ratio and any presence of transverse reinforcement. The values for such corrections are currently given in the UK National Annex (NA) to BS EN 13791 but will form part of the soon-to-be-published revised BS EN 12504-1 with a UK National Annex. In this Annex there is a requirement to report both the measured strength and the corrected strength. In addition, it is useful and sometimes essential to know the voidage of the cores for the interpretation of the information and the UK NA requires the excess voidage to be measured and reported. It should be noted that the corrected core strength does not include a correction for voidage as such a correction is inappropriate when determining characteristic in-situ strength.

The revised BS 6089 is intended to provide guidance on planning an investigation, selection of test methods, selection of the test location, assessment of individual core results within a group and assessment where the strength of concrete based on test specimens is in doubt. It will also provide guidance on aspects not covered by BS EN 13791 such as: the assessment of an unknown structure using a margin based on the t-statistic; use of indirect methods without correlation to core strength, relative testing, ie, comparison of a volume of concrete under investigation with concrete in similar elements that has been accepted; action when the producer has declared non-conformity.

prEN 206-9 Concrete – Part 9
BS EN 12350 Parts 8–12

A new draft part to BS EN 206[7] *Concrete* has been passed to CEN. Part 9 – there are no Parts 2–8 – *Additional rules for self-compacting concrete* will incorporate additional rules relating to the use of five test methods for self-compacting concrete. This part will eventually be merged into the main BS EN 206-1 when it is revised in 2010. The five test methods it refers to for assessing self-compacting concrete will be covered in BS EN 12350[8] *Testing fresh concrete* as follows:

- Part 8: *Slump flow test for self-compacting concrete*
- Part 9: *V-funnel test for self-compacting concrete*
- Part 10: *L-box test for self-compacting concrete*
- Part 11: *Sieve segregation test for self-compacting concrete*
- Part 12: *J-ring test for self-compacting concrete*

The present position with the above draft Standards is that the drafts have gone through CEN enquiry stage and received a positive vote. All the comments received (technical and editorial) have been considered and the agreed amendments forwarded to CMC via DIN in April. We are awaiting publication of the revised draft standards in English, French and German in order to go to the formal vote stage, probably sometime between June and September. Provided a positive vote is received, only editorial comments will be considered before final publication in late 2009/early 2010.

References:

1. BRITISH STANDARDS INSTITUTION, BS EN 13670. *Execution of concrete structures.* BSI, London, draft.
2. BRITISH STANDARDS INSTITUTION, BS EN 1992-1-1. *Eurocode 2: Design of concrete structures.* BSI, 2004.
3. BRITISH STANDARDS INSTITUTION, BS 6089. *Guide to assessment of concrete strength in existing structures.* BSI, 1981.
4. BRITISH STANDARDS INSTITUTION, BS EN 13791. *Assessment of in-situ compressive strength in structures and pre-cast concrete components.* BSI, 2007.
5. CONCRETE SOCIETY. *Concrete core testing for strength.* Technical Report 11, The Concrete Society, Camberley, 1987.
6. BRITISH STANDARDS INSTITUTION, BS EN 12504-1. *Testing concrete in structures. Cored specimens. Part 1 - Taking, examining and testing in compression.* BSI, 2000.
7. BRITISH STANDARDS INSTITUTION, BS EN 206-1. *Concrete. Specification, performance, production and conformity.* BSI, 2000.
8. BRITISH STANDARDS INSTITUTION, BS EN 12350. *Testing fresh concrete.* BSI, 2009.

BRE Digest 330: Alkali-silica reaction in concrete – the case for revision Part I

"Any change to guidance that has worked so successfully for so many years must be undertaken with considerable care that short-term expediency does not result in longer-term problems."

The current *BRE Digest 330* was published in 2004[1] updating the previous edition published in 1999[2]. The main change was the incorporation of BRE Information Paper 1/02[3] introducing guidance in the application of metakaolin, silica fume and lithium salts with other minor editorial revisions.

PAUL LIVESEY*

The first guidance documents on ways of minimising the risk of damage due to alkali-silica reaction in concrete were published in the early 1980s by the Concrete Society (Technical Report 30)[4] and BRE Digest 330. There has been no reported verified case of deleterious alkali-silica reaction in UK concrete where this guidance has been implemented. In fact, as the accompanying illustrations testify, some exceptional concrete structures have been built successfully using the guidance.

The case for review

It is five years since the review leading to the current edition and ten years since the last major review. During that time, there have been changes:

- to the concrete industry approach to sustainability and use of recycled materials, responding to changing attitudes by clients, UK and EU governments
- in concrete technology with more widespread use of self-compacting and high performance concretes requiring novel admixtures
- in cement production with changes to the product mix brought by pressure to reduce embodied energy and carbon dioxide
- in all constituent material production to reduce waste in manufacture resulting in changes to product characteristics
- increasing EU regulatory involvement in safety, durability and fitness for purpose in construction.

Any change to guidance that has worked so successfully for so many years must be undertaken with considerable care that short-term expediency does not result in longer-term problems.

The original guidance was drafted on the strength of a considerable volume of laboratory and site investigation evidence. Since the late 1980s, the volume of such laboratory investigations has dwindled to almost nothing. While petrography analysis of cores from existing structures is frequently undertaken, commercial confidentiality has limited the visibility of findings. In this situation it is difficult to make cases for changes in guidance based on new evidence. However, a number of the original criteria, although based on laboratory and site evidence at the time, were deliberately conservative bearing in mind the limited experience in their application. Re-examination of these criteria in the light of over twenty years in their application is timely, bearing in mind the long lead-time necessary before damaging reaction becomes evident.

Issues for review

- the classification of cement alkalinity and need for/ level of step changes between alkali classes
- the alkali classification of composite cements and cement combinations
- the alkali contribution from aggregates
- the reactivity and alkali contribution from recycled aggregate other than recycled concrete aggregate
- the classification of reactivity and alkali limit applicable to aggregates
- the limit of 0.60kg/m^3 Na_2Oeq alkali from other sources
- the appropriate publication medium for UK rules on ASR.

Detailed review

The need for/level of step changes between alkalinity of cements

Digest 330; Part 2 reports that investigations of UK structures affected by ASR have shown that damage is nearly always associated with using an abnormally high alkali cement (Na_2Oeq >1.0%). The Concrete Society sub-committee report[5] found that concretes containing such 'high' alkali cements with 'normal' reactivity aggregates showed damaging ASR reaction at alkali levels of 5.2kg/m^3 and above. Laboratory tests on these cements and 'normal' reactivity aggregates have not reported deleterious, expansive reaction below 4.8kg/m^3.

Digest 330 goes on to record the successful use of 'low' alkali cement ($Na_2Oeq \leq 0.60\%$) to minimise damage from ASR. It therefore classifies cements between the two extremes as 'moderate' alkali cements.

Digest 330 quotes its underlying principle as that more precautions are needed to minimise the risk of damaging ASR as the level of cement alkali increases. It gives no rationale as to why no safety margin is applied to the classification of cement as 'low' alkali while, for its classification of cement as 'high' alkali, applying a 25% safety margin. There is no logic to this latter as this 25% margin is applied in addition to limiting the overall alkali content of concrete with 'high' alkali cement with normal reactivity aggregates to 3.0kg Na_2Oeq/m^3, a further margin on margin of approximately 50%. That is for a 'moderate' alkali cement, taking into account extreme variations from the mean, the maximum expected alkali content would be 3.8kg/m^3; the margin of 1.0kg/m^3 against an assumed critical level of 4.8kg/m^3, which equates to 26% of the maximum expected alkali content; the corresponding values for a 'high' alkali cement being 3.2kg/m^3; 1.6kg/m^3 and 50%.

The classification of 'low alkali' cement is based on alkali not exceeding 0.60% Na_2Oeq/m^3 for any spot sample, while that for moderate and high alkali cements is based on the declared mean alkali level. Basing a limit on an indeterminate frequency of testing spot samples is questionable and open to dispute both statistically and from results of testing samples taken on-site. It is suggested that the basis of declared mean also be used for low alkali cements and that the limit be adjusted to ≤0.50% Na_2Oeq to allow for the variation around (above) the declared mean. This would ensure equivalence, for all practical purposes, to the former requirement for CEM I cement and improved clarity of specification for low alkali composite cements and combinations.

When Digest 330 was drafted and the limit for classification of 'high' alkali cement was selected at >0.75% Na_2Oeq there were few UK CEM I Portland cements in this category. Since then UK cement production has maintained this position by discarding alkali-rich dust. This procedure is now less environmentally acceptable nor sustainable on account of increasing restrictions on placing waste to landfill and in obtaining planning consent for waste sites. It should also be noted that there are now no certified 'low' alkali CEM I Portland cements available on the UK market.

There is some logic in maintaining the classification of cement alkalinity since, should they become available, 'low' alkali cements demonstrably impose little risk whereas 'high' alkali cements require more careful application. Any imposition of a strict division between classes automatically introduces critical comparisons at the boundary. The more technically correct approach might be to use a sliding scale. However, this would be difficult to operate in practice and therefore it is suggested that the step changes between classes be retained, while ensuring that the risk of ASR is not increased.

"There is some logic in maintaining the classification of cement alkalinity since, should they become available, 'low' alkali cements demonstrably impose little risk whereas 'high' alkali cements require more careful application."

In this context, the criterion for classification of cement as 'high' alkali needs to be reassessed. In the Irish Republic, there is no such differentiation between 'moderate' and 'high' alkali cements yet they have successfully produced damage free concrete with a higher proportion of 'highly reactive' aggregates than is generally encountered in the UK. We have also seen an approach from Lithuania to CEN/TC51[6] for the classification of 'low' alkali cements as those having <1.0% Na_2Oeq. Nevertheless, the UK approach allows clear specification for situations when assessing the two risk elements: cement alkali and aggregate reactivity. There is no evidence that the alkali from 'high' alkali cement is more of a risk than that from 'moderate' alkali cement, even in combination with a 'highly' reactive aggregate; the Irish experience suggests that the overall alkali content of the concrete is the determining factor. Nevertheless, highlighting the alkali content as 'high' alerts the concrete producer to the need for care in use.

- **Recommendation 1:** That cements continue to be classified as 'low', 'moderate' and 'high' alkali.
- **Recommendation 2:** That the classification for reactive alkalinity of all cements be based on the declared mean alkali content and be: 'low' alkali cements ≤0.50% Na_2Oeq; 'moderate' alkali cements >0.50 and <1.00% Na_2Oeq; and 'high' alkali cements ≥1.00% Na_2Oeq.

The alkali classification of composite cements and cement combinations

The requirements in Digest 330: Part 2: Table 1 classify the alkalinity of composite cements (including combinations) according to "the alkali *content* of the CEM I type component". It is noted that BS EN 197-1[7] NB.4.3 b) note 2, also uses *content*. The principle used as the basis of this classification should be reviewed to clarify that the criterion is the *contribution* of alkali from each constituent rather than the alkali *content* of one constituent.

Taken to the extreme, there is no technical basis for considering a CEM III/B cement, consisting of 28% of a CEM I type component with an alkali content of 1.01% Na_2Oeq, 2% gypsum and 70% blast-furnace slag, to be a 'high' alkali cement. The same would apply to a CEM IV fly ash cement. Consequently, the classification of alkalinity of composite cements and combinations in Digest 330 requires revision.

- **Recommendation 3:** That the alkalinity classification of composite cements and combinations be determined according to their declared mean alkali content, calculated in accordance with BS EN 197-1: national annex NB, Table NB. 2, and the alkali limits set out in Recommendation 2 above.

The alkali contribution from aggregates

Digest 330 requires that alkalis from other sources (other than cement) are taken into account against the overall alkali content of the concrete. In discussion of the limit of alkalis from 'other sources' the alkali introduced as salt from marine aggregates was considered. There has been no reported instance of other alkalis being released from virgin UK natural aggregates, although it is well known that many constituent minerals contain significant amount of alkalis locked in their mineral crystal structure.

"Increased pressure to use a variety of recycled and waste products, for example glass or metallurgical slags, to minimise demand on natural resources will result in unfamiliar aggregates."

Recovered aggregates (the term used in BS EN 206-1[8] and previously termed 'reclaimed aggregate' in BRE 330); that is natural aggregates recovered from the concrete production process before the cement has set, are open to the risk that alkali from the mixing water or from any admixture might have been absorbed into the aggregate. Aggregates are normally used wet so that any alkali gained would be by slow diffusion rather than more rapid absorption mechanism; also their use is limited to 5% of the total aggregate; therefore it is considered that the risk of significant reactive alkali content is low.

- **Recommendation 4:** That it should be explicitly stated in Digest 330 that for UK natural aggregates no reactive alkali shall be considered to be contributed other than that introduced by contamination, eg by marine salt.

In the case of lightweight aggregate there can be significant amounts of alkali bound within their structure. There is no evidence that current UK lightweight aggregates, either sintered fly ash or expanded clay, contribute alkalis to cause damaging ASR in concrete. This may be because the alkali remains locked within the structure or that the porous nature of the aggregate provides sufficient stress relief volume for any reactive gel formed. The basis for the latter is indicated in the consideration of the effect of air entrainment in the BRE Information Paper[3].

- **Recommendation 5:** That it should be explicitly stated in Digest 330 that no reactive alkali shall be considered to be contributed from sintered fly ash or expanded clay lightweight aggregates.

Other aggregates might release alkalis that contribute to ASR reaction. Increased pressure to use a variety of recycled and waste products, for example glass or metallurgical slags, to minimise demand on natural resources will result in unfamiliar aggregates. Such products might contribute alkalis, other than marine salts, to the concrete. In these cases reliance on measuring chloride to determine the alkali contribution might not be adequate. A RILEM method[9] has been developed and further investigation is necessary to confirm whether this can be correlated to assessment of reactive alkali in expansion levels with calibrated mixes of known UK reactive aggregate combinations.

- **Recommendation 6:** That experimental work should be undertaken to evaluate the RILEM method as a reliable indicator of reactive alkali contribution from aggregates. ■

Further information:

Part II of this article will appear in the August 2009 issue of *CONCRETE* and will consider the guidance on recycled aggregate; the classification system for aggregate reactivity; the treatment of alkali arising other than from cement and aggregate; and the possible routes for publication of updated rules in the light of activities in European standards committees.

Acknowledgements:

The author wishes to acknowledge the support provided by the Mineral Products Association in undertaking this review. Thanks are also due to those associated with concrete production, concrete constituents' production, consultants, specifiers and the members of the Irish Concrete Society for their input into this review.

** The author was chief chemist of Castle Cement, a member of The Concrete Society Hawkins Committee and chairman of its alkali limit working party. He is chairman of BSI committee B/516 Cement and building limes.*

References:

1. BUILDING RESEARCH ESTABLISHMENT, Digest 330: 2004. *Alkali-silica reaction in concrete. Detailed guidance for new construction.* BRE Bookshop, 2004.
2. BUILDING RESEARCH ESTABLISHMENT, Digest 330. *Alkali-silica reaction in concrete.* CRC Ltd, Watford, 1999.
3. BUILDING RESEARCH ESTABLISHMENT, Information Paper 1/02: 2002. *Minimising the risk of alkali-silica reaction: alternative methods*. CRC Ltd, Watford, 2002.
4. CONCRETE SOCIETY. *Alkali-silica reaction: minimising the risk of damage to concrete.* Technical Report 30, The Concrete Society, Camberley.
5. Concrete Society Sub-committee. Investigation of structures affected by ASR. *CONCRETE*, Vol.31, March 1997, pp.25 – 27.
6. Lithuanian request under mandate 114, CEN Technical Committee 51 Cement and building limes, Document N838, 2007.
7. BRITISH STANDARDS INSTITUTION, BS EN 197. *Cement, Part 1: Composition, specifications and conformity criteria for common cements.* BSI, London, 2007.
8. BRITISH STANDARDS INSTITUTION, BS EN 206. *Concrete, Part 1: Specification, performance, production and conformity.* BSI, London, 2000.
9. RILEM/CANMET, FOURNIER, B. and LU, D. International Centre for Sustainable Development of Cement and Concrete (ICON/CANMET), Canada & College of Materials Science and Engineering, Nanjing University of Technology, China, *Test Method for Alkali Release*, 2003.

The Concrete Bookshop

Visit: **www.concretebookshop.com**