RILEM TC106 ALKALI AGGREGATE REACTION - ACCELERATED TESTS
INTERIM REPORT AND SUMMARY OF SURVEY OF NATIONAL SPECIFICATIONS

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The paper provides an interim report on the progress of RILEM TC106 in developing tests for aggregate reactivity which would form the basis for internationally agreed methods. In addition, a major part of the paper summarises the results of a survey among RILEM TC106 members of current specifications for concrete to minimise the risk of damage from alkali aggregate reactions.

INTRODUCTION

The formation of RILEM TC106, Alkali Aggregate Reaction - Accelerated Tests, was reported at the Kyoto Conference and the 2nd and 3rd meetings of the committee were held immediately before and during that conference. The primary objective of the committee is to develop tests for aggregate reactivity which could form the basis for internationally agreed methods and progress towards that is reported here. Some extra tasks have been taken on. In particular a survey of national specifications for avoidance of ASR damage has been undertaken specifically for the present conference and the results are summarised below. In addition, the committee is carrying out an assessment of reports of damage to structures made with low alkali cement or which contain flyash or ground granulated blastfurnace slag.

RILEM TC106 now has members from 19 countries including virtually all those which have significant AAR problems. This wide membership is a great strength but does make it difficult for members to meet regularly. Much of the work of the committee has therefore to be carried out by post. This slows the progress significantly. However, conferences such as this provide a rare opportunity for the majority of members to meet.

It is planned that a more complete interim report with details of proposed methods will be produced this year and it is hoped that this will be published in Materials and Structures.

PROGRESS IN DEVELOPMENT OF ACCELERATED TEST METHODS

1. General questionnaire on test methods

This questionnaire on test methods in use or being developed, is designed as an 'active' collation to guide the committee. Its results suggest that it should be possible to agree a universally applicable assessment scheme; for example, commencing with a petrographical examination which may sometimes be secondarily supported by chemical testing and proceeding to expansion testing to identify potentially reactive aggregate combinations. Expansion testing would probably include both ultra-accelerated methods and longer term, less accelerated methods.

Although there exists a considerable range of AAR test methods or adaptations of methods and views on their application or usefulness are diverse, it is apparent that most of these procedures can be grouped under give basic headings, as follows:

i) Petrographic assessment
ii) Expansion tests using concrete specimens
iii) Expansion tests using mortar specimens
iv) Chemical methods
v) Ultra-accelerated test methods

Initially, TC106 has decided to develop a menu of test procedures essentially comprising a single recommended RILEM method from each of these groups. Progress on this exercise is summarised in the succeeding sections. Later, TC106 intend to provide guidance in the selection of the test procedures appropriate to particular materials and circumstances.

2. Petrographic assessment

Following consideration of a report on a questionnaire on petrographic methods at the November 91 meeting, a working group has been formed to review existing methods and recommend the basis for a RILEM method. It is planned that the method will cover both sampling and examination and include a qualitative description, quantitative assessment, the use of additional sophisticated techniques and, finally, interpretation. The interpretation of petrographic results will need to be related to local experience.

3. Expansion tests using concrete specimens

A draft RILEM outline method has been developed, making reference to standardised and semi-standardised procedures available in several countries, and this is currently being circulated to TC106 members for final comment and ballot. An optional range of test parameters will be included in the preliminary method and initially interpretation criteria will be left for countries to set according to national experience. The concrete expansion test method will require post-test microscopical examination in order to verify the cause of any expansion recorded.

4. Expansion tests using mortar specimens

A draft RILEM method has been developed, based upon the ASTM C227 procedures but using the RILEM 'shorter fatter' mortar specimens, and this is currently being circulated to TC106 members for final comment and ballot. Like the concrete test, the mortar expansion test method will require post-test microscopical examination.

5. Chemical methods

A draft RILEM screening method has been developed for use with selected rock or aggregate types, based upon a modification of ASTM C289, and this is currently being circulated to TC106 members for final comment.

6. Ultra-accelerated methods

A review of different methods has been produced and members are being balloted on which method(s) should be developed further as a RILEM draft.

SPECIFICATION OF CONCRETE TO MINIMISE RISK OF DAMAGE FROM ALKALI AGGREGATE REACTIONS

Summary of international specifications - survey by RILEM TC106

This summary is based on the replies to a questionnaire circulated to the members of RILEM TC106. The efforts of members of TC106 in providing the information are gratefully acknowledged.

Replies were received from the following countries: Argentina, Australia, Belgium, Canada, Cyprus, Denmark, France, Germany, Iceland, Ireland, Italy, Japan, New Zealand, Norway, South Africa, UK, USA, USSR[1].

[Note 1. The position following the break-up of the USSR is not clear so the term USSR is retained here.]

1. Types of specification

Of the countries for which we have information Iceland, Italy, Japan, Argentina, Denmark, Canada, South Africa, UK and USSR have some type of national specification; Cyprus, France, Germany, Ireland, New Zealand and Norway have recommendations and in Australia some Government Departments include requirements for AAR in their specification. In the USA each of the 50 states plus the Corps of Engineers, Bureau of Reclamation have their own specifications. The information given here gives the general thrust of these.

2. Content and approach of specifications

There seem to be two basic approaches. In the first, exemplified by Canada, the essence of the specification is that 'aggregates for use in concrete shall not react with alkalis in the cement to an extent that results in excessive expansion of the concrete'. In the second, there is an acceptance that because of the geology of the country much concrete will have to be made with potentially reactive aggregates and the specification of concrete is designed to enable this to be done safely. This approach is well exemplified by UK specifications. In fact, most of the specifications are a combination of both approaches but we have attempted a classification as below.

Concentration on avoiding reactive aggregates:	Norway, Italy, Canada, Germany Australia
Mixture of testing aggregate reactivity and limiting alkali levels in cement or concrete and/or use of mineral admixtures when potentially reactive aggregates are used:	New Zealand, Japan, Denmark, Argentina, France, USSR, South Africa, USA, Belgium, Cyprus, Iceland
Concentration on limiting alkali levels:	UK, Ireland

If the aggregate is a potentially reactive variety, there are a number of approaches to the subsequent specification of the concrete:

Use of low alkali cement:	Norway, Argentina, Germany, Cyprus
Restriction of alkali level in concrete:	New Zealand, Ireland, Denmark
Use of mineral admixtures:	Iceland, Italy, Australia, Canada
Use of low alkali cement or use of mineral admixtures:	USA
Low alkali cement or restriction of alkali in concrete or use of mineral admixtures:	Japan, France[2], UK, USSR, Belgium, South Africa

The only common theme that can be seen here is that the more a country has no option but to use potentially reactive aggregates, the greater the number of alternative routes of doing this that are allowed or recommended.

[Note 2. Restriction of alkali in cement in France applies only to slag cements - see (3) below.]

3. Low alkali cements

Most countries which specify a low alkali cement have adopted the ASTM limit of 0.60% Na_2O equivalent (Argentina, Belgium, Cyprus, Germany, Ireland, Japan, New Zealand, Norway, South Africa, UK, USA, USSR). Argentina and UK both make this an option under their standard for sulphate-resisting Portland cement. France, Belgium and some UK authorities also classify a ground granulated blastfurnace slag cement, or cement:ggbs blend as equivalent to a low alkali cement. In these countries there is a restriction on the total alkali in the blend which depends on the proportion of slag:

	Slag % of binder	Max total % alkali in cement blend as Na_2Oe
France	> 60	1.1
	> 80	2
UK	> 50	1.1
Belgium	< 50	0.9
	> 50	1.1

4. Restriction of alkali level in concrete

i) Limits. Within the nine countries which restrict the alkali level in the concrete, there is an appreciable variation in permitted levels of alkali:

New Zealand	2.5 kg Na_2Oe/m^3
Belgiun, Japan, UK, USSR	3.0
France	3.0 to 3.5 depending on information about variability of cement alkalis
Ireland	4.0 but 4.5 if reactive aggregate is only Carboniferous chert[3]

In Denmark the reactivity of the permitted aggregate depends on the alkali in the concrete, the following intervals being defined:

$Na_2O < 1.8\ kg/m^3$
$\geqslant 1.8 < 3\ kg/m^3$
$\geqslant 3\ kg/m^3$

Similarly, in South Africa, alkali levels between 2 and 4.5 kg Na_2O_e/m^3 are allowed depending on the source of aggregate.

[Note 3. It is maintained in the Irish recommendations that chert of Carboniferous age is less reactive than that of Cretaceous age (ie flint).]

ii) Sources of alkali included in limit. All the countries using an alkali limit aim for the total alkali level in the concrete though there are some variations in what is included in that

alkali in cement	– all.
aggregates	– UK, Ireland, New Zealand and Japan calculate from chloride ion with UK, Ireland and New Zealand using a factor 0.76 x Cl^-, whereas Japan uses 0.9 x Cl^-. In France the alkali is experimentally determined by leaching with $Ca(OH)_2$ at 100'C. In Denmark the declared alkali content of the aggregate is included in the calculation but details of how this is determined are not available.
mix water	– included by Denmark, USSR, New Zealand and France.
mineral additives	– considerable variation here. Denmark and Japan do not include. New Zealand and South Africa use 'available alkali' determined by $Ca(OH)_2$ leaching, the limit in SA is < 1.5%. UK, Ireland and France use 1/6 total alkali in flyash and half total alkali in slag, except that UK Concrete Society recommends only water soluble alkalis, and there is provision for future experimental determination in France for carbonaceous mineral additives. USSR and USA only have a limit on the alkalis in pfa which should be in the range 1.5 to 3.0% Na_2O in USSR and less than 1.5% 'available alkali' in USA.

iii) Variability of alkali in cement. South Africa, Japan, Denmark, USSR and New Zealand do not make special provision. In the UK and Ireland, the alkali level used is a certified average which includes an allowance for variability. However, the UK Department of Transport adds 2 Standard Deviations to this certified average in its specification. In France there is a sophisticated treatment of cement alkali variability:

(1) If statistical data on the cement alkali content are available

$$T_m < \frac{3.5}{1+2V_c}\ \text{kg/m3}$$

and $T_{max} < 3.5$ kg/m3

(2) If no such data are available

$T_m < 3.0$ kg/m3
and $T_{max} < 3.3$ kg/m3

Where T_m : Concrete average alkali content
T_{max} : Concrete maximum alkali content
V_c : Variation coefficient of the alkalis for the cement considered

5. Use of mineral admixtures

Many countries use mineral admixtures or blended cements containing them to reduce the risk of damage from ASR but there are differences in the way they are used.

i) Permitted mineral admixtures. Which admixtures are permitted seems to depend more on availability and familiarity in the particular country rather than proven effectiveness. Flyash and granulated blastfurnace slag are used in most countries with microsilica also being used in Canada, Australia, South Africa, Belgium and Denmark and natural pozzolanas in Italy, USSR, France and Iceland (where ground rhyolite is also used).

ii) Restrictions on proportions. The proportions are not restricted in most countries. However, the Queensland and USA Depts of Transport specify between 20 and 30% flyash and in Japan the minimum replacement level depends on the alkali content of the base cement, viz:

	Alkali in base cement	
	< 0.8%	> 0.8%
Flyash	> 15%	> 20%
BF slag	> 40%	> 50%

In the UK the Concrete Society recommends that both flyash and slag should exceed 25% by mass of total binder and additionally that the reactive alkalis in the concrete do not exceed 3.0 kg Na_2O_e/m^3, while in South Africa 40% slag, 20% flyash or 15% microsilica are recommended. In Iceland at least 7% micro silica or 25% ground rhyolite are required.

In Denmark where combinations of flyash and microsilica are used, they should not exceed 35% replacement and should only be used in 'passive' (see 7 below) conditions. Microsilica should not exceed 10% replacement. A similar restriction to 10% microsilica is also used in Belgium.

iii) Alkali in mineral admixtures. See above under alkalis in concrete.

iv) Acceptance tests. New Zealand and Iceland use ASTM C441. Canada uses the expansion of concrete prisms containing the admixture (A23-2-14A) with expansions exceeding 0.04% at 1 year generally considered excessive. In the USA a maximum of 1.5% 'available alkali' according to ASTM C311 and also an expansion of less than 0.02% at 14 days in mortar bars made with pyrex glass and the flyash when stored at 38°C. Similarly, South Africa has a limit of 1.5% 'available alkali' and a limit of 0.1% for the expansion of mortar bars made with reference reactive aggregate and the mineral admixtures and stored in NaOH at 80°C.

6. Tests for aggregate reactivity

The different tests used are summarised in Table 1. In this table the different versions of the same basic type of test have not been differentiated. For example the Japanese have evolved their own variation of the chemical method and there are several different versions of the mortar bar method.

The main impression is of a bewildering array of different methods and variations of methods. If anything the chemical, mortar bar and petrographic methods are favoured. It is difficult to see any connection between the types of method and the approach of the country to specification as discussed in (2) above. Some countries have developed very individual methods. Notable in this respect is Denmark which offers three methods (mortar bars exposed to a saturated NaCl solution at 50°C, petrography, chemical shrinkage) for sand and a density/water absorption method for coarse aggregate as the basis of classifying them for use in one of four environmental conditions. The intention of the density/water absorption method is to avoid the use of the lighter, porous flints in more aggressive conditions, as they have been found to be more reactive.

7. Effect of type of structure and environment on specification

Most specifications encapsulate the idea that concrete placed in a dry environment and which will remain dry, needs no special precautions against AAR.

Some countries have developed more sophisticated interactions of specification and environment and/or type of structure. The French recommendations divide structures into three classes. Class III are structures of exceptional importance (dams, nuclear reactors, prestigious buildings etc) which should have precautions against AAR regardless of environment, Class II is a general class where precautions should be applied in adverse environments and Class I structures need no precautions.

The Danish Basic Concrete Specification classifies three types of environment:

Passive:	dry, unaggressive atmosphere, inside buildings
Moderate:	moist, unaggressive outdoor and indoor without chloride and alkali metal ions
Aggressive:	atmosphere containing salt or smoke; sea water or brackish water.

The limits for the aggregate tests and the allowable alkalis in concrete are defined for each environmental class. The USSR defines three environments very similar to the Danish (but information is not available on how these affect the specification). The Canadian standard allows slightly greater levels of expansion in their concrete prism method for aggregates to be used in concrete not exposed to freezing and thawing or to deicing salts. It also insists on a tighter limit for aggregates to be used in critical structures such as nuclear containment. The Belgian recommendations similarly define the combination of deicing salts and a wet environment to be a particularly aggressive situation.

8. Interaction of requirements

The general approach of specifications is that if the aggregate can be shown to be non-reactive, no other precautions are necessary. If not, a variety of precautions are invoked as described in (2). Some specifications emphasise that only one out of a number of measures are necessary, eg the French recommendations state 'only one needed out of the following requirements':

- aggregates are non-reactive
- concrete formulation meets requirements on alkali level
- concrete formulation passes performance test (provision for future test development)

- concrete formulation has a long record of safe use
- concrete contains mineral admixtures in sufficient proportions.

TABLE 1. TESTS FOR AGGREGATE REACTIVITY

	Concrete methods	Mortar bar 80°C/ NaOH	Chemical method	Mortar bar	Petrographic examination	Microbar	NaCl 50°C	Chemical shrinkage	Density water absn.
Argentina			x	x	x				
Australia	x	x	x	x	x				
Belgium		x							
Cyprus			x	x					
Canada	x		x	x	x				
Denmark					x		x	x	x
Germany			x						x
France	x		x	x		x			
Iceland				x					
Ireland			x	x	x				
Italy			x	x	x				
Japan			x	x					
New Zealand			x	x	x				
Norway	x	x			x				
South Africa	x	x		x					
UK	x				x				
USSR			x	x	x				
USA		x	x	x	x				

Belgium also uses the Canadian 'Duggan' test