COMPARISON OF THE CANADIAN AND BRITISH STANDARD CONCRETE PRISM TESTS AND THE EFFECT OF REDUCED PERMEABILITY ON TEST RESULTS

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Eighty-two concrete prisms have been made using the Canadian and British Standards and concretes designed to CP110. The comparisons have included trial additions of Z90, a powder which reduces the permeability of the concrete. The results show that the British and Canadian tests are closely comparable. In longer term experiments, rocks found to be stable in the tests have led to expansion and serious cracking in both standard tests but not in the samples designed to CP110. The samples containing Z90 showed delayed inception of expansion and effectively reduced expansion.

INTRODUCTION

Eighty-two concrete prisms have been made using the draft BS 812 specification and the Canadian Standard (CAN B-A23.1 - M.77, 1986) In addition, prisms were made to both specifications with and without addition of the permeability reducing powder produced by Concrete Hitech which is known as Z90. Further prisms were made using a normal structural concrete mixture designed according to CP 110. The aggregates included a meta-argillite, which is widely known to be expansively reactive and which showed expansion in the NBRI test of 0.25%. All the other aggregates were of unknown reactivity but were suspected from their structure and composition to be either non-reactive or at worst moderately reactive. The aggregates and a selection of test prisms were also studied in thin section and with the electron microscope and some were tested for both acid and water soluble alkalies.

AGGREGATE TYPES

Meta-argillite: A very fine grained rock which X-ray diffraction showed to be composed of quartz (30%), feldspar (12%), chlorite (6%) and mica (54%). Other constituents in various pieces include epidote and calcite. The feldspar is mostly albite. The rock has a saturated density of 2780 kg/m^3 and a water absorption of 0.37%. The rocks are variable and the proportions given relate to the overall composition of a bulk sample. The particles are almost all less than 60 micrometres and some 30% are less than 10 micrometres.

Porphyritic andesite: This rock contains clusters of hydrothermally altered oligoclase crystals in a fine grained matrix of needles of plagioclase, more granular feldspar and quartz and mafic phases which include chlorite and pyroxene. Apatite needles are common. The matrix and phenocrysts are altered with the formation of calcite. The rock has a saturated density of 2680 kg/m^3 and water absorption of 0.12%. The groundmass crystals in some areas of the thin section are too small to be resolved with the optical microscope. This rock was considered possibly reactive.

Hydrothermally altered gabbro: This rock consists of pyroxene, plagioclase and ilmenite as large intergrowths with some large sphene crystals. These minerals have all been altered with the production of chlorite, white mica, epidote, and clinozoisite. The rock has a saturated density of 2920 kg/m^3 and a water absorption of 0.26. No reason was found for suspecting that this rock would be reactive.

Limestone: This rock is mainly coarse grained and recrystallized calcite, together with a minor amount of dolomite and traces of argillite. It is a robust rock with a saturated density of 2790 kg/m^3 and a water absorption of 0.40. It has been tested previously and found to be non-reactive and to produce no expansion and was therefore used as a control material for blending with the other aggregates as both coarse and fine aggregate.

Siliceous fluvio-glacial sand: Two varieties of this sand were employed which were similar and were labelled A and B. The sands consist of fine grained acidic volcanic rocks, argillite, sandstone, metaquartzite and quartz. Some of the rocks are very fine grained and the sands were regarded from both their composition and structure as possibly reactive.

Siliceous sand (C): This sand consists of well rounded particles of quartz, quartzite, feldspar, and occasional particles of argillite. Though there are occasional grains which have structures suggesting that the material might be reactive, on the whole the sand was regarded as not potentially reactive.

ALKALIES EXTRACTED FROM AGGREGATES

Some of the aggregates were tested by acid extraction using 100 ml of 10% v/v dilute nitric acid to extract 5g of rock. The rock was crushed and the 5g were taken from the size range 50 to 150 micrometres. The alkalies were also extracted using the same size range and amount of aggregate with 100 ml of water and with stirring for 72 hours. The results obtained are as follows:

Aggregate	Water solution Wt. %		Acid solution Wt. %	
	Na_2O	K_2O	Na_2O	K_2O
Fluvio-glacial sand	0.007	0.021	0.013	0.081

Altered gabbro	0.007	0.001	0.022	0.008
Andesite	0.012	0.006	0.030	0.031

MIX PROPORTIONS USED IN THE PRISM TESTS

The following represent the range of mix proportions employed with the variations reflecting the differing densities of the components.

	Canadian Standard	Draft British Standard	CP 110 Mixture
Coarse aggregate kg/m^3	c.1116	c.1080	c.1028
Fine aggregate kg/m^3	c.744	c.435	c.800
Cement kg/m^3	310	695	435
Free water	155-173	228	195
Alkalies (as Na_2O equiv.) kg/m^3	4.12 - 4.68	6.95 - 7.63	4.21 - 4.73

The ranges in alkalies take account of the alkalies found in the aggregate, the target alkali from the cement and alkali added as potassium sulphate or potassium hydroxide. The target was 4 kg/m^3 for the Canadian Standard and CP 110 mixtures and 7.00 kg/m^3 for the British Standard.

RESULTS OF PRISM TESTS

The mixtures employed, the expansions after one year, and the condition of the concrete at subsequent times are summarized in Table 1. After one year only the meta-argillite showed significant expansion. Substantial quantities of gel and numerous cracks were found in all prisms containing this aggregate. However, those samples containing the Z90 behaved differently from those without. Firstly the expansion with Z90 present was for most of the time much less than that for the prisms without Z90 and the expansion remained much less than for the British Standard prisms throughout the duration of the test. Secondly the amount of cracking was very much less for those samples with Z90 than for those without. Details are as follows.

British test	with Z90	without Z90
Number of cracks/cm	0.8	3.0
crack width μm/cm	9.0	30.0
Canadian test		
number of cracks/cm	1.5	3.0
crack width μm/cm	14.0	31.0

The prisms with Z90 show water standing on the surface throughout the period of the test with no obvious penetration. The reduction in magnitude of expansion is therefore considered to be due to reduced moisture penetration. This effect is especially

Table 1 Summary of mixtures and results

No.	*Standard mixture*	*Coarse aggregate*	*Fine aggregate*	*Alkali added*	*%expansion at 1 year*
1	Canadian	meta-argillite	sand C	NaOH	1.48
2	British	meta-argillite	sand C	NaOH	1.20
3	Canadian	meta-argillite	sand C	NaOH	1.21
4	British	meta-argillite	sand C	NaOH	1.73
5	Canadian	gabbro	sand B	NaOH	0.00
6	Canadian	gabbro	limestone	NaOH	0.00
7	Canadian	limestone	sand B	NaOH	0.00
8	Canadian	andesite	sand B	NaOH	0.00
9	Canadian	andesite	limestone	NaOH	0.00
10	British	andesite	sand B	K_2SO_4	0.04
11	British	andesite	limestone	K_2SO_4	0.03
12	CP110	andesite	sand B	NaOH	0.00
13	CP110	andesite	limestone	NaOH	0.00
14	British	andesite	sand A	K_2SO_4	0.05
15	British	gabbro	sand A	K_2SO_4	0.05
16	British	limestone	sand A	K_2SO_4	0.04
17	British	andesite	limestone	K_2SO_4	0.04
18	British	gabbro	limestone	K_2SO_4	0.03
19	CP110	andesite	sand A	NaOH	0.01
20	CP110	gabbro	sand A	NaOH	0.00
21	CP110	limestone	sand A	NaOH	0.01
22	CP110	andesite	limestone	NaOH	0.02
23	CP110	gabbro	limestone	NaOH	0.00

Condition after four years

No.	*coarse aggregate*	*fine aggregate*	*cracks*	*voids*
5		much gel	many	much gel
7	-----	much gel	-----	some gel
8	much gel	much gel	many	much gel
9	some gel	-----	some	
10	much gel	much gel	many	much gel
11	some gel	-----	-----	-----
12	-----	trace gel	-----	-----
14	much gel	much gel	some	much gel
15	-----	much gel	minor	-----
16	-----	some gel	minor	-----
17	some gel	-----	minor	-----
19	-----	trace gel	-----	-----
20	-----	trace gel	-----	-----
21	-----	trace gel	-----	-----

Note: mixture numbers 1 and 2 contain Z90, numbers not recorded in lower part of table show no evidence of reaction after 4 years.

marked for the British Standard samples for which water globulates on the concrete surface. The Canadian prism test requires a much higher water/cement ratio than the British standard and the effect of Z90 appears to be greater for the British test than for the Canadian prisms probably because the former has a lower permeability than the latter.

The tests of the other aggregates showed very low expansion in all tests after one year - only the prisms with the andesite and sands A and B showing slight expansion. In effect very few prisms reached a level at which cracking would be expected and no cracking could be found in any of the individual prisms. These tests have now been allowed to run for nearly four years with the samples being maintained in the wet environment at 38°C. Many of the samples are now showing marked cracking and gel formation (see Table 1). The British Standard test shows reaction for both the andesite and sands of types A and B but no reaction for the limestone and gabbro or sand C. The amount of cracking and gel formation is much the same in the Canadian tests as for the British Standard tests. The prisms made to CP110 showed no cracking but traces of gel were found associated with sands A and B when the samples were sliced after nearly four years. The effects observed seem to be determined largely by the permeability of the concrete and the alkali content. The relationships are as follows.

	W/C	Na_2O equiv.	Reaction
CP110 concrete	0.45	4kg/m^3	negligible
British standard	0.33	7kg/m^3	very high
Canadian standard	0.5 to 0.55	4kg/m^3	very high

This suggests that the porosity of the concrete coupled with the alkali levels are the main factors influencing the damage encountered. There is also clearly an important variation in expansion with time. None of these tests showed significant expansion until some 18 months to 2 years had elapsed. Even after 42 months the CP110 concrete with high alkalies showed no expansion. This also has low permeability and low water/cement ratio. Taken together with the results obtained using Z90 to reduce permeability, suggests as might be expected, that reduction in the rate at which moisture can penetrate into the concrete reduces the potential for reaction and consequent expansion. However, once expansion begins the effect of reduction in permeability is lessened because of the development of fine cracks in the surface. Hence the reaction at low permeabilities tends to be deferred rather than eliminated but might be deferred indefinitely if the permeability can be sufficiently reduced. One of the consequences of this is that the expansion in tests will vary with the quality of the concrete. It is therefore possible that the British Standard, despite the high cement content and high alkali content will produce no greater expansion in a given time than the Canadian test because of the lower water/cement ratio and potentially lower permeability. It is therefore suggested that the permeability of the test concrete be measured as a matter of quality control in the expansion tests. Further work on reducing permeability might allow control of the expansive reaction.

CONCLUSIONS

(i) The presence of Z90 in the test concretes has both delayed the expansion and reduced the expansion effected in the British Standard test for a highly reactive aggregate. The reduction in permeability is clear from the way in which water globulates on the concrete surface and was less effective in the Canadian test presumably because of the high water/cement ratio which lessens the reduction in permeability effected by the Z90. Further work of this type could lead to a measure for the control of potentially damaging reactions.

(ii) Two aggregates which are considered to be possibly reactive from petrographic evidence showed no reaction in either the Canadian prism test, the British prism test or in normal structural concrete after the usual test period of one year. The highest expansions reached were insufficient to produce any traces of cracking but occurred with the andesite and sands A and B.

(iii) After nearly four years both the Canadian test and the British test showed the andesite and fluvioglacial sand to be reactive with substantial quantities of gel being produced by both and with numerous cracks occurring within the aggregate particles. Petrographic examination of the reacted material shows that the cracks occur within the aggregate and that the fine grained trachytic volcanic rocks of the sands and argillite sand grains are the most reactive. For the andesite it is the larger particles that have reacted and the cracks run from one large andesite particle to another.

(iv) The collective test results indicate that the permeability of the concrete has a significant influence on rates of expansion so that the quality of manufacture of the prisms needs to be carefully controlled if significant variation in expansion rates is to be avoided. This may account for some inter-laboratory variations.

(vii) The tests also suggest that the comparison between normal concrete with high alkalies and the accelerated test prisms indicate that in the normal structural concrete reactions develop at less than a quarter of the rate found in the test prisms and for the aggregates tested may not reach a level of expansion likely to be damaging even at 38^{0}C and with more than 4 kg/m^3 of alkalies. The British and Canadian standards may be interpretable using the same background data.

Z90 is produced by Concrete Hitech International Inc. 91 rue du Faubourg Saint-Honore 75008 Paris France or Ceracem East Inc. 555 Madison Avenue Suite 250 New York NY10022 USA.