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Reactivity Assessment of Aggregates: Role of Chert Crystallinity

by Ciaran McNally and Mark G. Richardson

A systematic assessment scheme for determining the alkali reactivity of aggregates has been developed for international use. Expansion tests were conducted on Irish aggregates. Aggregates were subjected to a sequence of tests for alkali reactivity: petrographic examination and mortar bar and concrete prism expansion testing. No cases of damaging alkali-silica reaction have been identified to date in Ireland despite the presence of chert in significant commercial sources. Chert-bearing Irish aggregates performed poorly in expansion tests despite an exemplary service record. Chert crystallinity was examined through domain size and quartz crystallinity index. The crystallinity study helped explain the apparently anomalous behavior of the aggregates in tests. A preliminary study of the effect of alkali loading provided confirming evidence. It is suggested that enhanced crystallinity raises the alkali threshold value for reaction to one intermediate between that experienced in practice and in tests.

Keywords: alkali-aggregate reaction; chert; expansion.

INTRODUCTION

No cases of damaging alkali-silica reaction (ASR) have been identified to date in the Republic of Ireland. This is despite the fact that high-alkali-content cements were prevalent for a period and that glacial gravels covering much of the country contain significant quantities of chert, derived from the extensive limestone bedrock and the high relative humidity of the atmosphere, that is conducive to ASR. Cherts and flints have been identified internationally as a source of concern in the context of ASR. Guidance for specifiers on minimizing the risk of damaging ASR is typically presented nationally-for example, by Farny and Kosmatka¹ and the Irish Concrete Society/Institution of Engineers of Ireland² in 1991. The latter document, specific to Irish practice, recognized the anomalous behavior of chert in tests, and further research on the role of chert in ASR behavior was recommended. The guidance document has since been updated to take account of the research described in this paper.

The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) has proposed an international scheme for assessing aggregate reactivity, as reported by Sims and Nixon.³ The scheme embraces petrography, rapid expansion tests, and long-term expansion testing of concrete prisms.

RESEARCH SIGNIFICANCE

The development of an internationally accepted assessment scheme for minimizing the risk of deleterious ASR is complicated by the difficulty in setting standardized interpretation criteria. Test results may be significantly influenced by unique national petrographic features. The presence of chert content is the primary concern in respect to the reactivity of Irish aggregates, yet these aggregates have a satisfactory history of use. The application of tentative international interpretation limits to these aggregates in expansion tests produces anomalous results. This paper explores this anomalous behavior and demonstrates the significant influence of crystallinity characteristics on the alkali threshold level required for deleterious reaction.

EXPERIMENTAL METHODS

The proposed RILEM international scheme for assessing alkali reactivity of aggregates is to conduct a petrographic examination and, if necessary, to subject mortar bars and concrete prisms to dimensional stability tests. A test program based on these three tests was formulated using aggregates sourced in the Republic of Ireland. The program was conducted during a period of standards development, and this led to the use of both RTLEM and British Standard methods.

Materials

Twenty-three aggregate sources were selected through consultation with industry. It was known that the primary potentially reactive material present in Irish aggregates is chert, and this influenced the focus of the study. Aggregate selection, however, was also influenced by significant contributors to national concrete output and a desire to achieve a good spread across the geological map of Ireland (Fig. 1). Coarse and fine



Fig. 1—Geological map of Ireland showing aggregate locations.

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aggregates were included, with particular reference to the inclusion of aggregate combinations typical of current concrete practice.

Petrographic examination

Petrographic analyses were carried out to classify the aggregate reactivity in accordance with the proposed three RILEM classes. Chert content was determined, and the aggregates were ranked in increasing order of chert content and coded by alphanumeric codes (from N-l to H-9) based on the following categories:

- N series: aggregates free of chert;
- L series: aggregates with low chert contents (up to 3%); and
- H series: aggregates with high chert contents (over 3%).

Potentially reactive components were identified, and the aggregates were classified according to the RILEM assessment scheme.

Ultra-accelerated mortar bar test

An initial indication of reaction was rapidly determined from the accelerated tests on mortar specimens. The RILEM ultra-accelerated mortar bar test⁵ has been developed from the South African NBRI test⁶ and is broadly similar to the ASTM and British Standard⁸ accelerated tests. It permits rapid assessment of the aggregate's potential behavior in the long-term alkali reactivity tests. Six mortar bars of dimensions 25 x 25 x 280 mm were cast in two batches for each aggregate in accordance with the test requirements. The test demands use of finely crushed aggregate and a high-alkali cement. The cement used had an alkali content (expressed as sodium oxide equivalent) of 1.21% Na₂O_{ea}. The mortar bar specimens were demolded after 24 h. The oar lengths were determined through comparator readings prior to immersion in water that was maintained at a temperature of 20 °C. The water temperature was then raised to 80 °C over a period of 24 h to condition the bars for test. The extent of thermal expansion was monitored through comparator readings taken immediately before the bars were transferred to a container of 1 N sodium hydroxide solution that was preheated to 80 °C. The specimens were kept immersed in the NaOH solution for a period of 14 days, with the exception of short periods required for the interim comparator measurements. The final expansion value was calculated as the average percentage length change of the six mortar bar samples based on length change since initial immersion in sodium hydroxide.

Some researchers, including Hobbs,⁹ have expressed concern over the severity of the test and have questioned the validity of using a mortar bar specimen in benchmarking the potential behavior of an aggregate in concrete. The systematic approach is therefore to regard the accelerated test as a rapid screening method that provides a good indicator of the likely outcome of the longer-term concrete prism test.

The following tentative expansion criteria have been advanced³ for interpretation of the results:

• < 0.10%: likely to indicate nonexpansive materials;

- 0.10 to 0.20%: inconclusive, so assume potentially alkali-reactive; and
- > 0.20%: likely to indicate expansive materials.

Concrete prism test

Long-term concrete prism tests are respected internationally as the most definitive tests in the assessment of alkali reactivity. There are several variants of the test, but the differences are minor. The test method chosen for this study was that of British Standard BS 812-123.10 Three concrete prisms of dimensions 75 x 75 x 250 mm were manufactured per mixture with an elevated alkali content of 7.0 kg Na_2O_{eq}/m^3 , in accordance with the standard. Each specimen was wrapped in damp cloth and stored in sealed containers that encapsulated a moist atmosphere with a relative humidity in excess of 95%. The containers were stored for a period of 1 year while being maintained at a temperature of 38 °C. The degree of expansion was determined at intervals through comparator readings taken at room temperature. The final expansion value was calculated as the average percentage length change of the three prisms. The following tentative criteria have been advanced for interpretation of expansion test results applied to low- and normal-reactivity UK aggregates:

- < 0.05%: likely to indicate nonexpansive materials;
- 0.05 to 0.10%: probably nonexpansive;
- 0.10 to 0.20%: possibly expansive; and
- > 0.20%: expansive.

This test methodology is broadly similar to ASTM C 1293,¹² which uses a controlled alkali content of 5.25 kg Na_2O_{eq}/m^3 and a single expansion limit of 0.04% after 1 year.

RESULTS AND DISCUSSION Petrographic examination

The results of the petrographic examination of the 23 aggregate samples are summarized in Table 1, which further presents reference to potentially reactive components and the resultant RILEM classification. The aggregates were classified either as Class I (unlikely to be alkali reactive) or Class II-S (potentially alkali reactive/siliceous). It could be argued that all aggregates could have been classified as Class I on the basis of experience of use. Experience of use, however, may not adequately cover all future use of the material, and therefore Class II-S was used wherever potentially alkali-reactive constituents were detected.

The analysis found that only six aggregate samples were free of chert. Of these six, four were considered to be innocuous, but two contained potentially reactive material in the form of andesite and quartz silt. In the remaining aggregate samples, chert content was found to occur in concentrations ranging from 1 to 30%. The source of the chert varied from volcanic to sedimentary and ranged in color from white to almost black. Other potentially reactive constituents identified were greywacke and metaquartzite. Fine greywacke was identified in seven of the aggregate samples, but the alkali reactivity of greywacke aggregates is known to vary enormously. Strongly stretched metaquartzite was identified in one aggregate sample.

Results of ultra-accelerated mortar bar tests

Expansion tests were conducted on the 23 aggregate samples both individually and in 14 combinations. The aggregate combinations are listed in Table 2. The results of the tests on individual aggregates and on combinations are presented in Fig. 2 and 3, respectively. The aggregates generally performed poorly, with only seven out of 23 aggregates exhibiting expansions classifiable as nonexpansive under the draft criteria. The lowest expansions were recorded in four of the six examples of chert-free aggregate. No correlation between expansion and chert content was apparent, with highest expansions associated with aggregates containing less than 2% chert. The proportion of aggregate above both the 0.10 and 0.20% draft expansion limits was surprising given their history of satisfactory field performance. Twelve of the aggregates were in the potentially expansive range, while four were above the draft expansive threshold. The highest recorded expansions occurred with argillaceous limestone aggregate samples.

The results from individual aggregates were followed up by similar tests on 14 aggregate combinations typically



Fig. 2—Results of ultra-accelerated mortar bar tests on individual aggregates.

found in Irish concrete practice. Again, it can be seen that the aggregate combinations performed poorly, with three receiving a tentative classification of nonexpansive, nine falling into the potentially expansive zone, and two were tentatively classifiable as expansive. Once again, the highest expansions corresponded to argillaceous limestone aggregates containing little or no chert.

In light of the absence of a confirmed case of ASR in Ireland, the performance of the Irish aggregates and aggregate combinations in the ultra-accelerated test was disappointing. The margins by which the argillaceous limestones failed the test were particularly notable. It must be kept in mind, however, that the merit of the test is its rapid screening



Fig. 3—Results of ultra-accelerated mortar bar tests on aggregate combinations.

Aggregate reference		RILEM
no.	Potentially reactive components	classification
N-l	None	Class I
N-2	None	Class I
N-3	None	Class I
N-4	None	Class I
N-5	Consists of variety of weakly metamorphosed andesites.	Class IIS
N-6	Argillaceous limestone with moderate clay, quartz silt (in some grains) and organic matter.	Class IIS
L-l	Argillaceous limestone with moderate clay, quartz silt (in some grains) and organic matter. 1 % chert.	Class IIS
L-2	A series of trachytes and related rocks, extensively replaced by calcite. 1% volcanic chert-like material.	Class IIS
L-3	Mixed gravel, 60% very fine gray-green grey wackes, siltstones, and slates of lower paleozoic age. Also, 1 % chert.	Class IIS
L-4	Argillaceous limestone with clay matter concentrated along pressure seams. Some quartz silt, 1% coarse chalcedonic chert.	Class IIS
L-5	Predominantly quartz and limestone, with small amounts of phyllite and limestone fragments, 1% chert.	Class IIS
L-6	Contains 40% quartz and quartzite, 2% chert. Major components are very fine greywackes, siltstones, and slate.	Class IIS
L-7	Crushed gravel, primarily clean, clay-free limestone, 5% dolomite, 2% chert.	Class IIS
L-8	90% dolomite. 5% limestone, and 3% gray chert. Dolomite and limestone contain small amounts of quartz sand.	Class IIS
H-l	Coarse fraction is 90% limestone, 20% of which is dark and argillaceous. Remainder contains quartzite, sandstone, dolerite, traces of greywacke. Fine fraction is 45% quartz, 45% limestone, and 5% others.	Class IIS
' H-2	A variety of metaquartzites, many with strongly stretched fabrics, fine fraction is dominated by quartz, containing 4% chert.	Class IIS
H-3	Limestone pebbles with innocuous sandstones, 5% chert.	Class IIS
H-4	Limestone-rich sand with 7% chert, concentrated in the coarse fraction of sand, varying from gray to black.	Class IIS
H-5	Crushed gravel dominated by carboniferous limestone pebbles: 50% clean, 15% argillaceous with moderate clay, some quartz silt, and organic matter. Also, clean sandstones, quartzites, and granites. 8% chert, 6% fine greywackes, and siltstones.	Class IIS
H-6	Crushed gravel. 55% clean, bluish, carboniferous limestone, 10% clean sandstone, 6% quartzite. Also, 6% milky-white vein quartz, 2% dolomite. sre\\\ acke. and rare dark volcanic fragments. 15% chert varying from white to almost black.	Class IIS
H-7	Contains 15% quartz sand, traces of sandstone, quartzite, and volcanic fragments. 15% chert, small amounts of greywacke.	Class IIS
H-8	80% clean limestone, quartz, and sandstone. 20% chert.	Class IIS
H-9	Contains 30* chert. 20% quartz, small amounts of sandstone, quartzite, and aplite. Also, 6% fine greywacke and siltstone.	Class IIS

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potential, and by its nature it is therefore likely to yield a pessimistic outcome.

Results of concrete prism tests

Six of the combinations studied in the mortar bar tests were selected for trial in long-term concrete prism tests. In addition, following consultation with industry, three further combinations were tested: Nl and N-4, L-4 and L-6, and L-1 and H-9/L-1. The full list of selected combinations is presented in Table 3. The results for expansion after 52 weeks are presented in Fig. 4. The tentative expansion criteria are also included. It can be seen that the expansions produced in the tests are quite significant, with only one of the nine aggregate combinations classified as nonexpansive and a further two as probably not expansive. One aggregate combination lies in the possibly expansive range, while five may be considered expansive.

The results are disappointing given the satisfactory performance in service of these aggregate combinations. The highest recorded expansion of 0.300% corresponds to a chert-rich sand and an innocuous pure limestone coarse aggregate. Similarly, the aggregate combination N-2 and H-4 produced an expansion of 0.245%, with chert being the only potentially reactive material present. The disappointing performance of the argillaceous limestone aggregates in the ultra-accelerated mortar bar tests was mirrored in the concrete prism test. Three aggregate combinations containing argillaceous material were tested and all expanded significantly, with expansions ranging from 0.205 to 0.230%.

The concrete prism method used was that of British Standard BS 812-123 with an alkali loading of 7.0 kg Na_2O_{e9}/m^3 . It may be noted that a comparable test, RILEM Method AAR-3,¹³ employs a significantly lower alkali load of 5.5 kg Na_2O_{eq}/m^3 . It was speculated that the high loading of the British Standard test could explain how the recorded expansions were significantly higher than expected for aggregates with an exemplary service record over several decades.

Table 2—Aggregate combinations for mortar bar testing program

Aggregate combination no.	Coarse aggregate	Fine aggregate	Aggregate combination no.	Coarse aggregate	Fine aggregate
C-01	N-l	H-9	C-08	L-3	L-6
C-02	N-2	H-4	C-09	L-4	L-5
C-03	L-2	N-3	C-10	L-l	H-1
C-04-	L-l	N-4	C-11	L-8	H-2
C-05	N-5	H-9	C-12	H-3	H-8
C-06	N-6	H-9	C-13	H-5	H-9
C-07	L-l	H-9	C-14	H-6	H-7

Table 3—Aggregate combinations for concrete prism testing program

Aggregate combination no:	Coarse aggregate	Fine aggregate	Aggregate combination no.	Coarse aggregate	Fine aggregate
C-01	N-1	H-9	C-14	H-6	H-7
C-02	N-2	H-4	C-15	L-4	L-6
C-07	L-l	H-9	C-16	N-1	N-4
C-10	L-7	H-1	C-17	L-l	H-9/L-1
C-11	L-8	H-2	_		—

The application of expansion tests in the assessment of Irish aggregates for concrete paints a pessimistic picture of many sources if their history of satisfactory use is not invoked to classify them as innocuous. Their satisfactory record cannot be used as an aid to classification in some projects that demand higher cement contents than used previously. Petrographic analysis revealed the presence of potentially reactive material in a significant number of the aggregate samples studied. Their presence may give unease to specifiers who might then rely on the expansion test route rather than history of satisfactory use. Furthermore, research in the UK has shown that at intermediate chert concentrations (-20%), precautions are especially required due to the significance of the pessimum effect.¹ If one took the view that four of the 23 aggregates tested were classifiable as innocuous by petrographic assessment, the rapid mortar bar test would only clear one in five of the remaining Class II-S aggregates. This very conservative trend continues when the concrete prism test is applied to Irish concretes, with a significant majority classified as potentially expansive. Clearly, this pessimistic outcome errs on the side of caution, which is laudable, but it is not representative of the service history of the aggregates. This begs the question as to whether or not a further parameter could be used to reduce the possibility of restricting the use of aggregates that are probably nonexpansive in service conditions.

INFLUENCE OF CHERT CRYSTALLINITY

Chert was identified as the principal cause for concern in the alkali reactivity of Irish aggregates through a review of potentially reactive constituents reported in other countries. Therefore, a more detailed study of the chert characteristics was considered necessary. Strogen previously reported that Irish cherts were significantly more crystalline than flints that had caused deleterious expansion in England. He found that the reactive English flints, cretaceous in origin (approximately 100 million years old), had been exposed to temperatures of up to 200 °C, whereas the Irish carboniferous cherts (approximately 300 million years old) had been subjected to temperatures ranging from over 200 to 350 °C. The effect of the increased age and higher temperature levels is that the Irish cherts have, to some extent, been annealed, producing cherts that are more crystalline than the English flints. This should make them less susceptible to deleterious reaction.



Fig. 4—Results of concrete prism tests on aggregate combinations.

Quartz crystallinity index

The quartz crystallinity index (QCI), developed by Murata and Norman, has been used by concrete technologists to assess chert crystallinity. The index is expressed as a value on a range from zero to 10. The higher the number, the greater the degree of crystallinity. The QCI is based on the principle that poorly crystalline chert samples will display poorly developed peaks when analyzed using x-ray diffraction (XRD). In particular, the 212 peak is poorly formed in chert samples of lesser crystallinity. The QCI is calculated from the ratio of the relative height of the 212 peak over the high-angle and low-angle background. A pure quartz sample is taken to have a QCI of 10, and raw QCI data is normalized by a factor determined from the diffraction pattern of a pure quartz sample.

The crystallinity index was used to compare English flints, derived from selected reactive aggregates, and cherts, extracted from the Irish aggregate samples used in this study. In some aggregate samples, it was possible to extract different types of flint and chert. In these cases, average OCI values are reported. OCI values were calculated for a number of chert samples and for flint samples extracted from three reactive aggregates. Full details of the methodology employed and results for a large sample of Irish aggregates is presented in McNally et al. A subset of results relevant to this study is presented in Table 4. Determination of the OCI revealed that Irish cherts are quite crystalline, far more so than the English flint samples extracted from the reactive aggregates. The Irish cherts have QCI values ranging from a low of 5.9 to a high of 8.1, with an average of 7.0. The reactive flints, however, range from 2.0 to 3.1, with an average of 2.4. This is consistent with Strogen's¹⁴ study.

The QCI results supported the satisfactory history of use of the aggregates but contrast markedly with the conclusions drawn from using the expansion tests in the proposed assessment scheme. In this light, it was felt that the use of QCI alone would not always advance a specifier's knowledge of potential reactivity in cases of doubt. A more rigorous examination of crystallinity would be required. Domain size determination was investigated as a potential analytical tool.

Domain size

When subjecting chert and flint samples to crystallinity assessment, it must be kept in mind that any crystal is in fact composed of many individual domains, within each of which the crystal structure is perfect. Each domain, however, does not fit exactly with its neighbors, but joins them through a variety of crystal defects. This is illustrated in Fig. 5, where the role of these domains in forming a chert grain is shown. If a chert crystal has a small domain size, then many such defects will be present, most critically on the crystal surfaces where they form potential reaction sites. It seems reasonable to infer that a smaller domain size will lead to more reactive cherts. Domain size must not be confused with crystal size. Individual pieces of flint or chert are composed of multitudes of microcrystals of quartz, ranging from less than 2 microns to 30 microns in size in different cherts. Domains make up these microcrystals and are themselves two orders of magnitude smaller. Domain size and crystal size are not related.

Domain size was calculated by the method described by Cullity,¹⁷ and the results determined are presented in Table *5*. This method exploits the fact that low domain size will lead to a broadening of the peaks in the XRD profile. By modelling

the peaks as a series of Lorentzian distributions, the broadening effect can be quantified and the domain size measured. Further discussion of the precise methodology employed is presented in McNally et al.¹⁶ Once again, it can be seen that the average domain size of the Irish cherts exceeds that of the reactive UK flints, suggesting them to be less reactive. The difference between the upper and lower ranges of domain size, however, is not as pronounced as the use of QCI would have suggested. It can be seen that the average domain size for Irish chert samples ranged from 487 to 801 A. For the reactive flints, the domain size ranged from 271 to 319 A. While there remains a clear difference between the crystallinity of the Irish cherts and the reactive flints, the difference is now shown to be substantially less than was considered previously. This may help to explain the unexpectedly pessimistic trends identified in expansion tests.

Discussion of influence of domain size on assessment

The use of QCI alone suggests Irish cherts to be considerably more crystalline than their UK counterparts. When domain



Fig. 5—*Idealization of role of domains information of chert grain (McNally et al.).*

Table 4—Results f	rom quartz	crystallinit	y index
determination prog	gram	-	-

Aggregate reference no.	Average quartz crystallinity index	Aggregate reference no.	Average quartz crystallinity index
L-1	5.9	H-4	6.3
L-3	7.8	H-5	6.1
L-6	8.1	H-6	7.7
L-7	6.1	H-7	7.7
L-8	7.2	H-9	6.2
H-1	6.8	Reactive 1	2.1
H-2	6.7	Reactive 2	3.1
H-3	7.8	Reactive 3	2.0

Table 5—Results from domain size determination program

Aggregate reference no.	Average domain size A	Aggregate reference no.	Average domain size A
L-1	487	H-4	512
L-3	801	H-5	569
L-6	645	H-6	754
L-7	487	H-7	624
L-8	553	H-9	539
H-l	586	Reactive 1	298
H-2	649	Reactive 2	319
H-3	783	Reactive 3	271

size is considered as the defining parameter, however, the difference between the Irish cherts and the reactive flints is decidedly reduced. This is illustrated in Fig. 6, where it can be seen that the comfort zone that existed between the two has been considerably eroded. The position then for a large number of Irish cherts would be to move from the unreactive side of the chart to reside in the central gray area. In this area, it is considered that their crystallinity is enhanced relative to that of the reactive flints, but not to the point of being considered unreactive. This detailed measure of chert crystallinity sheds more light on the classification of Irish cherts as potentially reactive if solely subjected to the primary strands of a proposed international assessment scheme. Two unpublished industry surveys of Irish designers, specifiers, and concrete producers failed to unearth any examples of damaging ASR in service. The crystallinity of Irish cherts may be sufficiently high to prevent an occurrence of deleterious ASR in the field, yet not high enough to withstand the elevated alkali levels employed in standard test methods; that is to say that there exists an elevated alkali threshold below which deleterious ASR will not occur. It was considered that the alkali threshold lies between the upper bound of alkali loading

QCI

Fig. 6—Results of ultra-accelerated mortar bar tests on individual aggregates.

Fig. 7—Results of alkali threshold study.



 Table 6—Aggregate combinations for

 determination of critical alkali threshold

Aggregate combination	Coarse aggregate	Fine aggregate
C-06	N-6	H-9
C-07	L-l	H-9
C-12	H-3	H-8
C-14	H-6	H-7
C-15	L-4	L-6

Reactive

found in service (<4 kg Na_2O_{eq}/m^3) and that used in dimensional stability tests (for example, 7 kg Na_2O_{eq}/m^3 in the British Standard concrete prism test). A preliminary investigation of this hypothesis was conducted.

Alkali threshold level: preliminary study

To assess the possibility of the existence of a critical alkali threshold, selected aggregate combinations were subjected to dimensional stability tests based on the concrete prism test. Use of the concrete prism test for this purpose is being further investigated by RILEM. One criticism of the method is that it may underestimate the critical level due to leaching of alkalis from specimens under test. This requires further research, and has not been taken into account in this study. A series of concrete mixtures was designed with progressively increasing alkali contents. The control mixture, based on an Irish cement with an alkali content of 0.65% Na2Oea and a cement content of 330 kg/m³, had an alkali content of 2.1 kg Na₂O_{ea}/m³. Increased alkali loadings were achieved by the use of a cement with an increased alkali content of 1.21% Na₂O_{eq} and the addition of varying amounts of potassium sulfate to the mixture water. The British Standard test method specifies the use of potassium sulfate to elevate the alkali level unlike other methods that use sodium hydroxide. The selected aggregate combinations are listed in Table 6 and were tested at alkali contents of 4.0, 6.0, and 8.0 kg Na₂O_{eq}/m³. To promote any alkali reaction that may occur, the specimens were placed in a humid environment conducive to ASR development. The samples were demolded after a period of 24 h and placed in a curing tank at a temperature of 20 °C. They were maintained in the curing tank for a period of 1 week, after which they were placed in a humidity chamber at 50 °C and 90% relative humidity for 5 days. This was done to accelerate the reaction rate by increasing the mobility of the alkali and hydroxyl ions. After this, the samples were stored in moist conditions, as described in BS 812: Part 123, and maintained at 38 °C for a period of 6 months. Comparator readings were taken to determine any resultant expansion that may occur, and reported expansions are the average of two specimens. The results from this testing program are shown in Fig. 7.

It can be seen that for the aggregate combination AT-1, no clear alkali threshold exists. For the aggregate combinations AT-2 and AT-5, however, there is clearly an alkali threshold somewhere between 4.0 and 6.0 kg Na₂O_{2q}/m³. Similarly, for the aggregate combinations AT-3 and AT-4, there lies an alkali threshold between 6.0 and 8.0 kg Na₂O_{ea}/m³. Curious was the performance of aggregate combination AT-5 at an alkali load of 8 kg Na_2O_{eq}/m^3 . This aggregate combination failed to expand to any significant degree at this elevated alkali loading. It was noted, however, that both concrete prisms had discolored quite badly at the ends, suggesting that the reaction was expressing itself through this staining rather than through expansion. Also noteworthy is the performance of the aggregate combination AT-1, consisting of Aggregates H-6 and H-7. Domain size determination showed that the chert present in these two aggregates was among the most crystalline found. This is reflected in the performance in these tests, where the absence of a critical alkali threshold suggests that the alkali level required to provoke a reaction within the chert present was in excess of 8.0 kg Na_2O_{eq}/m^3 .

It was considered that the poor performance of Irish concretes in the standard international test methods was due to the existence of a critical alkali threshold above that experienced in concrete practice, but below that used in expansion test methods.

CONCLUSIONS

A number of conclusions may be drawn from the tests about the assessment of chert-bearing aggregates that demonstrate satisfactory field performance but significant expansion in laboratory tests:

1. Petrographic examination of chert-bearing aggregates may initially classify them as potentially alkali reactive due to the presence of the chert. The degree of alkali reactivity, however, is a function of crystallinity. If measures to minimize risk (for example, alkali load limitation) prove too onerous in a particular situation, the degree of crystallinity should be further investigated;

2. Ultra-accelerated mortar bar tests can produce pessimistic findings in assessing the alkali reactivity of chert-bearing aggregates that have a proven record of satisfactory

performance at alkali levels found in service. The strength of the test is its rapid screening potential, but resultant pessi mistic findings require careful interpretation. The particular usefulness of the test lies in the rapid assessment of innocuous aggregates that can demonstrate very modest expansions. National and international guidance documents should

emphasize that failure to pass the test should not be used to classify the material as reactive. Further testing is required;

3. The concrete prism test was found to be somewhat pessimistic in assessing the alkali reactivity of certain Irish aggregates. This was particularly significant in the case of argillaceous limestone aggregate combinations, but the

number of other combinations that exceeded the draft interpretation limits was surprising. It is concluded that national and international guidance documents should

include a commentary on interpretation limits in concrete prism expansion testing to assist engineering judgment in cases where aggregates fail the test but have good records in service at lower alkali levels. In the particular case of chertbearing aggregates, there may be merit in studying the degree of crystallinity if alkali limitation is not a desirable control measure;

4. QCI is a useful tool, but domain size determination is required to provide meaningful information on the potential degree of reactivity at intermediate ranges of crystallinity; and

5. The development of tests to determine the critical alkali threshold levels is worthy of further study. These may be based on existing concrete prism expansion test methodologies.

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