THE USE OF FLY ASH TO SUPPRESS DELETERIOUS EXPANSION DUE TO AAR IN CONCRETE CONTAINING GREYWACKE AGGREGATE

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Concrete mixes with a range of alkali contents and various levels of fly ash were cast using two sources of greywacke aggregate, previously implicated in AAR in UK structures.

After 15 months, deleterious expansion was observed in opc concretes (without fly ash) with alkali content in excess of 5.18 kg/m^3 Na_2O_e. Concretes with 25% and 35% fly ash showed no damaging expansion. These results were corroborated by accelerated tests. The results indicate that fly ash is effective in suppressing damaging expansion due to AAR in concrete containing greywacke aggregate. However, long term expansion measurements are required to ensure that the effect is not merely a delaying one.

INTRODUCTION

Greywacke and greywacke type turbidite sandstones have been implicated in alkali aggregate reaction (AAR) in concrete structures around the world (1-5). In most cases an alkali silica type reaction (as opposed to alkali silicate) has been proposed, the reactive constituent generally being microcrystalline quartz in the rock matrix.

As a result of recent investigations a number of structures in the UK using greywacke aggregate have been identified as having deleterious expansion attributed to AAR (4, 5). Apart from their alkali reactivity, these UK greywackes are generally good quality aggregates suitable for structural concrete. As greywacke outcrops often occur in less accessible areas in the UK where there are few or no alternative sources of aggregate, a means of suppressing alkali-silica reaction in concrete containing this aggregate would have considerable economic benefits.

The use of fly ash as a partial replacement for Portland cement to control AAR is well established and has proven application with greywacke aggregate both in the laboratory (2, 3, 6, 7) and in the field (2, 5). This paper describes a laboratory investigation on the effect of British fly ash in concrete containing greywacke aggregate from sources previously implicated in AAR in UK structures.

LOCATION OF GREYWACKE AND AFFECTED STRUCTURES

The exact definition of the term "greywacke" is problematical as both petrographic and field relationships are implied (8). Rigid adherence to existing petrographic classifications has proved unsatisfactory when considering this gradational suite of rocks and terms such as "greywacke type" sandstone or "sub-greywacke" have evolved to accommodate the deficiency. Within these limitations, greywacke deposits in the UK are shown in Figure 1.

Greywacke outcrops are mainly restricted to the Lower Palaezoic strata of Mid Wales and related borderlands, North Yorkshire and the Southern Uplands of Scotland with related sequences in Northern Ireland. A few Upper Palaeozoic greywacke deposits are found in South West England and shallow water "sub-greywacke" sandstones (not shown in Figure 1) are encountered in the Carboniferous of South Wales and Northern England. Epidotised varieties are found in the Precambrian of the Welsh borderland. Much of the Lower Palaeozoic sedimentation was within the ancient basins situated on the northern and southern margins of the geologic 'Iapetus' ocean. The line of final closure in late Silurian/early Devonian is marked as the 'Caledonian Suture' in Figure 1. The Lower Palaeozoic greywacke deposits found north and south of the suture are on the same Caledonian belt which laterally extends from Scandinavia through the UK, to the Maritime Provinces of Canada. Some greywackes from this part of Canada have been shown to be alkali-reactive(3). Comparative studies of rock from one of these deposits has shown it to be petrographically similar to some UK deposits, when studied by both optical and electron microscope(4). Systematic petrographic examination of the UK greywackes, and testing for their alkali reactivity, is in progress.

The Building Research Establishment is currently investigating three field occurrences of AAR with greywacke aggregate, namely the Maentwrog Dam in Northern Wales (4), the Dinas Dam in the Rheidol Scheme (Mid Wales) (5) and a road bridge in County Down, Northern Ireland(9). The location of these is shown in Figure 1. The sources of aggregate used in the Maentwrog Dam and the road bridge were sampled for the purpose of this laboratory investigation. These sources were not selected solely on the basis that they had been used in AAR affected structures, but also because they are fairly representative of the spectrum of greywacke found within the UK.

The old Maentwrog Dam (now replaced), built in 1926-1928, and situated in the geologically ancient structure known as the "Harlech Dome", utilised a locally extracted lower Cambrian greywacke. This rock, being a well-sorted quartzo-feldspatic greywacke with a heavily silicified chloritic/sericitic matrix, has been metamorphosed to a grade within the "lower greenschist facies".

The Northern Ireland road bridge, approximately 20-25 years old, contains a local greywacke aggregate of Silurian age. This rock is ill-sorted with an abundance of microcrystalline quartz clastics of volcanic origin, set within a less well-developed phyllosilicate/quartz matrix. The metamorphic grade of the material is plainly lower than the Maentwrog aggregate and is apparently just of regional grade.

In both rocks there is an absence of the swelling phyllosilicates described by Gillot et al (10) thus the possibility of an alkali-silicate reaction does not arise. The reactive constituent in these rocks has been identified as microcrystalline quartz within the matrix and clastic material (4,9). It should be pointed out that not all the distress in the structures can be attributed to AAR, and diagnosis of AAR in the road bridge is not as unequivocal as that in the dam. Both are the subject of continuing investigations.

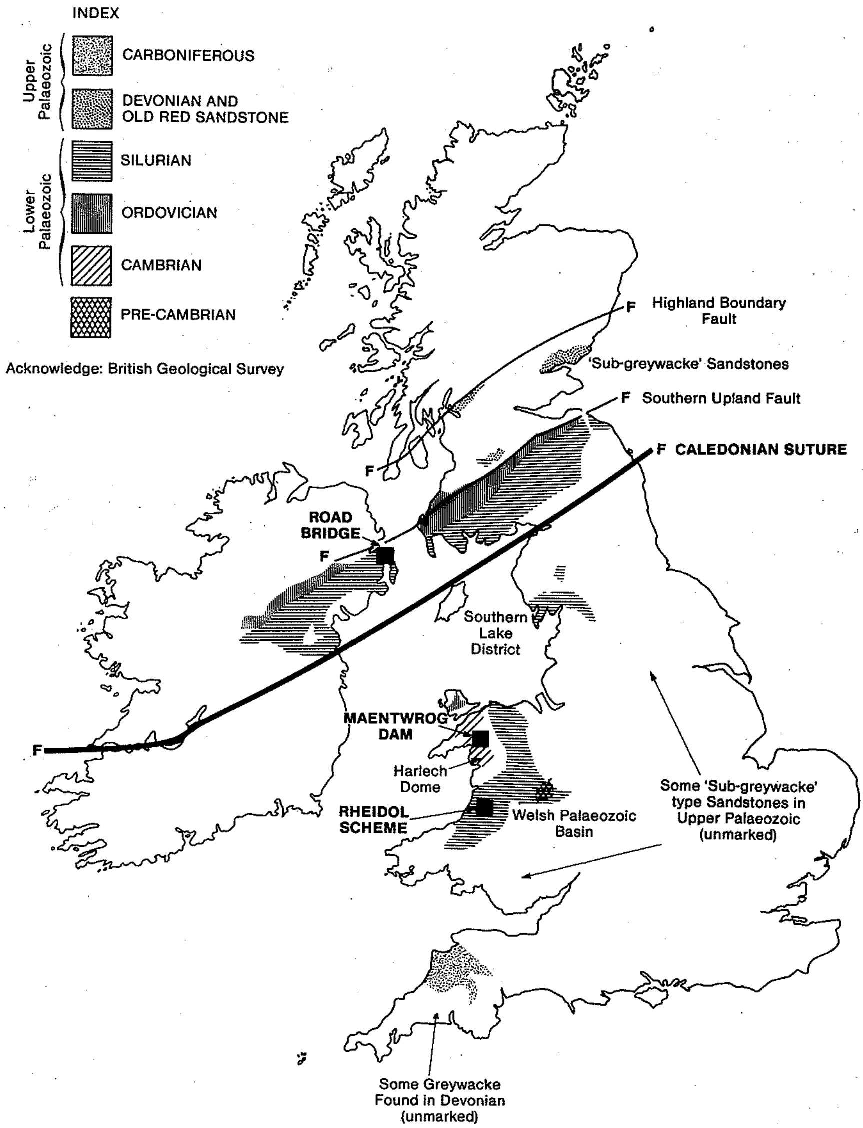

Figure 1 Sketch map of Palaeozoic strata which may contain Greywacke type rocks

STANDARD TESTS TO DETERMINE ALKALI REACTIVITY OF GREYWACKE

Expansion tests were carried out on concrete prisms according to the method specified in the draft BS 812; Part 123 Test 'Alkali-Silica Reactivity - Concrete Prism Test' and on mortar bars using the 'NBRI - Rapid Test Method' described by Davies (11). In the concrete prism tests, a high alkali cement and small additions of K_2SO_4 are used to produce a total alkali content of 7 kg/m^3 Na_2O_e. Expansion measurements are then made on concrete prisms stored at 38°C and 100% RH. In the NBRI test, expansion measurements are made on mortar bars stored in 1N NaOH at 80°C.

The results from these standard tests are given in Table 1. Although no fixed guidelines have been proposed for the concrete prism test, a value in excess of 0.10% is normally assumed to indicate deleterious expansion. For the NBRI test a value greater than 0.10% at 12 days is used to distinguish 'reactive' and 'non-reactive' aggregates. The values in Table 1 generally classify the greywacke from both sources as reactive.

The NBRI test using a W/C of 0.5 was also used to assess whether the greywacke aggregates exhibited a pessimum proportion for expansion. Tests were carried out on mortar bars containing blends of greywacke and a non-reactive Carboniferous limestone in various proportions. The expansion results at 12 days are compared in Figure 2 with results for a reactive Thames Valley sand containing 50% flint - being the reactive constituent (also blended in various proportions with limestone). From previous investigations using concrete specimens the aggregates has a known pessimum of 10% flint (12).

In contrast it can be seen that the expansion of greywacke mortar bars generally increases with greywacke content. Although there is a flattening of the expansion curves above 60% greywacke content, a pessimum proportion cannot be discerned in this test regime. The absence of a pessimum proportion was corroborated with concrete prism expansion tests where the replacement of one or more size fractions with inert limestone led to a reduced expansion. Further the curves indicate that deleterious alkali-reactivity may occur in concretes where greywacke in low concentrations is used in conjunction with other innocuous aggregates. The NBRI test has proven to be a remarkably sensitive test in respect of both the greywackes and Thames Valley sand.

Further standard laboratory tests carried out on these greywackes confirmed that they were neither moisture nor frost susceptible.

Table 1 Results of Standard Tests

Aggregate Source	Expansion %	
	BS Concrete Prism Test at 12 months	NBRI Mortar Bar Test at 12 day
Maentwrog	0.16	0.19
Northern Ireland	0.20	0.27

EXPANSION TESTS ON FLY ASH CONCRETES

Concrete mixes with greywacke aggregates were produced with cement contents of 450 kg/m^3 using three sources of opc (analyses given in Table 2), blended in various proportions to provide alkali contents in the range 3 kg/m^3 to 5.18 kg/m^3 Na_2O_e. Higher alkali contents, up to 7 kg/m^3 Na_2O_e, were produced by dosing the mixing water with K_2SO_4.

Fly ash concretes were produced by replacing 25% or 35% (by mass) of the cement with a UK fly ash (analysis given in Table 2). Where K_2SO_4 had been used in the opc mixes (no fly ash), the same level of addition was made to the corresponding fly ash mixes. The fly ash source was selected as it was known to have a high alkali content (4.0% Na_2O_e) and would potentially represent the worst case for fly ash concrete.

In all these mixes, the water content was controlled to produce a slump value in the range 30 mm to 60 mm. This resulted in a water reduction of between 7% to 10% for the fly ash concretes.

Expansion results for concrete prisms (75 x 75 x 200 mm) stored at 38°C and 100% RH for 15 months are shown in Figure 3 (the expansion of concretes with 35% fly ash are not shown, but were less than comparable concretes with 25% fly ash). It is generally held that values in excess of 0.05% are indicative of the onset of deleterious expansion. The alkali level expressed are those from the cement and addition of K_2SO_4 (where appropriate) only. Any possible alkali contribution from the fly ash has been disregarded.

Smaller concretes (50 x 50 x 200 mm) were stored in 1N NaOH at 80°C, having been allowed to cure at 20°C for 60 days prior to immersion to allow some degree of pozzolanic reaction to occur. Expansion results for these mixes are given in Figure 4 (again the expansions of concretes with 35% fly ash are not shown, but were less than comparable concretes with 25% fly ash). As this is a non-standardised test there are no accepted guidelines for determining potential reactivity using this test. Although relative expansions values can be used to judge over time the effect of the fly ash partial cement replacement.

Table 2 chemical analysis of material

	Materials	Oxide										
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI	C_3A	Na_2O_e
CEMENTS	M386	20.40	4.84	3.21	62.50	2.62	1.11	0.43	2.92	0.84	7.4	1.15
	896	20.60	4.87	2.96	63.60	2.70	0.88	0.28	2.79	0.91	7.9	0.86
	856	22.55	5.07	3.10	64.51	1.53	0.73	0.15	2.53	1.51	8.2	0.63
	Fly ash 901	51.00	25.30	9.92	1.48	1.38	3.69	1.58	0.79 (total C 2.71)	3.69	-	4.00

In addition, the 'standard' NBRI test were carried out on mortar bars with 25% fly ash. This test has been shown previously to be capable of

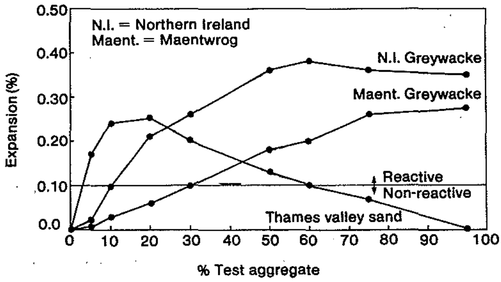

Figure 2

Figure 2 NBRI rapid test. Comparing pessimum effects of Greywacke with that of a flint-based sand, (at 12 days).

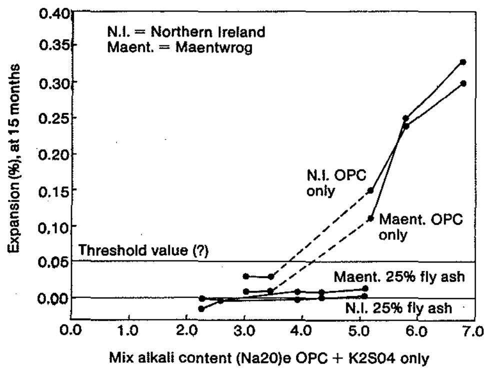

Figure 3

Figure 3 Concrete prism test. Greywacke OPC and corresponding 25% fly ash concrete at different alkali levels. No possible alkali contribution from fly ash included, 75 x 75 x 200mm prisms stored at 38°C/100% RH.

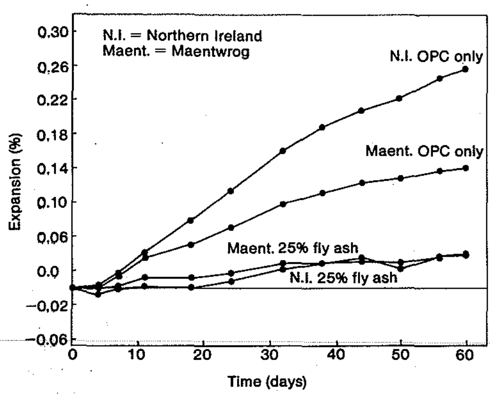

Figure 4

Figure 4 Accelerated concrete prism test. Greywacke OPC and corresponding 25% fly ash concrete, 50 x 50 x 200mm prisms stored in NaOH/80°C.

determining the effectiveness of mineral admixtures in reducing expansion due to AAR (11). The expansion results are given in Table 1. An expansion in excess of 0.1% indicates potential deleterious reaction with the cement/aggregate combination tested (10).

DISCUSSION

Petrographic examination of thin sections from AAR-affected concrete structures containing the greywacke aggregates used in this laboratory study indicated that the greywacke was alkali reactive. Previous work has shown the reactive constituent of the greywacke to be microcrystalline quartz found within the rock matrix. Additionally, it has been speculated that lattice dislocations within this microcrystalline quartz may enhance alkali-reactivity (13).

It has been indicated that the Lower Palaeozoic greywacke groups, the majority of the UK deposits, lie along the narrow late Proterozoic/early Palaeozoic orogenic belt. The petrogenesis of these rocks are apparently similar, which may allow a more global understanding of the reactivity of this rock type.

The expansion results of laboratory concrete specimens at 15 months show that deleterious expansion occurs in the opc concrete at alkali contents of 5.18 kg/m^3 Na_2O_e and above. Further work is still required to establish the threshold alkali level for expansion in the laboratory. Specimens with alkali contents in the range 3.5 kg/m^3 to 5 kg/m^3 Na_2O_e are of a younger age and are still under test. However Sibbick (14) has shown that the Maentwrog greywacke produces expansion above the threshold values at 4.5 kg/m^3 Na_2O_e (at 1 year) which fits well with the extrapolation in Figure 3. Evidence from the Dinas dam (5) has suggested that greywacke may produce damaging AAR in field concrete when the alkali content is of the order of 3 kg/m^3 Na_2O_e.

It is clear from the results of this study that in concrete specimens containing above about 5 kg/m^3 Na_2Oe replacement of 25% or more of opc with fly ash is effective in eliminating damaging reactivity at 15 months. This is the case even when the alkalis derived form the Portland cement and added salts (ie disregarding any alkali contribution from the fly ash) are sufficient to promote considerable expansion in concretes without fly ash.

The expansion results from the specimens stored in 1N NaOH at 80°C show that fly ash reduces expansion due to AAR even when the alkalis are derived from external sources. However, the fly ash may be merely delaying expansion by slowing down the diffusion of alkalis from the host solution. Long term measurements are required to determine the effect of the fly ash on the ultimate expansion.

In the absence of long term laboratory data, the results from this study should be treated with caution. However, evidence from field structures and laboratory data from other workers supports the effectiveness of fly ash in preventing damaging AAR in concrete containing greywacke aggregate. Fly ash was used (20% replacement) to minimise the risk of AAR in the Lower Notch Dam in Ontario, which was constructed using a greywacke aggregate proven to be reactive (2). In addition, the study of the Rheidol Scheme (5) revealed that a fly ash concrete dam in the same scheme as the Dinas Dam was free from signs of distress despite the use of the same reactive aggregate.

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