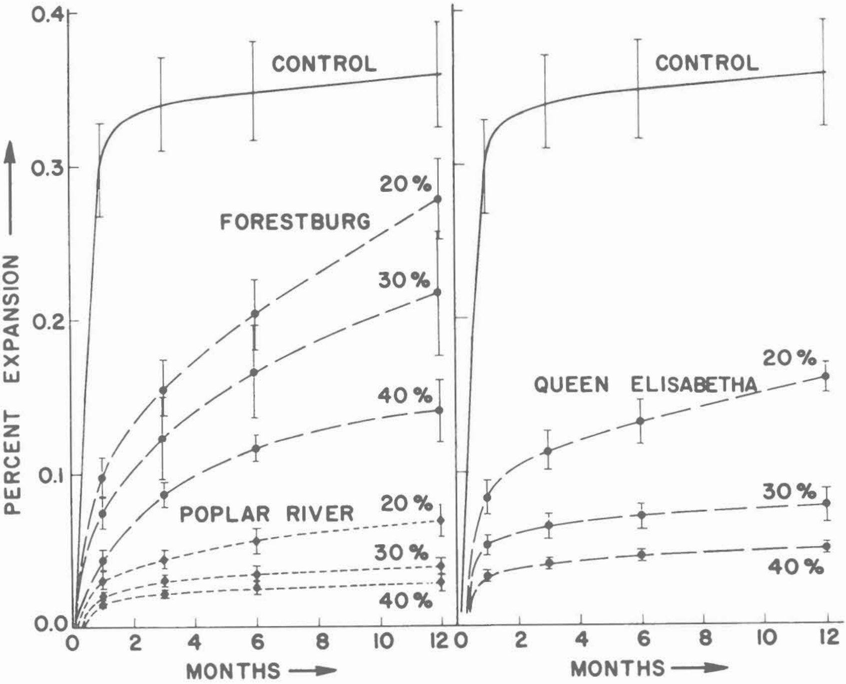

Fig. 1. Expansion of mortar bars containing 4% opal and three fly ashes at various cement replacement levels.

Control bars containing opal but no fly ash expanded 0.36% at 12 months. Reduction in expansion due to fly ash ranged from 5% to 81% at 20% cement replacement, 34% to 89% at 30% cement replacement and 47% to 92% at 40% cement replacement. ASTM C227 indicates that expansions greater than 0.1% at 6 months imply potentially deleterious behaviour. The amount of fly ash required to reduce expansion to below this level was used for purposes of comparison and was found to vary from less than 20% to more than 40%.

Regression analyses were carried out to identify the important physical and chemical properties of the fly ashes. Initially, simple linear regression was used to relate reduction in expansion at 20%, 30% and 40% cement replacement to each of the properties listed in Table 1. From these analyses, a reasonably significant correlation was found between acid-soluble alkali and reduction in expansion for all ash-replacement levels. For example, the correlation coefficient (R) of -0.551 for 20% replacement is different from zero at the 5% significance level. Other properties did not correlate well with reduction in expansion. Some scattergrams are shown in Figure 2.

A number of authors have reported that expansion is suppressed less effectively by high alkali fly ashes (Oberholster and Westra, 1981; Hobbs, 1982; Carrasquillo and Snow, 1986) although Dunstan (1981) observed no effect. The present data corroborate the former view.

Dunstan (1981) found that fly ashes with high CaO content were less effective in reducing expansion, although this was not confirmed in later work (Carrasquillo and Snow, 1986). The present data (Fig. 2) do not support Dunstan's conclusions.

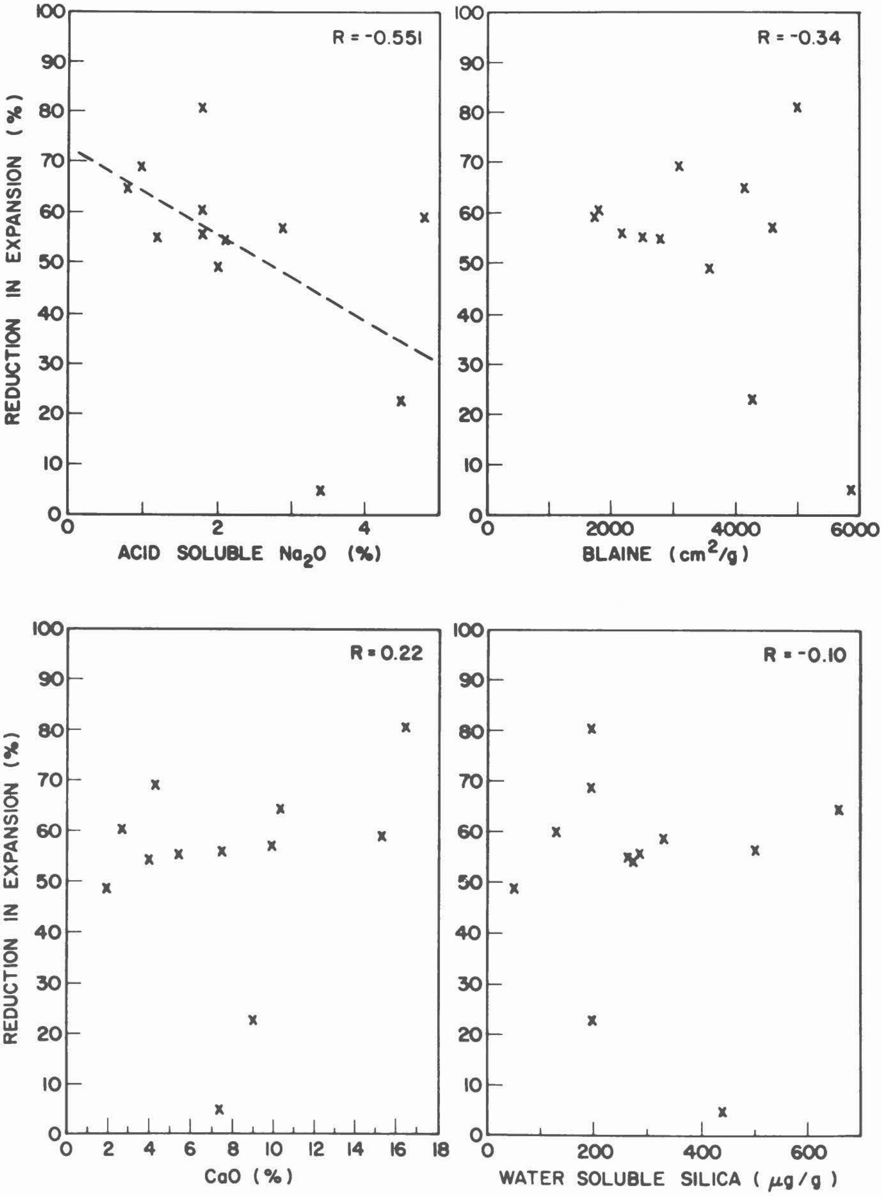

Fig. 2. Correlation diagrams for reduction in expansion at 20% cement replacement and various fly ash properties.

Surface area is a likely factor in determining the ability of fly ash to suppress expansion, and a trend to increased performance for finer fly ashes has been reported (Sprung and Adabian, 1976; Hobbs, 1982). If anything, the present results tend to support the opposite view that an increase in the specific surface of the ash results in a reduction in effectiveness (Fig. 2); however, the correlation is low and further testing is clearly indicated before any conclusions can be made. In addition, poor correlations were obtained with Pozzolanic Activity Index.

Analysis of results by interactive multiple-linear-regression showed that the combination of (a) acid soluble alkali; (b) lime content; and (c) surface area (by Blaine) gave a correlation of R=0.88 with reduction in expansion. The correlation coefficient of 0.88 was not improved significantly by the addition of 'water-soluble silica content' as a parameter in the regression equation.

A reduced correlation was obtained when surface area by nitrogen was substituted for surface area by the Blaine test. It may be that the distribution of particle sizes in the ash are more important than the actual surface area of the ash. Also, the surface area as measured by nitrogen adsorption includes the surface area of the carbon which may be considerable.

Results reported here support the idea that specific properties of fly ash have important roles in determining effectiveness against alkali-silica reaction. At present, acid-soluble alkali content, lime content and specific surface area (Blaine) seem the most likely candidates. Nevertheless, the properties of the ashes measured here do not completely explain the wide range in abilities to suppress expansion. A more fundamental study using techniques such as x-ray diffraction, scanning electron microscopy, infrared spectroscopy and thermal analysis is currently underway which may reveal a more significant fly-ash property.

REFERENCES

ASTM, 1983, Potential alkali reactivity of cement-aggregate combinations, ASTM C227-81. 1983 Annual Book of ASTM Standards, Vol. 04.05, pp. 152-157.

ASTM, 1982, Chemical analysis of hydraulic cement; water-soluble alkalis, ASTM C114-82a. 1982 Annual Book of ASTM Standards, Part 13, p. 123.

Carrasquillo, R.L. and Snow, P.G., 1986. Effect of fly ash on alkali-aggregate reaction in concrete. Presented at: 2nd Int. Conf. on the Use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete.

Dunstan, E.R. Jr., 1981. The effect of fly ash on concrete alkali-aggregate reaction. Cement Concr. Aggreg. 3(2): 101-104.

Hobbs, D.W., 1982. Influence of pulverized-fuel ash and granulated blastfurnace slag upon expansion caused by alkali-silica reaction. Mag. Concr. Res. 34(119): 83-94.

Oberholster, R.E. and Westra, W.B., 1981. The effectiveness of mineral admixtures in reducing expansion due to alkali-aggregate reaction with Malmesburg Group aggregates. In Proc. 5th Int. Conf. on Alkali-Aggregate Reaction, ed. R.E. Oberholster, S252/31: 11pp. Pretoria, S. Africa: Nat. Building Res. Inst. of CSIR.

Sprung, S. and Adabian, M., 1976. The effect of admixtures on alkali-aggregate reaction in concrete. In Proc. 3rd Int. Conf. on Effects of Alkali on the Properties of Concrete, ed. A.B. Poole, pp. 125-137. London, England: Cement and Concrete Association.