

ASTM C1260 AND THE ALKALI REACTIVITY OF NEW ZEALAND GREYWACKES

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ABSTRACT

Initial attempts to determine acceptance criteria for New Zealand aggregates tested to ASTM C1260 showed little difference between the expansions of known reactive aggregates and Wellington greywacke, which was included as an unreactive control because it has not been seen to react in concrete structures. It was also shown that in this test the workability of the fresh mortar significantly affects expansion. Because results from ASTM C289 to date have generally reflected the field performance of aggregates in concrete, it was concluded that ASTM C289 is a more appropriate quick test than ASTM C1260 for New Zealand aggregates.

Wellington greywacke is widely used and is similar to reactive greywackes from other countries. To check whether it is indeed unreactive, structures built with concrete containing high alkali cement and greywacke aggregates were examined. Neither site inspections nor petrographic examination of core samples revealed clear evidence of AAR. Networks of microcracks were seen in the thin sections but it is not known whether they were caused by expansion or shrinkage. Current investigations on the effect of temperature and alkalinity on the reactivity of New Zealand greywacke will give more insight into its reactivity in concrete structures.

Keywords: alkali aggregate reaction, accelerated testing of concrete aggregates, greywacke aggregates

INTRODUCTION

In the 1960s and 1970s many aggregates and potential aggregate sources were tested for alkali reactivity by ASTM C289 (quick chemical test) and ASTM C227 (mortar bar test) (Kennerley and St John, 1988). To date there has been no evidence that the results contradict field performance. However a feature of alkali silica reaction (ASR) in New Zealand structures is that the widespread use of low alkali cement has meant that there have been few cases severe enough to attract attention during routine maintenance inspections. Not until we looked specifically for signs of ASR in structures containing rhyolitic and andesitic aggregates did we realise that the reaction is quite common but is not recorded in maintenance reports because damage is usually limited to minor surface cracking (Freitag, 1994). We have not systematically surveyed structures containing greywacke because mortar bar and chemical tests indicated that New Zealand greywacke is unreactive, despite similarities to reactive greywackes from other countries. The fact that no damage has been reported by maintenance personnel means that even if greywacke is reactive, ASR itself does not present a significant threat to durability.

Despite having no evidence that aggregate reactivity was being identified incorrectly by existing methods we felt that the accelerated mortar bar test, ASTM C1260, would be welcomed by aggregate producers because it is a quick test and can be used to test a fine aggregate "as supplied". We therefore set out to evaluate its accuracy, repeatability and reproducibility when used to test aggregates "as supplied" and to establish acceptance criteria appropriate for New Zealand aggregates.

During initial trials, mortar made from one greywacke with no history of reactivity in laboratory tests or in structures expanded significantly. Mortar made from a second greywacke aggregate which contained small amounts of rhyolite exhibited similar damage as well as damage consistent with reaction of the rhyolite. Instead of fine-tuning the test for New Zealand aggregates as planned, we decided to investigate the behaviour of these greywackes in more detail because they are widely used in New Zealand concrete and have always been believed to be innocuous.

ASTM C1260 – ACCELERATED MORTAR BAR TEST

Materials

Wellington greywacke and Egmont andesite sands were chosen to represent non-reactive and highly reactive aggregates respectively. Rangitikei River sand is predominantly greywacke, but contains some volcanic material which is believed to be the cause of minor reactions observed in structures and in ASTM C227 mortar bar tests (Freitag, 1990, and Doyle, 1988). Waikato River sand, which contains acid and intermediate volcanic material, is known to react in concrete and exhibited a pessimum proportion in earlier tests. It was blended in three proportions with an Auckland basalt to see whether the pessimum effect would be detected by the ASTM C1260 method. Samples from all five sources were examined petrographically to identify constituents that might react under the test conditions. These are listed in Table 1. The sands were used unwashed and in the gradings supplied so that we could compare the test results with observations of the performance of the same products in existing concrete. All sand samples contained more fines than the grading specified by ASTM C1260.

TABLE 1. Potentially Reactive Materials in Sand Samples

Sample	Potentially reactive or unstable constituents and amount of reactive material based on grain counts.
Egmont Andesite	Glassy groundmass ^[3] , iron oxyhydroxides ^[2] , vesicular andesite ^[1,3] , chloritic clay ^[1] . 100% reactive material.
Waikato River sand	Rhyolite ^[3] , obsidian ^[3] , pumice ^[3] , glass ^[3] , andesite/dacite ^[3] , ignimbrite ^[3] . 30-40% reactive material.
Rangitikei River sand	Obsidian ^[3] , rhyolite ^[3] , pumice ^[3] , andesite ^[3] , chert ^[3] , argillite ^[1] . <10% reactive material.
Auckland basalt	Glass in groundmass ^[3] , iron oxyhydroxides ^[1,2] . <1% reactive material.
Wellington greywacke	Chert ^[3] , argillite ^[1] , quartz ^[1,3] , chlorite ^[1] , sericite ^[1] . 1% reactive material.

^[1] Volumetrically unstable under normal service, ^[2] Potentially unstable under test conditions, ^[3] Potentially alkali reactive.

One bag of Golden Bay type GP cement was purchased for the tests. Its ASTM C151 autoclave expansion was 0.02%. No other properties were measured. Its alkali content was assumed, from manufacturer's records, to be 0.6% Na₂O equivalent.

A sulphonated naphthalene formaldehyde superplasticiser (W R Grace's Daracem 40), with an alkali content of 6.5% Na₂Oeq, was used in two mortars.

Mortar Mix Designs

The sand and cement proportions given in ASTM C1260 were used. In the first series of tests, water was added to give a total water to cement ratio (w/c) of 0.47. In the second and third series, this was changed to an available w/c of 0.47 to account for the absorption of water by aggregate, and superplasticiser was added to improve the workability of two of the mortars (Egmont andesite and 10% Auckland basalt – 90% Waikato River sand blend) which were significantly stiffer than the others and difficult to compact. Mix designs and fresh mortar properties are given in Table 2.

Test Conditions

Mortars were mixed following the ASTM C1260 procedure, and three 285 x 25 x 25 mm mortar bars cast from each mix. In series 1 and 2 the specimens were subjected to the conditions specified by ASTM C1260 for two months. In the third series the specimens were stored at 40-42°C for one year.

Expansion Test Results

Mortar bar expansions at 14, 28, 56 days and 1 year (series 3) are given in Table 2.

Comparison of series 1 and 2 results from Egmont andesite and the 10% Auckland basalt – 90% Waikato River blend suggests that at a given w/c the workability of fresh

TABLE 2: Mortar Details and Expansion Test Results

Aggregate	Series ^[1]	Total w/c	Free w/c	Super-plasticiser (ml)	Flow ^[2] (%)	Fresh density ^[2] (kg/m ³)	Expansion (mean of three bars, %) ^[3]			
							14 days	28 days	56 days	1 year
Wellington greywacke ("Well gw")	1	0.47	0.45	-	88	2260	0.286	0.492	0.720	-
	2	0.49	0.47	-	92	2260	0.306	0.556	0.804	-
	3	0.49	0.47	-	92	2270	0.0029	0.0115	0.0372	0.561
Rangitikei R. sand ("Puketapu")	1	0.47	0.45	-	107	2260	0.539	0.812	1.134	-
	2	0.49	0.47	-	125	2230	0.542	0.852	1.164	-
	3	0.49	0.47	-	115	2250	0.0041	0.0194	0.089	0.948
Egmont andesite	1	0.47	0.42	-	32	2310	0.307	0.522	0.708	-
	2	0.52	0.47	1.5	96	2300	0.445	0.712	0.855	-
	3	0.52	0.47	1.5	92	2290	0.0061	0.0446	0.169	0.645
10% Waikato R. sand, 90% Auckland basalt ("Pu 10")	1	0.47	0.45	-	99	2420	0.213	0.266	0.305	-
	2	0.49	0.47	-	103	2410	0.204	0.256	0.292	-
	3	0.49	0.47	-	93	2380	0.0034	0.0142	0.0247	0.117
40% Waikato R. sand, 60% Auckland basalt ("Pu 40")	1	0.47	0.45	-	88	2300	0.639	0.840	1.003	-
	2	0.49	0.47	-	95	2290	0.665	0.851	1.001	-
	3	0.49	0.47	-	94	2280	0.011	0.148	0.261	0.553
90% Waikato R. sand, 10% Auckland basalt ("Pu 90")	1	0.47	0.45	-	36	2070	0.441	0.751	1.072	-
	2	0.49	0.47	3.0	72	2060	0.616	0.987	1.323	-
	3	0.49	0.47	3.0	83	2070	0.181	0.202	0.331	0.731

[1] Storage temperatures were 80°C for series 1 and 2 and 40-42°C for series 3.

[2] Measured as described in ASTM C185.

[3] In series 1 and 2 some readings were taken a day earlier or later. Series 3 dates were 11/12 days, 36/37 days & 62/63 days.

mortar significantly affects its subsequent expansion. This is probably because mortar which is difficult to compact contains voids which can accommodate expanding gel. The difference in expansion is unlikely to be due to the extra alkali from the superplasticiser, which is insignificant compared to the amount of alkali in the storage solution. It is recommended therefore that a plasticiser be used to achieve a suitable workability when testing aggregates in a non-standard grading.

The small differences between series 1 and 2 results of the four mortars without superplasticiser show that the slightly higher total w/c of the series 2 mortars had a smaller effect on expansion than did the differences in workability. Proportioning the mortar to a free w/c has the advantage that it ensures similar paste porosity for all aggregates irrespective of their absorption.

All the aggregates tested produced expansions classified by ASTM C1260 as indicative of potentially deleterious expansion. As expected, no pessimum effect was detected for the Waikato River sand. Wellington greywacke has not been seen to react in concrete structures yet its expansion results are indistinguishable from those of known reactive materials. This demonstrates why the test can be used to accept aggregates but not to reject them. The 90% Auckland basalt – 10% Waikato River sand blend is likely to represent a non-reactive material but we have no evidence of its field performance. Thus no acceptance criteria can be determined by the data obtained.

Petrographic Examination of Mortar Bars after ASTM C1260 Testing.

Varying amounts of a colourless gel appeared in the storage solutions during the test, indicating that a chemical reaction was occurring rather than expansion due to moisture or temperature instability of the aggregate. Once the expansion tests were completed, samples of the mortar bars were examined by low power stereo microscope and then in thin section to ascertain whether the expansions were caused by ASR.

Similar features were observed in bars tested at both temperatures. This suggests that not only temperature but also the alkali concentration and chemistry of the storage solution determine the reactivity of aggregates in this test. In the series 3 mortars, a larger area was affected by the reaction, indicating greater alkali penetration, probably due to the longer duration of test.

The greywacke mortars exhibited more microcracking and gel than those containing Egmont andesite or Waikato River sand. Few of the volcanic particles in the Rangitikei River sand reacted, and the samples exhibited similar features to those from the Wellington greywacke mortars, indicating that a component of the greywacke was the chief reactant. The reaction was related to the fine matrix within the greywacke particles but the reactive species were not identified.

REACTIVITY OF NEW ZEALAND GREYWACKE

Laboratory investigations by St John and Smith (1976 and 1978) and Shayan et al. (1992) suggested that New Zealand greywackes do have the potential to react with alkalies, but were unable to distinguish between expansion due to ASR and expansion of phyllosilicate minerals. Previous examination of concretes containing Rangitikei River sand found that only the volcanic contaminants had reacted (St John, 1987). Because greywacke particles clearly reacted in the ASTM C1260 mortar bar test, we thought it was important to

ascertain whether New Zealand greywacke is indeed as unreactive in concrete as we had assumed from the lack of reported damage.

Selection of Sites

Twenty-five bridges containing concrete made from Wellington greywacke were inspected for signs of ASR. All were built between 1955 and 1965, when medium to high alkali cement was available in New Zealand. Apart from minor random cracks on two, no evidence of ASR was seen. Drilled powder samples of concrete were taken from 16 of these bridges, including the two with minor cracking. The powder samples were analysed by the procedure described by Goguel and St John (1993) and all were found to contain the medium to high alkali cement. Their alkali contents were also measured. Core samples were taken from five of these bridges representing a range of concrete alkali contents, again including the two with minor cracking.

Petrographic Examination of Core Samples

All five concretes contained greywacke aggregate and exhibited textures typical of concrete used in New Zealand bridges. Concretes from Puffer Creek and Whiteman's Valley bridges had higher water to cement ratios than the others and consequently were more deeply carbonated. Concrete from Rimutaka Stream bridge and Port Road bridge contained entrained air. There was limited fine cracking on the external surfaces of most of the cores.

Internal microcracking, usually less than 10 microns wide, was widespread in the Ngakonui Bridge concrete and progressively less extensive in the other concretes as shown in Table 3. The pattern formed by the cracks (see Fig.1) suggested that they were related to aggregate movement, possibly expansion rather than shrinkage because of the limited amount of external cracking or other signs of excessive drying shrinkage. The amount of movement was estimated to be 0.1 to 0.2%. Similar microcracking was seen on samples of two other greywacke concretes made from unknown cement. No alkali silica reaction products were observed. It is possible that ASR was in its early stages in the concretes sampled and that insufficient gel had been produced to be visible under the petrographic microscope. Small amounts of gel might have been detected by treating the cores with uranyl acetate but this option was overlooked.

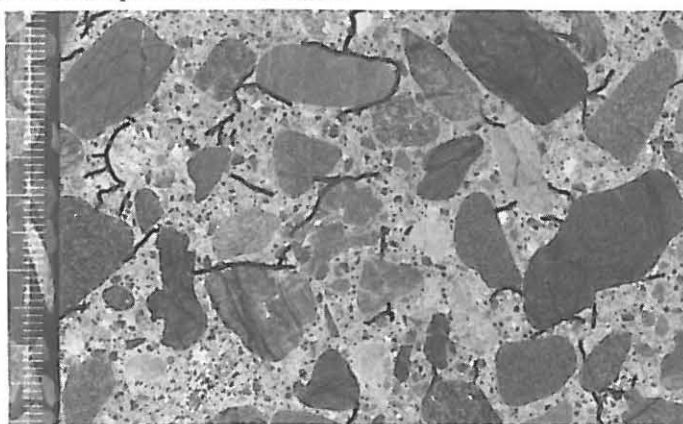


Fig 1. Internal microcracking in core from Ngakonui Bridge. Graduations on scale are 1mm. Cracks have been highlighted.

Cause of Microcracking

The amount of microcracking in the core samples increases with the amount of cement in the concrete (Table 3), although the differences in the four lower cement contents are small and possibly not significant.

TABLE 3. Cement and Alkali Contents and Extent of Microcracking

Ranking of extent of microcracking	% cement in concrete ^[1]	Cement alkali content (% Na ₂ O eq) ^[2]
Ngakonui Bridge (most microcracking, and most extensive visible cracking)	18.0	0.8
Rimutaka Stream bridge	14.0	1.3
Port Rd bridge (minor visible cracking)	13.6	1.2
Whiteman's Valley bridge	12.8	2.7 ^[3]
Puffer Creek bridge (least microcracking)	12.7	1.0

^[1] Based on Ca content of leachate; ^[2] Based on alkali content of leachate; ^[3] Measured sodium content was abnormally high. There was not enough sample to repeat the analysis (R.L. Goguel, pers comm).

There is no obvious relationship between the extent of cracking and the alkali content of the leachates (Table 3). Therefore either ASR did not cause the cracking, or the alkalies in the leachates have come from other sources, such as silicate minerals in the aggregate. The silica, alumina and manganese contents of the leachates were slightly higher than would be expected from the cement used, which could indicate some reaction between the aggregate and the cement paste (R.L. Goguel and N.B. Milestone, pers. comm.). However the microcracking cannot be attributed to ASR without positive identification of reaction products.

There were no signs of excessive drying shrinkage in the concrete overall, and microcracking at external surfaces was minimal. The microcracking could be due to localised shrinkage of the cement paste, perhaps due to the presence of individual aggregate particles with high absorption. It could also be due to shrinkage of the aggregate. Roper et al (1964) reported microcrack patterns similar to those observed here in concretes containing aggregate with excessive drying shrinkage. Freitag (1998) found that the moisture movements of several New Zealand greywackes were similar to those of Scottish dolerites which had been reported by Snowden and Edwards (1962) to cause excessive external cracking in concrete exposed to natural Scottish weathering.

Potential for Expansion

To ascertain whether the greywackes in these concretes have the potential to react, one core from each of the bridges named in Table 3 was preconditioned in a fog room for two months, wrapped in a damp alkali-resistant cloth and then a polythene bag and stored at 40°C. Core lengths were monitored with demec gauges. Expansions to date (1 year) are all less than 100 microstrain and increase with increasing cement content. Freitag & St John (1996) suggested that in situ expansion would be indicated by accelerated core expansion greater than 1000 microstrain at two years or 700 microstrain at three years.

Industrial Research Ltd is currently investigating the release of alkalies, alumina and silica from Wellington greywacke at various temperatures and in different storage solutions to find out whether the reactions that occur in accelerated laboratory tests could

be expected in concrete exposed to ambient conditions. Results should be available by the time of the conference.

CONCLUSIONS

ASTM C1260 results do not accurately reflect the field performance of New Zealand greywacke observed to date. ASTM C289 therefore remains the preferred rapid test for alkali reactivity of New Zealand aggregates, since previous work has shown that field performance is in keeping with test results.

ASTM C1260 results show that the workability of the fresh mortar significantly affects expansion and that an available water to cement ratio (i.e. one which allows for the absorption of water by aggregate) should be specified, with the ability to use an admixture to improve workability when necessary.

Site investigations support our belief that Wellington greywacke does not react significantly in concrete although it does react in mortars exposed to elevated temperatures and highly alkaline solutions. We were unable to identify the cause of microcracking in concrete from bridges built between 1955 and 1965 with high alkali cement and Wellington greywacke. Laboratory core expansion tests are currently underway to see whether these concretes do have the potential to react.

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