technique. Briefly, the above method consists of monitoring the amount of electrical current passed through a 102-mm diameter by 51-mm thick concrete specimen when a potential difference of 60V dc is maintained across the specimen for a period of six hours. Chloride ions are forced to migrate out of a NaCl solution subjected to a negative charge through the concrete into a NaOH solution maintained at a positive potential.

The conditioning of the concrete disc specimens for the test procedure consists of one hour of air drying, three hours of vacuum (pressure <1 mm Hg), one hour of additional vacuum with specimens under de-aerated water, followed by 18 hours of soaking in water. The total charge passed, in coulombs, is used as an indicator of the resistance of the concrete to the passage of chloride ions.

The test results encompassing a number of investigations involving the use of several different fly ashes have indicated that the resistance of high-volume fly ash concrete to the penetration of chloride ions, as measured by the charge in coulombs, is very high. The values of the charge ranged from 150 to 973 coulombs for concretes tested at ages ranging from 28 to 91 days. It is generally agreed that for low permeability concretes, the value of the charge in coulombs passed through the specimens should not exceed 1000 and for very low permeability concretes this value should preferably be less than 600. In silica fume concrete incorporating 400 to 500 kg/m³ of portland cement and 10 per cent silica fume, chloride-ion penetration tests yield charge in coulombs generally less than 800.

Carbonation

Limited data on carbonation tests performed on broken portions of cores drilled after five years from a large block of high volume fly ash concrete have been obtained. The block was cast in December 1985 and moist cured for 28 days. Following that the block was left in a room with limited ventilation and at a temperature of about 23°C and a relative humidity of 40 to 50 per cent. The average carbonation depth was less than 10 mm after 5 years.

Control of Expansion Due to Alkali-Aggregate Reaction

The undesirable expansion of concrete due to reaction between the cement alkalies and certain types of silica in aggregates is a universal problem. Research at CANMET and elsewhere has shown that the above alkali-silica reactions in concrete can be controlled by incorporating good quality fly ash as a partial replacement for cement. The generally recommended levels of cement replacement by fly ash are between 25 and 40 per cent.

As described earlier, high-volume fly ash concrete incorporates about 56 per cent of fly ash as a percentage of total binder, together with large dosages of a superplasticizer. It was, therefore, considered prudent to perform investigations to ensure that the contribution of alkalies, both from the fly ash and the superplasticizers, will not adversely

affect the ability of high-volume fly ash concrete to control or considerably reduce the above expansive reaction when reactive aggregates are used.

In order to determine the role of high-volume fly ash concrete in controlling expansion due to alkali-aggregate reaction, two concrete mixtures were made, one control and one incorporating ASTM Class F fly ash (13). The coarse aggregate used was 19-mm crushed limestone; this limestone contains a highly reactive silica phase and has a known history of expansive reaction in concrete.

A number of 75 x 75 x 305-mm prisms were cast and subjected to the following seven test regimes to determine the expansion due to the alkali-silica reaction.

Test regime 1: Continuous curing of the prisms in a moist-curing room maintained at 38°C.

Test regime 2,3: Continuous curing of the prisms in 5% NaCL solution maintained at 38 and 80°C after an initial moist curing for 24 h.

Test regime 4,5: Continuous curing of prisms in 1 normal NaOH solution maintained at 38 and 80°C after an initial moist curing for 24 h.

Test regime 6,7: Continuous curing of prisms in 1 normal KOH solution maintained at 38 and 80°C after an initial moist curing for 24 h.

The prisms were exposed to the above regimes for a period of 275 days.

The test results which have been published elsewhere indicated that, regardless of the test procedure used, the test prisms cast from the high-volume fly ash concrete did not show any expansion in spite of the very reactive coarse aggregate used in the concrete (13). The above tests confirm the previously published data that fly ash can play an effective role in controlling the alkali-silica reactions in concrete.

LIMITATIONS

The major limitations in the utilization of high-volume fly ash concrete is the availability of good quality fly ash within economic haulage of the construction site and adequate silo capacity. The other limitations include the compatibility between fly ash/cement and superplasticizer. This needs to be investigated as each source of fly ash is unique. In some instances the initial and final setting of the high-volume fly ash concrete may be retarded by several hours. This problem can likely be resolved by changing the type and brand of the superplasticizers used.

The performance of high-volume fly ash concrete subjected to de-icing salts is relatively poor and further research is needed before the use of this type of concrete can be recommended for this application involving this kind of exposure.

ACKNOWLEDGEMENT

This paper is an abbreviated version of a Chapter entitled "High-Volume Fly Ash Concrete", written by the author in a publication "Advances in Concrete Technology", issued in 1993 by CANMET, Ottawa, Canada.

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Table 1- Physical Properties and Chemical Analysis of Various Fly Ashes Used in High-Volume Fly Ash Concrete

	Fly Ash A	Fly Ash B	Fly Ash C
Physical Properties			
Fineness - passing 45 μm, %	78.8	82.7	80.6
- Blaine, m²/kg	--	289	326
Specific Gravity	2.38	2.53	2.05
Chemical Analysis			
Insoluble residue	--	--	--
Silicon dioxide (SiO_2)	45.1	47.1	55.6
Aluminum oxide (Al_2O_3)	22.2	23.0	23.1
Ferric oxide (Fe_2O_3)	15.7	20.4	3.48
Calcium oxide (CaO), total	3.77	1.21	12.3
Magnesium oxide (MgO)	0.91	1.17	1.21
Sulphur trioxide (SO_3)	1.40	0.67	0.30
Sodium oxide (Na_2O)	0.58	0.54	1.67
Potassium oxide (K_2O)	1.52	3.16	0.50
Loss on ignition	0.32	2.88	0.29

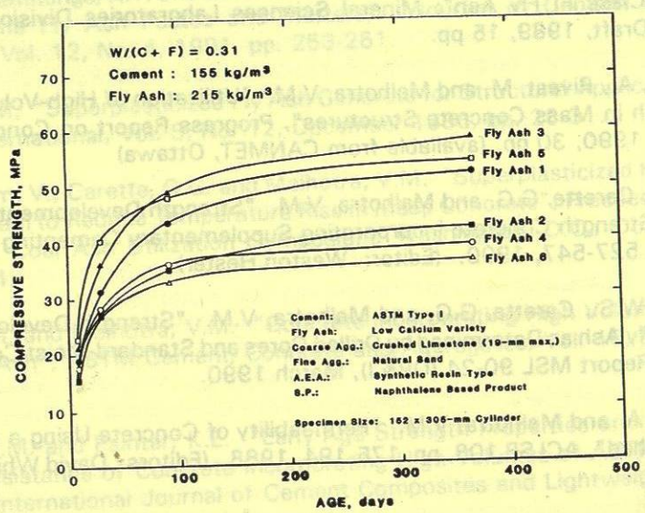

Fig. 1- Compressive strength development of high-volume fly ash concrete with 155 kg/m³ of cement.
From reference 14.

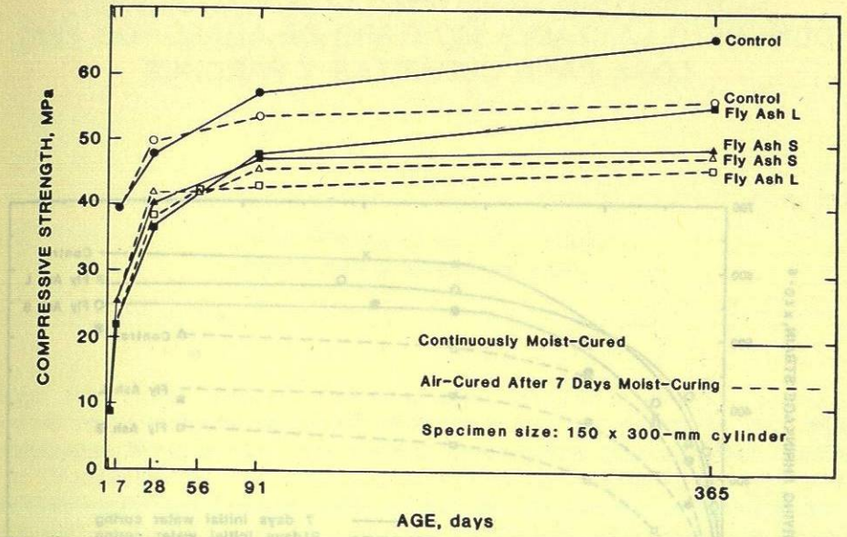

Fig. 2 - Compressive strength development of test cylinders under moist-cured and air-cured conditions.

From reference 12.

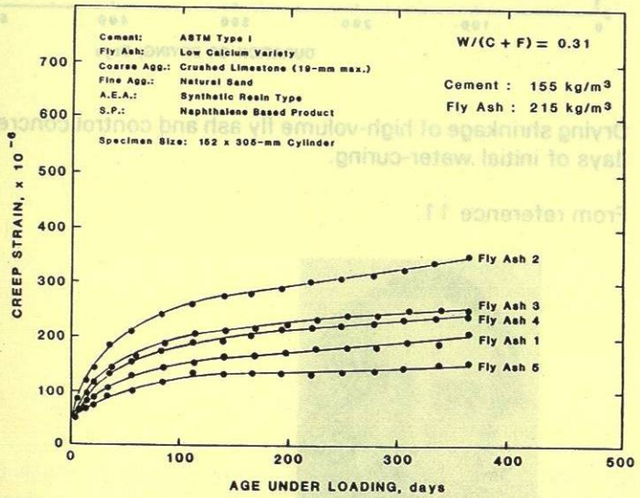

Fig. 3 - Creep strains for high-volume fly ash concrete.

From reference 14.

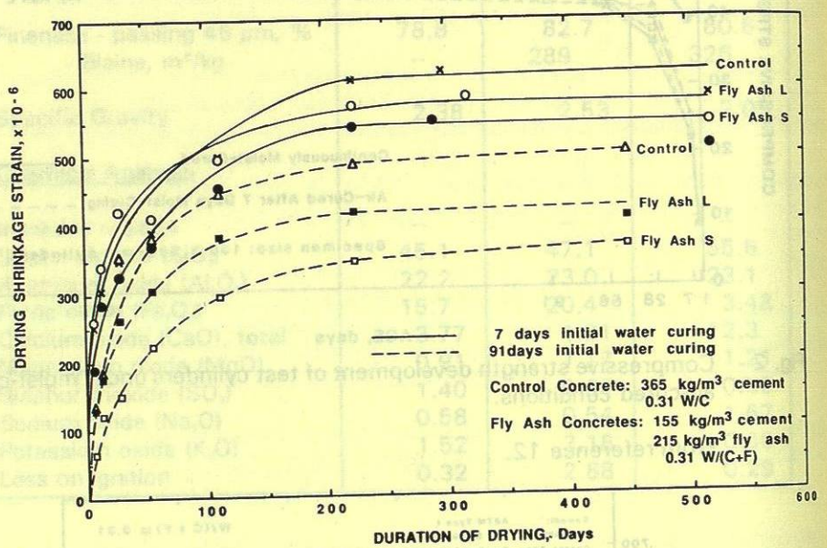

Fig. 4 - Drying shrinkage of high-volume fly ash and control concrete after 7 and 91 days of initial water-curing.

From reference 11.

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