New Zealand's Approach to Evaluating the Alkali-Aggregate Problem

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ABSTRACT

The true extent of the alkali-aggregate problem in New Zealand is being evaluated in a five part programme.

1. Quarries and Minerals Survey. 4500 sources of aggregates have been located and identified from existing geological maps to define potential problem areas more closely.
2. Review of alkali-aggregate tests. All test data for the last forty years has been collated and is being reviewed.
3. Pozzolans. The application and economic appraisal of the use of pozzolans is being reviewed.
4. An economic appraisal of the manufacture of low-alkali cement has been completed.
5. Surveillance programmes of structures are in progress and damaged structures located are being investigated.

INTRODUCTION

The alkali-aggregate problem has been investigated in New Zealand since 1943 because of the reactivity of rocks from the volcanic zone in the North Island (Kennerley, St John & Smith 1981). It is known that less than a quarter of the cement produced or imported prior to 1968 was high-alkali and after 1968, only low-alkali cement has been used. Questions are now being raised about the extent of alkali-aggregate reaction in New Zealand due to the use of high-alkali cement before 1968. It also is important to ascertain to what extent could the present production of low-alkali cement be modified to allow the use of higher alkali cements. The existing cement plants using older technology will eventually be replaced by modern plants and the present exclusive production of low-alkali cement may no longer be possible.

QUARRIES AND MINERAL SURVEY

An annual return of mineral production is published by the Ministry of Energy. Using these returns as a starting point for the period 1968-1984, supplemented by data from field visits to local authorities and published surveys and reports, 4500 sources of minerals were located that have been or are still operating. Analysis of the data collected in the records for the "Building" category gives the results shown in Table 1. When the figures are related to area it was found that the reactive aggregate problem is restricted to about a quarter of the country in which 32% of the aggregates are potentially reactive.

TABLE I - REACTIVITY OF NEW ZEALAND BUILDING AGGREGATES

TYPE	QUARRIED		ALLUVIAL	
	Unreactive	Reactive	Unreactive	Reactive
Greywacke	12.4%	-	39.6%	-
Greywacke + other	-	-	10.1%	7.9%
Coastal qtz sands	-	-	5.4%	<0.1%
Basalts, phonolites	12.3%	-	-	-
Rhyolites, dacites	-	0.3%	-	2.8%
Andesite	-	-	-	7.8%
Limestones	1.0%	-	-	-
Misc.	0.4%	-	-	-
Totals	26.1%	0.3%	55.1%	18.5%

REVIEW OF ALKALI-AGGREGATE TESTS

Most of the information required for this review has now been collected and a critical assessment is still in progress. Initial inspection of the data shows that little testing of river sands contaminated with reactive volcanic materials has been performed especially for the lower Waikato river which is a major sand source. Critical assessment of this data will provide the necessary documented basis for future action. It is evident from the information already gained that the use of low-alkali cement has been an effective method of suppressing the alkali-aggregate reaction in New Zealand. We do not as yet appear to have any documented cases of alkali-aggregate reaction occurring with low-alkali cements.

POZZOLANS

The last major investigation of pozzolans in New Zealand was published twenty five years ago (Kennerley & Clelland 1959). The use of pozzolans in New Zealand has been limited to projects in which the pozzolan has usually been added at the site. In all cases low-alkali cement was used so that the pozzolan has been used primarily as a workability aid and to reduce the heat output of mass concrete even though the original intention had been as an additional safeguard against the possibility of an alkali-aggregate reaction. Recently flyash and a silica precipitated from geothermal water, similar to silica fume, have been shown to be suitable as pozzolans. Dependent on economics and further investigation both materials appear to have a potential for use with cements.

To illustrate some of the problems, results of current work on pozzolans (Smith & St John unpublished results) are shown in Table II and fig.1 for mortar studies and Table III and fig.2 for concrete. Also some tests were carried out where alkali contents were maintained at the control level irrespective of pozzolan replacement. The increase in expansion due to the extra alkali added is indicated by arrows in fig.1 and separate expansion curves in fig.2. Of the pozzolans tested according to ASTM C441 only the diatomites appear to fully comply with the 75% reduction in expansion required by this method. After 1000 days, expansion has reached a plateau which is not the case in the concrete tests where the rate of expansion shows no sign of diminishing. The adjustment of alkali contents to control levels has only a minor effect on expansion indicating that the dilution effect on alkali caused by pozzolan replacement is not a significant factor.

TABLE II - IDENTIFICATION OF POZZOLANS USED IN ASTM C441 TESTS
(Pyrex Glass Aggregate)

No	Pozzolan	Spec. surface (m^2/kg)	No	Pozzolan	Spec. surface (m^2/kg)
BT	Basaltic tuff	380	CM1	Calcined marl	1160
OP	Ohaaki pumicite	1000	CM2	" "	1440
KP1	Kopokorahi pumicite	590	IG1	Ignimbrite	1000
KP2	" "	1050	IG2	"	1240
MED	Mercer diatomite	3420	IG3	"	1520
MD1	Middlemarch diatomite	2780			
MD2	" (fired)	3020			

TABLE III - DETAILS OF CONCRETE MIXES CONTAINING POZZOLANS*

No	Pozzolan	Cement kg/m^3	Pozzolan kg/m^3	W/C+P	Alkali kg/m^3	Spec. surface m^2/kg
C	Control	560	-	0.3	6.74	-
IG	Ignimbrite	448	112	0.3	5.73	1000
IGA	+ alkali	"	"	"	6.74	"
OP	Pumicite	448	112	0.3	5.38	1000
OPA	+ alkali	"	"	"	6.76	"
MD	Diatomite	463	82	0.35	5.55	4250
MDA	+ alkali	"	"	"	6.76	"

* Made with Taranaki andesite. Prisms moist cured at 21°C

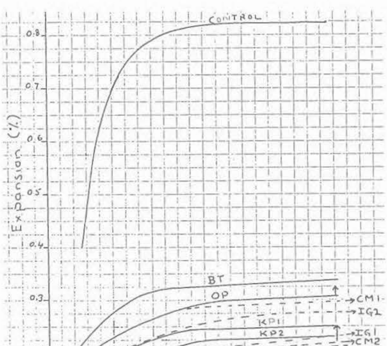

Fig.1 Expansion of Mortar Bars (ASTM C441) containing New Zealand pozzolans identified in Table II.

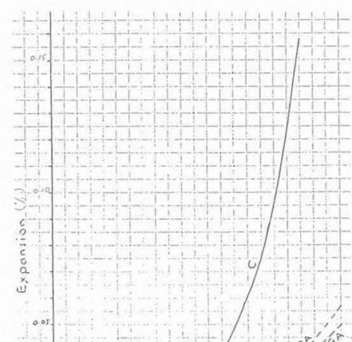

Fig.2 Expansion of Concrete Prisms containing New Zealand pozzolans identified in Table III.

ECONOMIC APPRAISAL OF CEMENT PRODUCTION

Attempts to carry out an economic appraisal of the extra costs incurred in producing low-alkali cement in New Zealand have only been partially successful because many costings are commercially confidential. In addition the situation in New Zealand has not been a simple "either/or" situation. Some of the cement works find it necessary to burn hard to operate their older style kilns and thus tend to produce cements of moderate alkali content. Another has been fortunate in having naturally occurring low-alkali raw materials available. Two small works, now closed, produced high-alkali cement but none of their production was used in any sizeable construction. It appears that only one works, because of its process, may have suffered significant economic penalties. Thus the actual economic cost to the country has not been as great as we originally thought.

SURVEILLANCE PROGRAMMES

Prior to the institution of surveillance programmes only five bridges and one concrete apron at an airbase were known to be suffering from alkali-aggregate reaction. This last case is of interest. The apron was built in 1966 as two contracts. Both portions contained Auckland basalt and high-alkali cement but in one case inert, quartz-rich coastal sand was used while the other contained a reactive sand from the Waikato river. Visible cracking was limited, and external gel absent. In 1984, petrographic examination confirmed the presence of the reaction and showed that cracking and gel had concentrated in the bottom portions of the concrete. Subsequent engineering investigation (McNamara 1985) shows that the concrete has suffered a 40% loss in strength due to alkali-aggregate reaction. Recently strains exceeded restraint and the dramatic damage illustrated in fig.3 occurred twenty years after construction.

Fig.3 Strains built up over twenty years through alkali-aggregate expansion were abruptly released in and caused the damage illustrated.

Currently teams from the Ministry of Works and Development (MWD) are making inspections and where any unusual concrete conditions are noted it is referred to Chemistry Division for petrographic analysis. To date, inspections of hydro-structures have not revealed one single case of alkali-aggregate reaction. The surveillance of State Highway bridges has been of greater interest. The MWD teams noted a number of bridges with moderate but unexplained cracking in the Taranaki area. Of the ten bridges re-inspected for unusual cracking two have already been shown by petrographic analysis to be suffering from alkali-aggregate reaction.

DISCUSSION

In spite of investigations spanning forty years it is clear that further work is required to keep the alkali-aggregate problem under control in New Zealand. As surveillance programmes proceed they are revealing more damaged structures. This past lack of recognition and analysis of the alkali-aggregate reaction has led to a political climate that does not lend itself to easy solutions. Where reactive aggregates are used there is an implied suggestion that it is the aggregates that are at fault and not the cement. Thus the cement manufacturers in many countries have been able to successfully argue that it is not their problem and if remedial action is required, it should be applied by other methods. All the evidence in New Zealand suggests that this is not a suitable method of tackling the problem. What is required is to clearly identify areas at risk and then specify the use of low-alkali cements or suitably modified cements in these areas. Only then will damage to structures caused by alkali-aggregate reaction be eliminated.

However the problem with the above approach is that unless highly reactive siliceous admixtures are available, such as silica fume, blended portland-pozzolan cements may be commercially unacceptable. When large additions of siliceous admixtures are made to cement, high water demand and slow rates of strength development can become a problem in concrete mix design. In addition our economic appraisals have shown that costs of transport are a dominating factor in New Zealand cement manufacture. Thus, while New Zealand is rich in pozzolan deposits, the materials must not only have suitable physical properties but be located in sufficient quantity in the right place to be considered for commercial cement production. In New Zealand, it is this problem that must be investigated and solved as the modern methods of cement manufacture are introduced.

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