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THE USE OF ACCELERATED MORTAR BAR TEST METHODS FOR ASSESSMENT OF ALKALI-AGGREGATE REACTIVITY OF AGGREGATE IN HONG KONG

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FOREWORD

This report briefly describes the types and mechanisms of the alkali-aggregate reaction (AAR). It also covers the use of different accelerated mortar bar test (AMBT) methods by the Public Works Central Laboratory (PWCL) of the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), for assessing the AAR potential of aggregate in Hong Kong and the conclusions and recommendations drawn.

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1. INTRODUCTION

Good quality concrete should be of adequate strength and durable. A judicious choice of components in concrete in the right proportions and proper placing and adequate curing of concrete are important for achieving the required strength and durability. The alkali content of cement, which is important to the strength development of concrete, may however affect its durability. A typical alkali-aggregate reaction (AAR) occurs when the alkali in concrete reacts with some deleterious minerals in the aggregate, causing expansion and cracking of the concrete.

This report aims to introduce to readers briefly the types and mechanisms of the AAR. It also covers the use of different accelerated mortar bar test (AMBT) methods by the Public Works Central Laboratory (PWCL) of the Geotechnical Engineering Office (GEO), Civil Engineering Department (CED), for assessing the AAR potential of aggregate in Hong Kong and the conclusions and recommendations drawn.

2. ALKALI-AGGREGATE REACTION IN CONCRETE

2.1 Types and Mechanisms of AAR

AAR takes place in concrete when alkali in concrete, or from an external source, reacts with certain aggregate to form products that deleteriously expand, which may result in severe cracking of the concrete. There are three types of AAR, namely alkali-silica reaction, alkali-silicate reaction and alkali-carbonate reaction. The mechanisms of these different types of AAR are described in Table 1. Alkali-silica reaction is the only type of AAR that has been reported to have occurred in Hong Kong.

2.2 Conditions and Sources of AAR

In order for AAR to take place in concrete, three conditions must be satisfied:

(a) the presence of alkali,
(b) the presence of reactive aggregate in concrete, and
(c) the presence of water.

The extent of AAR induced deterioration of concrete and the rate at which it occurs are affected by a number of factors, which can generally be grouped as follows:

(a) the reactivity of the siliceous material,
(b) the total alkali content of concrete, and
(c) the supply of moisture.

The alkali in concrete may come from different constituent materials introduced into the concrete, e.g. cement, pozzolana, aggregate and admixtures or from other sources external to the concrete, e.g. de-icing salts (see Table 2).

2.3 Occurrence of AAR in Hong Kong

Although AAR has been known to be a problem in many parts of the world, it was not diagnosed in Hong Kong until 1991 (Wong & Koirala, 1992; Irfan, 1994). The Standing Committee on Concrete Technology (SCCT), which was formed to co-ordinate inter-departmental efforts in resolving problems related to concrete technology, became aware of a number of concrete structures in Hong Kong that showed signs of map cracking. Consequently, an AAR sub-committee of SCCT was set up in 1991 to coordinate all investigative and research efforts related to AAR in concrete. The sub-committee issued a technical circular (Works Branch Technical Circular No. 5/94 (Works Branch, 1994)) which recommended limiting the alkali content in concrete to $3 kg/m^3$ to safeguard concrete against AAR.

As requested by the SCCT, the PWCL, with the assistance of the Planning Division of the Geotechnical Engineering Office, has investigated a number of suspected AAR cases in Hong Kong (Wong & Koirala, 1992; Tse & Gilbert, 1994; Gilbert, 1995; Sewell & Campbell, 2001). The investigation also covered the assessment of the AAR potential of aggregate from a number of quarries in Hong Kong and Mainland China using the AMBT methods (see Section 4).

3. METHODS OF ASSESSMENT FOR ALKALI-AGGREGATE REACTIVITY

3.1 Petrographic Examination

Petrographic examination of hardened concrete is a useful tool for the identification of the mineralogy in aggregate, composition of cement paste and texture of concrete for the purpose of assessing the presence of or potential for AAR. The standard method for such an examination is given in ASTM C295-98 (ASTM, 1998) and RILEM AAR-1 (RILEM, 2001a (in draft)).

The general procedures for identification of AAR involve an examination of polished slabs with the naked eye and under a binocular microscope, followed by a detailed examination of thin sections under a polarizing microscope. The examination of polished surfaces of concrete can identify the size range, shape and type of aggregate and the unusual features in aggregate, such as the presence of foliation, strained quartz, evidence of recrystallization and/or mineralization. In addition, obvious deleterious effects such as cracking, bleeding, infilling of voids and carbonation can also be delineated. In thin sections, the presence of gel filling cracks through the cement paste, across grain boundaries and on the margins of the aggregate fragments are the characteristic features of AAR.

3.2 Accelerated Mortar Bar Test (AMBT) Methods

Oberholster & Davies (1986) of the National Building Research Institute (NBRI) in South Africa first developed the AMBT method. The development of all subsequent national or international standard AMBT methods was largely based on the NBRI method. In 1993 the Public Works Laboratories (PWL) started to develop its own method, namely the PWL CON 5.5 method (PWL, 1999), due to the need to investigate the AAR problems in Hong Kong in the early 1990s' and as there were no national and international standard AMBT methods published at that time. The American standard method ASTM C1260 (ASTM, 1994a) and Canadian standard method CSA A23.2-25A (CSA, 1994a) for AMBT were subsequently issued in 1994. The British Standards Institution published its draft AMBT method DD249 (BSI, 1999a (in draft)) in 1999. The RILEM (a French acronym for the International Union of Laboratories and Experts in Construction Materials, Systems and Structures founded in 1947) published its AMBT method RILEM AAR-2 (RILEM, 2000a) in 2000.

The procedures specified in the above AMBT methods are generally similar, although there are minor variations between them. They all involve the preparation of a set of a minimum of three mortar bars of size 25 x 25 mm and 250 – 300 mm long for each test. Mortar is prepared by mixing aggregate of maximum size up to 4-5 mm with water and cement that contains the specified alkali content. It is then compacted into a steel mould and stored for about 24 hours. It is subsequently demoulded and cured by immersing it in water at about 80°C for another 24 hours. An initial reading is taken of the length of the mortar bar so formed. It is then immersed in sodium hydroxide solution, which is maintained at a temperature of about 80°C. Thereafter the bar is taken out of the solution at certain time intervals and further readings are taken. A comparison of the different AMBT methods is given in Table 3.

It should be noted that the RILEM method uniquely specifies the use of cement with specific surface area greater than 450 m^2/kg and a minimum alkali content of 1.0%. The method mentions that suitable reference cement that meets these requirements is available from Norway (the 'Norcem' cement) or the National Council for Cement and Building Materials in India. The draft BS standard method DD 249: 1999 also specifies similar requirements for the cement to be used.

The criteria for the classification of the potential deleteriousness of the aggregate expansion measured using the AMBT methods are specified in the ASTM C1260 (ASTM, 1994a), CSA A23.2-25A (CSA, 1994a) and draft BS standard method DD249: 1999 (BSI, 1999a (in draft)) (see Table 4). However, no similar criteria are specified in the RILEM AAR-2 (see note 6 in Table 4 for advice by RILEM on this subject) and PWL CON 5.5 methods.

3.3 Other Assessment Test Methods

Besides the petrographic examination and the AMBT method, there are other test methods for the assessment of AAR potential, namely the concrete prism test (CPT) and the accelerated concrete prism test (ACPT).

For the CPT, concrete prisms of 75 x 75 mm cross-section are prepared with the aggregate to be tested. They are then stored in humid conditions and at a temperature of about 38°C for 12 months. Measurements are made at periodic intervals to determine any expansion that has occurred. Several national and international standard methods exist for this test (see Table 5). However, little is known regarding their use in Hong Kong. RILEM is the only standards body who is developing a standard method for the ACPT (RILEM AAR-4 method (RILEM, 2001b (in draft)), which aims to elevate the temperature to 60°C and relative humidity close to 100% for the storage of the concrete prisms and to complete the test within 20 weeks.

ASTM has also produced a standard mortar bar test method, ASTM C227 (ASTM, 1997), and a standard chemical method, ASTM C289 (ASTM, 1994b), for the assessment of AAR. However, the mortar bar test method takes a year to complete and is now commonly replaced by the AMBT methods. The chemical method, although can be completed within 24 hours, is not very reliable. Moreover, the results of this chemical test method may not be correct for aggregate containing carbonates of calcium, magnesium or ferrous iron, such as calcite, dolomite, magnesite or siderite, or containing silicates of magnesium such as antigorite (serpentine). In all cases, further confirmatory testing using other methods is required.

A summary of the currently available standard test methods for assessing AAR potential is given in Table 5. The results of the petrographic examination, AMBT, CPT and ACPT methods are indicative only, and whenever possible they should be correlated with field performance if long-term performance of a concrete structure with respect to AAR is to be assessed.

4. ASSESSMENT OF AAR POTENTIAL OF AGGREGATE IN HONG KONG USING AMBT METHODS

4.1 Scope of Tests Conducted

Since 1996, the PWCL has carried out a series of AMBT to assess the AAR potential of a comprehensive range of local aggregate as well as aggregate imported from Mainland China. The aggregate tested included granite aggregate, aggregate of volcanic ash tuff and aggregate which has been known to be highly alkali-aggregate reactive. The aggregate from the SPRATT Quarry in Canada (a reference aggregate) was also included in the testing programme for reference purposes. The testing of the aggregate was repeated using different AMBT methods, namely the ASTM C 1260, CSA A23.2-25A, PWL CON 5.5 and RILEM AAR-2 methods. Besides assessing the AAR potential of the aggregate from different origins, the testing programme also aimed to compare the results obtained using different AMBT methods.

4.2 Results and Discussion

The results of the series of AMBT are summarised in Table 6 and presented in Figure 1. As can be seen, the percentage expansions of mortar bars of granite aggregate are mostly below 0.1%. According to the criteria recommended by national or international standards for interpretation of the AMBT results (see Table 4), these aggregates should be considered as innocuous with respect to AAR. The results of the Aggregate Type HK4 and Aggregate Type C10 of volcanic ash tuff and the reference aggregate from the Spratt Quarry (Canada) exceed 0.2%. These aggregates should be considered as potentially deleteriously reactive with respect to AAR. The expansion of the Aggregate Type C9 of granodiorite exceeds 0.1% but below 0.2%, the alkali aggregate reactivity of which should be considered as inconclusive. The expansion of the aggregate from the SPRATT Quarry was found to be the greatest (> 0.4%).

As can be seen from Figure 1, for expansions below 0.2% the RILEM AAR-2 method tends to give higher expansion values than the other methods. This may be due to the higher alkali content of the cement (viz. 1% minimum as compared with 0.8-0.9% in other methods) and the stringent requirement for high specific surface area of the cement (> 450 m^2/kg) specified for use in this method. However, the measurement of higher expansion by this method is not observed when expansion exceeds 0.2%. This may be due to the possibility that for highly reactive aggregate, the effect of the buffer solution (i.e. the 1 M NaOH) becomes dominant and outweighs that of the higher alkali content of the cement.

The results obtained using the RILEM AAR-2 method would likely be more repeatable, as only the reference cement, which is produced at a highly consistent standard, can meet the stringent requirements in respect of alkali content and specific surface area of the cement specified for use in this method. The BS method DD249 (BSI, 1999a, (in draft)) also specifies similar requirements for the cement. RILEM is currently the only standards body that is preparing a complete series of tests (petrographic examination, AMBT, CPT and ACPT) for the assessment of AAR potential (see Table 5). It would be useful to adopt the RILEM methods as the standard methods, when they are all finalised. This is because a complete series of test methods for assessment of AAR potential will then be available and a full assessment for AAR potential can be conducted, if needed. Therefore, it is recommended to adopt the RILEM AAR-2 method as the standard AMBT method for use in Hong Kong. The SCCT has endorsed this recommendation. It has also endorsed a recommendation put forward by PWCL that when using the RILEM AAR-2 method, 0.1% expansion is accepted as the limit below which aggregate is considered to be innocuous. This is in line with most of the internationally accepted practices (see Table 4). A copy of the standard specification for the RILEM AAR-2 method is reproduced in Appendix for easy reference.

The results obtained using the PWL CON 5.5 method were correlated with those obtained using the ASTM C1260 and CSA A23.2-25A methods, and the results are shown in Figures 2 and 3 respectively. As can be seen, the results obtained using the PWL CON 5.5 method are in better agreement with those obtained using the ASTM method. Therefore, in case interpretation of results previously obtained by the PWL CON 5.5 method is needed, the criteria adopted by the ASTM method for the classification of potential deleterious expansion of aggregate (see Table 4) can be adopted .

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the work done by the PWCL as described in this report, the following conclusions and recommendations can be made:

(a) Based on the results of the series of AMBT conducted by the PWCL as described in this report, the expansions of nearly all aggregates commonly adopted for use in concrete production in Hong Kong were found to be below 0.1%.

(b) The results obtained by the PWL CON 5.5 method show better agreement with those obtained by the ASTM C1260 method than the CSA A23.2-25A method. Accordingly, the criteria for the classification of potential deleterious expansion of aggregate recommended in the ASTM method can be adopted as those for the PWL CON 5.5 method in case interpretation of results previously obtained using the PWL CON 5.5 method is needed.

(c) Where the AMBT method is to be adopted for assessing the AAR potential of aggregates included in concrete production in Hong Kong, the RILEM AAR-2 method is recommended to be adopted as the standard method, as a set of clear and consistent conditions is specified for testing using this method (e.g. the use of cement of minimum specific surface area and alkali content).

(d) For assessing the AMBT results, most national and international standards recommend adopting 0.1% as the expansion limit below which aggregate is considered to be innocuous with respect to AAR (the "innocuous" limit). Only the Canadian standard recommends adopting a "innocuous" limit of 0.15%. It is therefore recommended that the 0.1% expansion measured using the RILEM AAR-2 method be adopted as the "innocuous" limit at this stage. Further work is however needed to be carried out to deal with the aggregates with expansion exceeding this limit.

(e) For aggregates that are found to exceed the 0.1% expansion limit when tested using the RILEM AAR-2 method, it is also recommended that further evaluation of the AAR potential of aggregates is permitted by re-testing using other national or international AMBT methods. The results should then be compared with the corresponding "innocuous" limits adopted for use with these methods. The AAR potential of the aggregates should be confirmed by such tests in conjunction with other methods such as petrographic examination. Whether the above recommended 0.1% expansion limit could be relaxed to a higher value will be reviewed when more data are obtained in future.

(f) The RILEM's methods for petrographic examination, AMBT, CPT and ACPT (i.e. RILEM AAR-1 to -4) is the only complete series of test methods produced by the same standards body that presents a holistic approach to the assessment of AAR potential. They should therefore be considered for use as the basis of a framework for screening aggregate for AAR potential in Hong Kong.

(g) The RILEM's methods for CPT and ACPT (i.e. RILEM AAR-3 and -4) should be tried out using local aggregates.

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Table 1 – Types and Mechanisms of Alkali-aggregate Reactions

Type of AAR	Mechanism of Reaction
Alkali-silica reaction	The alkali-silica reaction takes place in concrete when the alkali, mainly sodium and potassium oxides (Na_2O and K_2O) in concrete, reacts with the reactive silica in aggregate. The chemical reaction begins with the attack of the reactive silica by the alkaline oxides. The reaction would lead to the formation of calcium-rich alkali-silica gel, which has a strong affinity for water. The gel absorbs water and expands, exerting pressure in all directions and forming cracks through the aggregate and cement paste. Some of the gel may ultimately leach out through the cracks. The expansion of the gel can cause deterioration of the concrete which may take 2 to 25 years before it can develop to a significant extent in the field, depending on the reactivity of the aggregate, the total alkali content in concrete and the exposure conditions.
Alkali-silicate reaction	The alkali-silicate reaction is somewhat similar to the alkali-silica reaction, except that the reactive constituents in the aggregate are not the free silica but the silicate which exists in a combined and fine-grained form – phyllosilicates. The phyllosilicates, if not in a fine-grained form, are not very reactive. Alkali-silicate reaction has not been reported to have occurred in Hong Kong.
Alkali-carbonate reaction	The alkali-carbonate reaction occurs in concrete when alkali comes into contact with clay containing dolomitic limestone. The alkali reacts with the reactive silica in dolomite, causing dolomite to break down into brucite and calcite. This process is known as dedolomitisation. As a result of the dedolomitisation, cracks would be formed on the aggregate, leading to ingress of moisture. This would then cause the clay to swell, disrupt the aggregate and finally crack the concrete. Alkali-carbonate reaction has not been reported to have occurred in Hong Kong.

Table 2 – Possible Sources of Alkali in Concrete

(a) Cement	Cement could be a major source of alkali as it contains alkaline oxides (Na_2O and K_2O).
(b) Pozzolana	Pozzolana is a common cementitious material. The siliceous or aluminous materials contained in pozzolana may react with lime (CaO) at ambient temperature to form cementitious compounds. Alkali is then released during the process.
(c) Aggregate	Feldspar, mica, glassy rock and glass in aggregate may release alkali in concrete. Marine sand may contain traces of sodium chloride which, if not washed thoroughly, can introduce a significant amount of alkali in concrete.
(d) Admixture	Admixture (e.g. accelerators, retarders, water reducers, superplasticizers and air entraning agents) may contain sodium and potassium compounds which can increase the alkali content of concrete.
(e) De-icing salts	In cold areas, the use of de-icing salts containing sodium ions may increase the alkali content of concrete.
(f) External sources	Soils containing alkali may also increase the alkali content of the concrete that comes into contact with them.

Table 3 – Comparison of Different Accelerated Mortar Bar Test Methods

	PWL CON 5.5	ASTM C1260 (94)	CSA A23.2-25A(94)	RILEM AAR-2	DD 249 : 1999(1)
Size of specimen	25 x 25 x 285 mm	25 x 25 x 285 mm	25 x 25 x 285 mm	25 x 25 x 285 mm(2)	25 x 25 x 250 mm
Number of bars	3	≥3	≥3	≥3	≥4
Laboratory conditions	20 ± 2°C; RH ≥ 65%	20°C to 27.5°C; RH ≥ 50%	20°C to 26°C; RH ≥ 50%	20 ± 2°C; RH ≥ 50%	20 ± 5°C; RH ≥ 50%
Temp. of water used	20 ± 2°C	23 ± 1.7°C	23 ± 2°C	20 ± 2°C	20 ± 5°C
Alkali content of cement	0.85 ± 0.05%	Requirement not specified	0.9 ± 0.1%	Min. 1.0%	1 ± 0.1%
Specification of cement	Locally available cement, preferably with alkali content >0.55%	Complies with specification C150; autocave expansion < 0.2%	Portland Cement (Type 10) specified in CAN/CSA-A5	Specific surface > 450 m^2/kg; autocave expansion < 0.2 or MgO soundness = 0 mm	Specific surface > 450 m^2/kg; autocave expansion < 0.2 or MgO soundness = 0 mm
Aggregate size distribution 10% 25% 25% 25% 15%	4.75 mm to 2.36 mm 2.36 mm to 1.18 mm 1.18 mm to 600 µm 600 µm to 300 µm 300 µm to 150 µm	4.75 mm to 2.36 mm 2.36 mm to 1.18 mm 1.18 mm to 600 µm 600 µm to 300 µm 300 µm to 150 µm	5 mm to 2.5 mm 2.5 mm to 1.25 mm 1.25 mm to 630 µm 630 µm to 315 µm 315 µm to 160 µm	4 mm to 2 mm 2 mm to 1 mm 1 mm to 500 µm 500 µm to 250 µm 250 µm to 125 µm	5 mm to 2.36 mm 2.36 mm to 1.18 mm 1.18 mm to 600 µm 600 µm to 300 µm 300 µm to 150 µm
Amount of water required	Determined by flow value	Water/Cement ratio = 0.47	Water/Cement ratio = 0.44 for natural fine aggregate or 0.50 for crushed coarse aggregate	Water/Cement ratio = 0.47	Water/Cement ratio = 0.47
Flow value required	105 – 120%	Not mentioned	Not mentioned	105 – 120% (Superplasticizer may be added)	Optional
Mixing of mortar and time required for the mixing	Mixing of mortar for 2¾ min in mixer, fill mould in 2 equal layers and compacted with tamper	Mixing in accordance with ASTM C305, fill mould within 2¼ min. in 2 equal layers after mixing	Mixing in accordance with ASTM C305, fill mould within 2¼ min. in 2 equal layers after mixing	Mixing in accordance with EN 196-1 ≤3 minutes for moulding after completion of mixing in 2 equal layers	Mixing, filling mould, compacted, finished and cured in accordance with BS 4551-1:1998, Clause 12.2.6
Conditions and duration of storage of specimens in mould	20 ± 2°C; RH ≥ 95% 24 ± 2 hours	23 ± 1.7 °C; RH ≥ 95% for 24 ± 2 hrs	23 ± 2°C; RH > 95% for 24 ± 2 hrs	20 ± 1°C; RH ≥ 90% 24 ± 2 hours	20 ± 5°C, RH > 95% for 24 ± 2 hrs
Initial curing after demoulding	Immersed in distilled water, then raise water temp. from 20 to 80 °C over a period of 4 ± 0.5 hr, maintain water temp at 80 ± 2° C for 20 ± 0.5 hr	Immersed in tap water at room temp. and placed in oven or water bath at 80 ± 2° C for 24 hrs	Immersed in tap water at room temp. and placed in oven or water bath at 80 ± 2° C for 24 hrs	Immersed in distilled water container at room temp. and placed in oven at 80 ± 2° C for 24 hrs	Immersed in 20±5°C distilled water container and placed in oven at 80 ± 2° C for 24 ± 2 hrs
Volume ratio of NaOH solution to specimen	Min. 4 times vol. of mortar bars	4 ± 0.5 times vol. of mortar bars	4 ± 0.5 times vol. of mortar bars	4 ± 0.5 times vol. Of mortar bars	4.8 times vol. of mortar bars
Conditions of storage for specimens pending expansion measurement	1M NaOH @ 80° ± 2°C	1N NaOH @ 80° ± 1°C	1N NaOH @ 80 ± 2°C	1M NaOH @ 80° ± 2°C	1M NaOH @ 80° ± 2°C
Measurement frequency after casting	Readings taken at 2, 7, 9, 14 & 16 days	Readings taken at 2 days & at least 3 intermediate readings before final reading at 16 days, and at least one reading was taken weekly if the measurement is to be continued further	Readings taken at 2 days & at least 3 intermediate readings before final reading at 16 days, and at least one reading was taken weekly if the measurement is to be continued further	Readings taken at 2, 3 days & at least 3 intermediate readings taken before final reading at 16 days	Readings taken at 2, 3, 9 and 16 days
Time within which expansion measurements should be taken after a bar specimen is taken out of the NaOH solution	20 sec	15 ± 5 sec	15 ± 5 sec	15 sec	15 ± 5 sec
Storage period	Not Specified	16 days after casting or longer	16 days after casting or longer	16 days after casting or longer	Not specified
Compliance criteria	Not specified	Criteria specified, see Table 4	Criteria specified, see Table 4	Not specified	Criteria specified, see Table 4

Notes:
1. The DD249 is a draft British Standard.
2. Length in the range of 250-300mm is also acceptable. Other bar size (e.g. 40 x 40 x 160 mm) can also be used as an alternative option subject to a suitable conversion factor.

Table 4 – Criteria for Classification of Potential Deleterious Expansion of Aggregate Recommended in Various AMBT Methods

AMBT Method	Days Immersion in NaOH Solution	Expansion Limit (%)	Classification
NBRI	14	≤ 0.10	Innocuous
		> 0.10 < 0.25	Potentially reactive, slowly expanding
		≥ 0.25	Potentially reactive, rapidly expanding
ASTM C 1260		< 0.10	Innocuous(1)
		0.10 to 0.20	Innocuous as well as potentially deleteriously reactive(2)
		> 0.20	Potentially deleteriously reactive
CSA A23.2-25A		< 0.15(3)	Innocuous(4)
DD 249: 1999		< 0.10	Innocuous
		0.10 to 0.20	Inconclusive (other assessment required)
		> 0.20	Potentially expansive

Notes:
1. ASTM notes that some granitic gneisses and metabasalts have been found to be deleteriously expansive in field performance even though their expansion in AMBT is less than 0.10 % at 14 days after immersion in NaOH. With such aggregate, ASTM recommends that prior field performance should be investigated. In the absence of field performance data, mitigation measures (such as the use of low-alkali Portland cement) should be taken.
2. ASTM considers it particularly important to obtain supplementary information through petrographic examination, examination of the tested specimens and field service records. It may also be useful to take further expansion readings until 28 days after immersion in NaOH solution.
3. CSA recommends a lower limit (0.1%) for some siliceous limestones.
4. CSA notes that several types of aggregate with expansions > 0.15% have given satisfactory field performance and it recommends further testing to be conducted.
5. No similar criteria are specified in the PWL CON 5.5 method (see Section 5.2 of this Report).
6. No similar criteria are specified in the RILEM AAR-2 method. However, on the basis of trials carried out by RILEM on aggregate combinations of known field performance from various parts of the world, RILEM considered that results in the test of less than 0.10% were likely to indicate non-expansive materials, whilst results exceeding 0.20% were found to indicate expansive materials (draft 'Outline Guide to the Use of RILEM Methods in Assessments of Aggregates for AAR Potential', dated 22 April 2001 issued by RILEM).

Table 5 – Standard Test Methods for Assessment of Alkali-aggregate Reactions

Test Method	RILEM	ASTM Standard	Canadian Standard	Hong Kong Test Specification	British Standard
Petrographic Examination	AAR-1 (RILEM, 2001a (in draft))	ASTM C295 (ASTM, 1998)	---	---	BS 812:Part 104 (BSI, 1994)
Accelerated Mortar Bar Test (AMBT)	AAR-2 (RILEM, 2000a)	ASTM C1260 (ASTM, 1994a)	CSA A23.2-25A (CSA, 1994a)	PWL CON5.5 (PWL, 1999)	DD 249: 1999 (BSI, 1999a (in draft))
Concrete Prism Test (CPT)	AAR-3 (RILEM, 2000b)	ASTM C1293 (ASTM, 2001)	CSA A23.2-14A (CSA, 1994b)	---	BS 812:Part 123 (BSI, 1999b)
Accelerated Concrete Prism Test (ACPT)	AAR-4 (RILEM, 2001b (in draft))	---	---	---	---
Mortar Bar Test		ASTM C227 (ASTM, 1997)			
Chemical Method		ASTM C289 (ASTM, 1994b)			

Table 6 - Percentage Expansion of Mortar Bars Prepared Using Aggregates From Different Sources and Measured by Different Test Methods

Type of Aggregate	Mean Percentage Expansion of Mortar Bars After 14 days of Testing (%)			
	PWL CON5.5	ASTM C1260 (94)	CSA A23.2-25A (94)	RILEM AAR-2
Type C1, China (Granite)	0.017	0.016	0.016	0.029
Type C2, China (Granite)	0.019	0.019	0.019	0.039
Type C3, China (Granite)	0.020	0.025	0.024	0.039
Type C4, China (Granite)	0.023	0.024	0.021	0.027
Type C5, China (Granite)	0.026	0.033	0.025	0.041
Type HK1, Hong Kong (Granite)	0.026	0.016	0.036	0.052
Type C6, China (Granite)	0.029	0.030	0.026	0.052
Type C7, China (Granite)	0.044	0.050	0.047	0.073
Type C8, China (Diorite)	0.059	0.064	0.055	0.072
Type HK2, Hong Kong (Granite)	0.068	0.084	0.078	0.061
Type HK3, Hong Kong (Granite)	0.074	0.090	0.076	0.108
Type C9, China (Granodiorite)	0.184	0.137	0.135	0.186
Type C10, China (Ash tuff)	0.298	0.285	0.224	0.217
Type HK4, Hong Kong (Ash tuff)	0.350	0.334	0.359	0.309
Spratt (SC), Canada (Ash tuff)	0.458	0.421	0.423	0.464

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Figure 1 - Percentage Expansion of Mortar Bars Prepared Using Aggregates From Different Sources and Measured by Different Test Methods

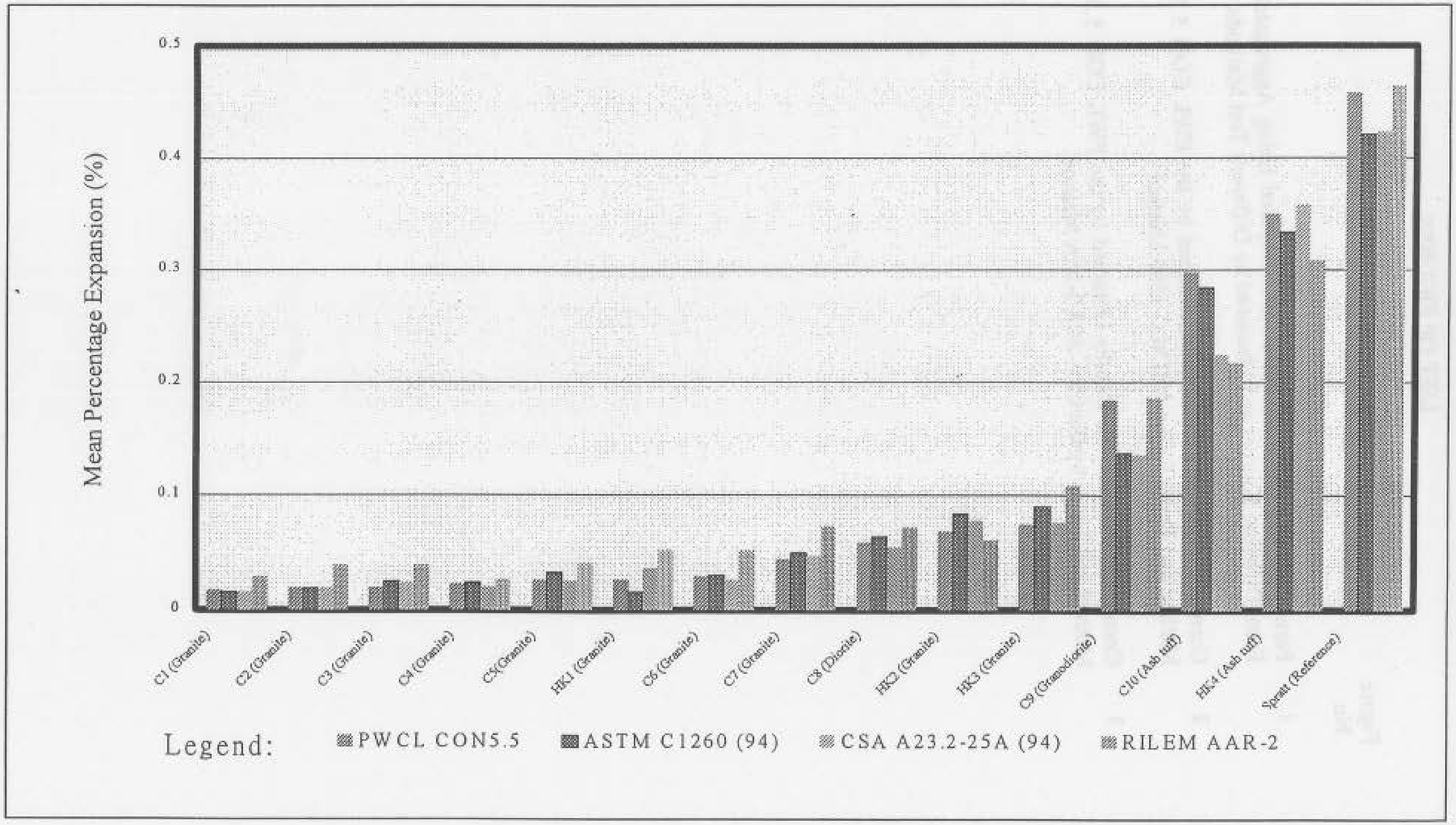


Figure 2 – Correlation Between the Results Obtained by the PWL CON 5.5 Method and Those by the ASTM C 1260 Method

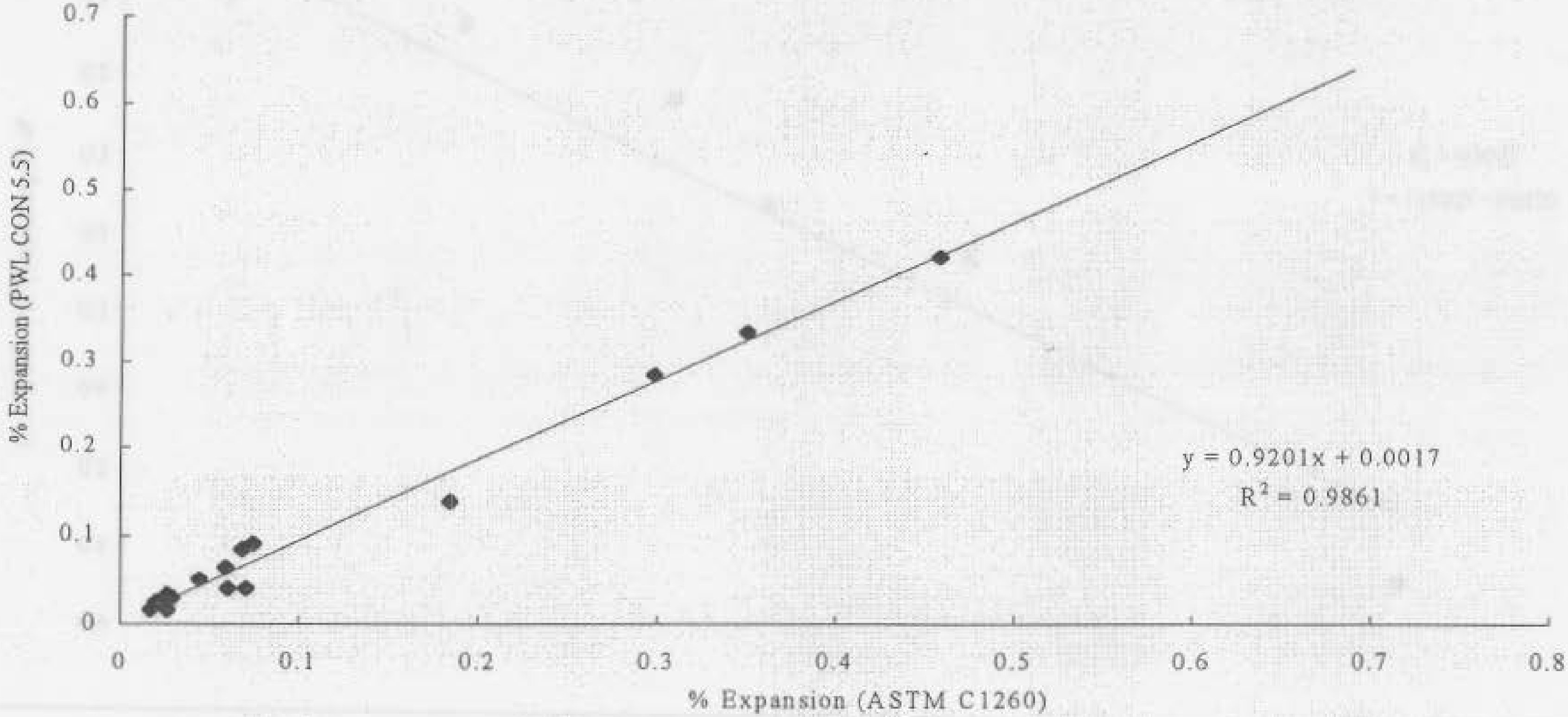
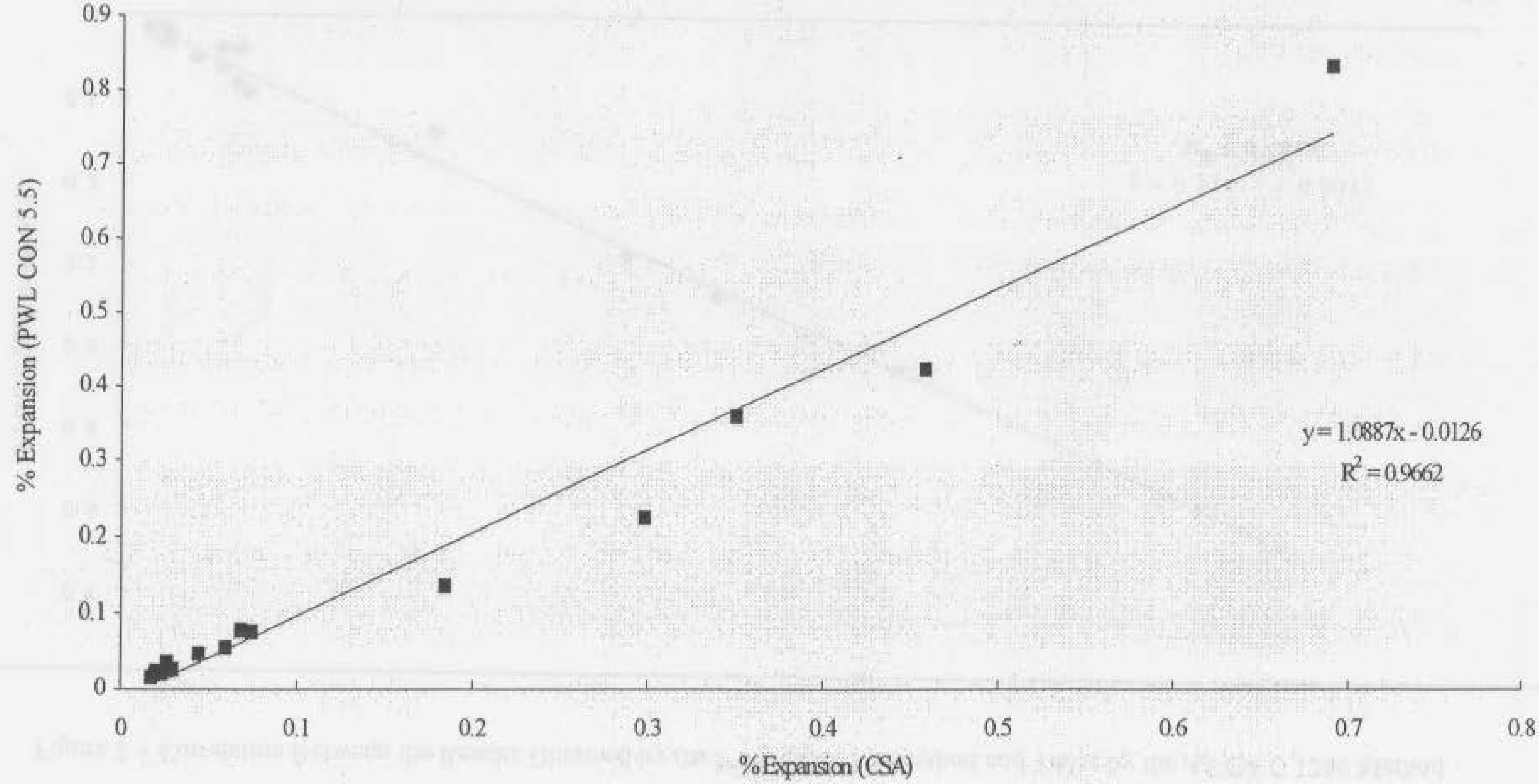


Figure 3 – Correlation Between the Results Obtained by the PWL CON 5.5 Method and Those by the CSA A 23.2-25A Method



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RILEM TC 106-AAR: ALKALI-AGGREGATE REACTION

Recommendations

A – TC 106-2 – Detection of potential alkali-reactivity of aggregates – The ultra-accelerated mortar-bar test
B – TC 106-3 – Detection of potential alkali-reactivity of aggregates – Method for aggregate combinations using concrete prisms

The texts presented hereafter are drafts for general consideration. Comments should be sent to the TC Chairman: Dr. Philip J. Nixon, Building Research Establishment, WD2 7JR Garston Watford, United Kingdom; e-mail: nixonP@bre.co.uk, by 31 December 2000.

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INTRODUCTION

The methods confirm and supersede drafts published in 1996. The progress of TC 106 has been reviewed by Nixon and Sims in 1996 [1] and again in a recent issue of *Materials and Structures* [2]. In their 1996 review, Nixon and Sims included two draft test methods: the ultra-accelerated mortar-bar test (TC 106-2) and the concrete prism test (TC 106-3). These tests have now been subjected to further development by TC 106, including some modifications recommended by the 'STAR' consortium following their trials for the European Commission [3], and final versions of the tests are provided in this paper.

Work is continuing on a petrographical examination procedure (TC 106-1) and this will be published separately in due course. TC 106 is also actively developing various other AAR test methods (see reference [2]), as well as overall guidance for their application and interpretation.

REFERENCES

[1] Nixon, P., Sims, I., 'Testing aggregates for alkali-reactivity. Report of RILEM TC 106', *Mater. Struct.* 29 (190) (1996) 323-324.

[2] RILEM Recommendation TC 106-AAR: International assessment of aggregates for alkali-aggregate reactivity, *Mater. Struct.* 33 (2000) 88-93.

[3] European Commission, 'Standard Tests for Alkali-reactive Rocks, Final report', DGXII contract no SMT4 - CT96 - 2128 STAR Project.

A – TC 106-2 – Detection of potential alkali-reactivity of aggregates – The ultra-accelerated mortar-bar test

1. FOREWORD

This draft method has been prepared by RILEM TC 106-AAR (Alkali-Aggregate Reaction) - Accelerated Tests. It is based on the South African NBRI (National Building Research Institute) accelerated test method.

2. SCOPE

This test method is intended to determine rapidly the potential alkali-reactivity of aggregates through the evaluation of the expansion of mortar-bars immersed in NaOH solution at elevated temperature, as specified in the method. The test may be also used in experiments to assess the pessimum behaviour of reactive aggregates (See Annex - A2). The test is not suited for the determination of the potential alkali-reactivity of aggregates containing more than 2% (by mass) of porous chert and flint (See Annex - A3).

3. SIGNIFICANCE AND USE

This test method provides a means of screening aggregates for their potential alkali-reactivity. It was developed as a quicker more reliable alternative to the ASTM C 227 mortar-bar test. It may be especially useful for aggregates that react slowly or produce expansion late in the reaction such as granite, rhyolite, andesite, volcanic tuff, gneiss, quartzite, hornfels, phyllite, sandstone, greywacke, shale, tillite, non-porous chert and flint, diatomite, quartz-bearing dolomitic limestones and quartz-bearing calcitic dolostones. It is recommended that a petrographic examination of the aggregates should accompany the accelerated test method (See Annex - A3).

4. PRINCIPLE

In this method prisms are moulded from mortar prepared with the aggregate to be tested. The prisms are demoulded after 24 ± 2 hours and their initial length measured. The specimens are then placed in water, transferred to an oven at 80°C ± 2°C for 24 hours, removed from the water and the length measured immediately before the temperature has dropped substantially (zero reading). The specimens are immediately placed in containers with a 1M NaOH solution already at 80°C ± 2°C, the containers sealed and placed in an oven at 80°C ± 2°C (subsequent 14 days). Length measurements are taken periodically.

5. APPARATUS

5.1 Sieves

A set of sieves conforming to series A of ISO 6274, having square apertures of 4 mm, 2 mm, 1 mm, 500 µm, 250 µm and 125 µm. Alternatively, the equivalent sieves of series B (4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm and 150 µm) or C (5 mm, 2.5 mm, 1.25 mm, 630 µm, 315 µm and 160 µm) can be used.

5.2 Balance

A balance capable of weighing 1000 g with an accuracy of 1 g.

5.3 Measuring cylinders

Graduated in ml, with a capacity of 200 ml.

5.4 Mixer, paddle and mixing bowl

Mixer, paddle and mixing bowl, as used in the procedure for testing the strength of cement with plastic mortar.

5.5 Flow table

Flow table consisting essentially of a circular rigid table top, with a diameter of about 250 mm, that can be raised vertically by means of a cam, and dropped through a nominal height of 12.7 mm (*e.g.* conforming to ASTM C 230).

5.6 Mould for flow test

A frustum of a cone with height 50 mm, base diameter 100 mm and top diameter 70 mm (*e.g.* conforming to ASTM C 230).

5.7 Tamper

Tamper, made of non-absorbent, non-abrasive, non-brittle material and with a cross-section of 13 × 25 mm. A convenient length is 230 mm to 300 mm. The tamping face shall be flat and at right angles to the length of the tamper.

5.8 Prism moulds

Moulds, providing for prisms with a nominal length of 285 mm and a cross section of 25 mm × 25 mm (lengths in the range of 250 to 300 mm are also acceptable). The end plates of the moulds must have threaded holes in the centres to take stainless steel pins of 6 mm diameter and 20 mm length used for length measurements (see Note 1).

5.9 Length comparator

Consisting of:

- an apparatus to measure the length of the specimens conveniently and rapidly,
- a high-grade dial micrometer, or other measuring device, graduated to read in 2.5 µm units, accurate to within 2.5 µm in any 25 mm range, and within 5 µm in any 0.25 mm range. The measuring range shall allow for small variations (± 10 mm) from the nominal gauge length of the specimens,
- an Invar® reference bar (or similar) of the same nominal length as the specimens for checking the measuring device, before and after each set of readings.

5.10 Containers

Rigid containers for the test specimens made of plastic or other material resistant to corrosion by a solution of sodium hydroxide at a temperature of 80°C for a prolonged period of time. Each container must be of such dimension and shape to accommodate at least three specimens and must be provided with lids or other suitable means to prevent loss of moisture by leaking or evaporation. The prisms must be positioned and supported in such a way that the solution has access to the whole of the bar. It should further be ensured that the specimens do not touch each other or the sides of the container. The specimens, if stood upright in the solution, shall not be supported by the steel pins.

5.11 Storage

A cabinet or moist storage room maintained at a temperature of 20°C ± 1°C and a relative humidity more than 90% (*e.g.* conforming to EN 196-1).

5.12 Oven

An oven or room of suitable size to accommodate the required number of containers maintained at a temperature of 80°C ± 2°C.

5.13 Crusher

A laboratory-type crusher of suitable size and design capable of crushing aggregate to the prescribed size fractions.

NOTE 1: Moulds for prisms size 40 × 40 × 160 mm can also be considered. (See Annex - A5).

6. REAGENTS AND MATERIALS

6.1 Water

Distilled or deionised water.

6.2 Sodium hydroxide solution (NaOH)

Each litre of sodium hydroxide solution shall contain 40.0 g of NaOH dissolved in 900 ml of water and, after cooling to about 20°C, it shall be diluted with additional distilled or deionised water to obtain 1.0 litre of solution. The concentration of the solution shall lie between 0.99 and 1.01M. A new solution shall be prepared for each series of tests.

6.3 Cement

An ordinary Portland cement CEM I or ASTM type I with a minimum Na_2O equivalent (Na_2O + 0.658 K_2O) of 1.0%. The specific surface of the cement, when measured according to the air permeability method (*e.g.* EN 196-6), shall be greater than 450 m^2/kg. The autoclave expansion, determined according to ASTM test method C 151 shall be less than 0.20%. Alternatively the MgO soundness can be evaluated by Le Chatelier test (*e.g.* EN 196-3) and the increase in separation of indicators ends shall be 0 mm.

NOTE 2: Suitable reference cements are available from Norcem A.S, R&D Department, 3950 Brevik, Norway (contact Dr K. O. Kjellsen), or from National Council for Cement and Building Materials, Calibration Testing & Quality Control, 34 Km Stone, Delhi-Mathura Road (NH-2), Ballabgarh 121 004, Haryana State, India (contact Mr R. C. Wason).

7. PROCEDURE

7.1 Preparation of the aggregate sample

The quantity of sample delivered to the laboratory should be in accordance with the sampling procedures recommended in RILEM Recommendation TC 106-1 (Method for Petrographic Analysis of Alkali Reactive Concrete Aggregates) [1]. The material to be tested shall consist of particles ≤ 4 mm and ≥ 125 µm, graded according to 7.1.1, 7.1.2 and 7.1.3, washed and dried as indicated in 7.1.5.

7.1.1 Natural fine aggregate

The natural material proposed for use as fine aggregate in concrete shall be tested in the grading as submitted, except that particles retained on a 4 mm screen or equivalent shall be crushed and included.

NOTE 3: The particles retained on the 4 mm screen or equivalent shall be removed only if petrography has confirmed that they are no different from the particles passing through.

7.1.2 Crushed fine aggregate

The crushed material proposed for use as fine aggregate in concrete shall be tested in the grading prescribed in Table 1.

Table 1 – Grading requirements

Sieve Size		Mass, %
Passing	Retained	
4 mm	2 mm	10
2 mm	1 mm	25
1 mm	500 mm	25
500 µm	250 µm	25
250 µm	125 µm	15

(See clause 7.1.2)

7.1.3 Coarse aggregate

The material proposed for use as coarse aggregate in concrete shall be processed by crushing and sieving to produce a graded sample in accordance with the requirements prescribed in Table 1. This sample shall be representative of the composition of the coarse aggregate as proposed for use.

> NOTE 4: *Coarse aggregate crushed to sand size may give increased expansion, owing to the increased surface exposed upon crushing. Therefore, if coarse aggregate tested by this method is found to be potentially reactive, tests should be performed on concrete specimens, according to RILEM Recommendation TC 106-3 (Method for Aggregate Combinations using Concrete Prisms)[2] to verify the results found with the mortar samples.*

7.1.4 Fine and coarse aggregate

The material proposed for use as fine and coarse aggregate in concrete shall be separated by sieving on a 4 mm sieve or equivalent. Fine and coarse aggregate shall be tested separately as indicated in clauses 7.1.1, 7.1.2 and 7.1.3.

7.1.5 Final aggregate preparation

After the fine or coarse aggregate has been processed and washed to remove adhering dust or fine particles (< 125 µm) from the aggregate, dry the fractions at 100°C to 110°C for 16 hours and cool. Unless used immediately, store each fraction individually in a clean container provided with a tight-fitting cover.

7.1.6 Combining the aggregates

If the test method is to be used in an experimental programme to assess the pessimum behaviour of a reactive aggregate, undertake a petrographic examination of the test sample according to RILEM Recommendation TC 106-1 (Method for Petrographic Analysis of Alkali Reactive Concrete Aggregates) [1]. This examination should be sufficiently detailed to identify all the rock types or mineral constituents that compose the test sample. The results from the petrographic examination could then be used to establish a suitable test protocol (See Annex A7.1.6) such that any potentially damaging pessimum behaviour is identified.

7.2 Conditioning

The temperature of the moulding room, apparatus, dry materials, mixing water and of the cabinet or moist storage room shall be maintained at 20°C ± 2°C. The relative humidity of the moulding room and of the cabinet or moist storage room shall not be less than 65 ± 5% and 90 ± 5% respectively.

7.3 Proportioning of mortar

Proportion the dry materials for the test mortar using 1 part of cement to 2.25 parts of aggregate by mass. The minimum quantity of dry materials to be mixed at one time for making three 25 mm × 25 mm × 285 mm specimens shall be 400 g of cement and 900 g of aggregate.

Use a free water/cement ratio of 0.47 by mass, where the free water is the water available for hydration of cement and for the workability of the fresh mortar. The total water added to the mix is the free water plus the water absorbed by the aggregate to bring it to a saturated surface dry condition. Measure the workability of the mortar on a flow table (*e.g.* EN 1015-3). The flow value (mean diameter of the mortar) shall be in the range of 205 to 220 mm and, in the cases of mixes with a flow initially less than 205 mm, use a superplasticizer (not one combined with an air entraining agent) in order to achieve the required flow.

7.4 Moulding test specimens

Make at least three 25 mm × 25 mm × 285 mm specimens out of each one of two batches of mortar for every aggregate to be tested (see Annex A5).

Prepare the specimen mould with a suitable releasing agent that will not affect the setting of the cement or leave any residue that will inhibit the penetration of water into the specimen. Mix the mortar in accordance with the procedure for testing the strength of cement with plastic mortar (*e.g.* EN 196-1). Start moulding the specimens not more than 3 minutes after completion of the mixing of the mortar batch. Fill the moulds with two approximately equal layers, each layer being compacted with the tamper. Work the mortar along the surface of the mould with the tamper until a homogeneous specimen is obtained, making sure that the mortar is fully pushed under the reference inserts before a second layer is placed into mould. After the top layer has been compacted, cut off the mortar flush with the top of the mould and smooth the surface with a few strokes of the trowel.

> NOTE 5: *Particular care should be taken to attain a consistent compaction of the mortar, as the degree of compaction greatly influences the degree of expansion, the better the compaction the lower the expansion.*

7.5 Initial curing and measurement

Place the moulds in the moist cabinet or in the moist storage room for a period of 24 ± 2 hours. Remove the specimens from the mould and, while they are being protected from loss of moisture, properly identify each specimen in such a way that they, when subsequently measured, are placed in the measuring equipment in the same manner. Make and record the length (Li) and all subsequent measurements to the nearest 0.002 mm.

Place the specimens made with each aggregate sample in a storage container with sufficient distilled or deionized water, at room temperature, to immerse them totally. Seal and place the containers in an oven at 80°C ± 2°C for a period of 24 hours.

Remove the containers from the oven one at a time.

Remove other containers only after the bars in the first container have been measured and returned to the oven. Remove the bars one at a time from the water and dry their surfaces with a towel or cloth paying particular attention to the two metal pins. Take the zero measurement of each bar (Lo) immediately after drying and read as soon as possible after the bar is in position. Complete the process of drying and measuring within 15 s of removing the specimens from the water.

The measuring device should be checked with the reference bar prior to and after measurement of each set of specimens .

7.6 Final storage and measurement

Place the specimens made with each aggregate sample in a container with sufficient 1M NaOH, preheated at 80°C ± 2°C, totally to immerse the specimens. The recommended volume proportion of sodium hydroxide solution to mortar-bars in a storage container shall be 4 ± 0.5 times the volume of the mortar-bars. Seal the container and return it to the oven.

Take subsequent measurements (Ln) of the specimens periodically, with a reading after 24 hours of immersion in the NaOH solution and at least three intermediate readings before the final reading at 14 days. If so desired, measurements may be taken at 24-hour intervals and may be continued beyond 14 days. All measurements should be taken at approximately the same time each day. The measuring procedure is identical to that described in clause 7.5 and the specimens are returned to their container after each measurement.

In some cases, the solution may become cloudy due to the presence of alkali-silica gels.

7.7 Safety measures

Reliable safety precautions should be taken and suitable personal protective equipment should always be used to avoid the hazards of the hot alkaline solution such as severe burns and injury to unprotected skin and eyes.

8. CALCULATION AND REPORTING OF RESULTS

8.1 Expansion

The linear expansion of each specimen is obtained by calculating the difference between the length of the specimen at each period of measurement (Ln) and the zero measurement (Lo), to the nearest 0.001% of the effective length, as follows:

$$\text{Expansion, \%} = 100 \times (Ln - Lo)/\text{Gauge length}$$

where:

Ln = reading taken at each period of storage in sodium hydroxide solution,

Lo = measurement of specimen before subjection to sodium hydroxide solution,

Gauge length = distance between inner ends of the metal pins, measured to the nearest 1 mm.

8.2 Expansion recording and further examination

Record and report to the nearest 0.01% the average expansion of the specimens for a given period (see Annex A5). In the case of breakage of specimens during tests, the test will be considered valid provided the average is based on at least four specimens (at least two from each of the two batches). For average values of expansion greater than 0.10%, the repeatability is considered satisfactory if the expansion of each specimen is within 10% of the average value. For average values of expansion less than 0.10%, the repeatability is considered satisfactory if, for each specimen, the deviation from the average value is within 0.01%. If these values are exceeded, deem the test invalid and repeat the test.

After the final measurement, the specimens shall be examined and any relevant features recorded. Warping, if observed, shall be measured on 3 moulded surfaces by placing the specimens on a plane surface, with curved ends facing downwards, and measuring the maximum separation between the specimen and the surface to the nearest 0.2 mm. Location, type and pattern of any cracking should also be recorded.

NOTE 6: If the mortar-bars exhibit an expansion that is judged to be deleterious, a petrographic examination of the interior of the bars that have expanded most should be carried out together with an examination of the internal crack pattern to confirm that the cause of expansion is likely to be an alkali-silica reaction [3]. If it has been concluded from the expansion results and supplementary examination of the prisms that a given aggregate should be considered potentially alkali-reactive, additional studies using the RILEM Recommendation TC 106-3 (Method for Aggregate Combinations using Concrete Prism) [2], may be appropriate to develop further information on its potential alkali-reactivity and to evaluate the effect of coarse aggregate, different aggregate gradings and different alkali contents of the concrete.

9. TEST REPORT

The following information shall be given in the report:

- identification and source of the aggregate sample and reference to petrographic analysis, if available;
- type and maximum size of the aggregate;
- type of processing undertaken on the aggregate sample in the laboratory (washing, drying, crushing, sieving etc.);
- grading of the aggregate as used in the test;
- identification and source of the Portland cement;
- alkali content of the cement expressed as equivalent

sodium oxide (% Na_2O + 0.658 % K_2O);

- autoclave expansion or Le Chatelier value of the cement;
- Blaine fineness of the cement;
- workability of mortar (flow);
- type and content of superplasticizer (if used to achieve the mortar workability in the range of 105 to 120%), and its contribution to the alkali content of the mortar mix;
- size of the mortar-bars;
- tested combinations of the aggregate with a reference non-reactive fine material (if the pessimum behaviour has been investigated);
- initial expansion of the bars after 24 h of storage in water at 80°C;
- average percentage length change after each measurement of the specimens;
- a graph of the percentage length change vs time from the zero reading to the end of the 14-day period of immersion in NaOH solution;
- results of any warping measurements of the specimens;
- any significant features revealed by examination of the specimens and the sodium hydroxide solution during and after the test.

ANNEX

(comments relate to clauses as numbered in the method)

A2. SCOPE

With some reactive aggregates it has been found that there is a proportion of reactive constituents in the aggregate that leads to a maximum expansion. This proportion is called the "pessimum" content and the relationship between expansion and reactive constituents content is called the "pessimum behaviour" of the reactive aggregate.

A3. SIGNIFICANCE AND USE

It is recommended to start all screening of aggregates for their potential alkali-reactivity with a petrographic examination of the aggregate. On the basis of the results of the petrographic examination, a decision can be made with respect to further testing. If aggregates contain more than 2% (by mass) of porous chert and flint, further testing by means of the accelerated mortar-bar test is not recommended. It is reported (see Note A7) that application of the accelerated mortar-bar test to reactive aggregates containing porous chert and flint sometimes gives rise to misleading results and inappropriate approval of such aggregates.

NOTE A7:

[A1] E. Soers 'The Alkali-Aggregate Reaction in Belgium', Proceedings of the Advanced Seminar on Alkali-Aggregate Reaction – the European Dimension' –, Queen Mary and Westfield College, University of London, London, 1990, 147-160.

[A2] STAR Project, 'Standard Tests for Alkali-reactive Rocks', Final Report, European Commission, DG XII, contract n° SMT4-CT96-2128, 1998, 148 pp.

A5. APPARATUS

The use of other mould sizes (*e.g.* 40 × 40 × 160 mm) can be used as an alternative option. In this case a minimum volume of 1.0 litre should be prepared for a single batch, according to clause 7 of the test method.

A relationship between the expansion of long thin (25 × 25 × 250 - 300 mm) prisms and short fat (40 × 40 × 160 mm) prisms, based on statistical data, is not available yet. A comparative programme has suggested a factor of 0.54 (Reference A2 of Note A7):

*Expansion % (40 × 40 × 160 mm) = 0.54 * Expansion% (25 × 25 × 250 - 300 mm)*

However it is not known whether this relationship would apply similarly to all aggregate combinations.

Different limits for the mortar-bar expansions must be considered for alternative specimen sizes.

A7.1.2 Crushed fine aggregate

Alternatively the equivalent sieves of series B and C of ISO 6274 could be used

A7.1.6 Combining the aggregates

If the aggregate sample is composed of,

a) particles of a single rock, sand, gravel or mineral type that has previously been shown not to have an associated pessimum behaviour and it is intended to use this aggregate unblended,

or,

b) the reactive constituent in a single rock, sand, gravel or mineral type is found at concentrations outside the pessimum limits previously established for the reactive constituent type and it is intended to use this aggregate unblended,

then only a mortar with an aggregate component composed wholly of the test aggregate needs to be tested.

Alternatively, if an aggregate sample is,

a) composed wholly or in part of a rock, sand, gravel or mineral type which has particles or mineral constituents that have an associated pessimum proportion and the reactive constituents are found in concentrations that are deemed to be potentially reactive, or it is either unknown or not prescribed where the "safe" limits lie,

or,

b) if it has not been established whether the rock or mineral constituent type has or does not have an associated pessimum proportion,

or,

c) if the sample is a blend of aggregate types where the behaviour of the aggregates when combined is unknown,

or,

d) if a petrographic analysis is not available,

then several combinations of test aggregate and non-reactive fine material will need to be tested, as indicated

Table A2 – Suggested Aggregate Proportions

Combination	Aggregate to be tested (%)	Reference non-reactive fine material (%)
I	100	0
II	50	50
III	25	75
IV	15	85
V	5	95
VI	0	100

in the following paragraph, in order to identify any pessimum behaviour.

The aggregate to be tested shall be mixed with a reference non-reactive fine material (natural sand or crushed rock) with the same grading as the sample under test. The material used for this purpose shall give an expansion of less than 0.05% by this test method (See Note A8) and shall not exhibit a pessimum behaviour. It should be preferably a non-siliceous material and previously evaluated. Some suggested proportions of test aggregate and reference non-reactive fine material are shown in Table A2. As preliminary tests, only three combinations should be used (*e.g.* I, II and IV). Special aggregates may require some other levels to make sure that any possible pessimum behaviour is identified.

NOTE A8: This expansion limit is deliberately more restrictive than is generally applied to identify non-reactive aggregates to ensure that the non-reactive reference aggregate has minimal effect on the results of this test.

TC 106-2 REFERENCES

[1] RILEM Recommendation TC 106-1, 'Petrographic analysis of alkali-reactive concrete aggregates', (in preparation).

[2] RILEM Recommendation TC 106-3, 'Detection of potential alkali-reactivity of aggregates – Method for aggregate combinations using concrete prisms' (in this paper).

[3] Report of a Working Party, 'The Diagnosis of Alkali Silica Reaction' (British Cement Association, 2nd Edition, 1992), BCA, Slough (now Crowthorne), UK.