# The Importance of Petrography in the ASR Assessment of Aggregates and Existing Concretes

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## ABSTRACT

A range of procedures currently available for the assessment of aggregates in the UK is reviewed. The importance of petrographical examination is emphasised, either as the main approach or as an essential preliminary approach. A new procedure for petrographical examination of UK aggregates is described and some interpretative commentary is provided. Investigation of structures for any evidence of ASR involves both site inspection and laboratory analysis, but petrographical examination of concrete is considered to be the only unequivocal means of identifying or discounting the occurrence of ASR. However, it is difficult to demonstrate definite causal links between microscopic evidence of ASR and damage observed on the structure. Suggestions are made to assist in the evaluation of laboratory findings to achieve more definite diagnoses. Core expansion tests to indicate continued expansion of the concrete are briefly considered.

## 1. ASSESSMENT OF AGGREGATES

### 1.1. Introduction

Recommendations for minimising the risk of ASR in the UK (Hawkins 1983) are based on the consideration that three conditions each need to be satisfied before damage can be caused by ASR: (i) sufficient moisture, (ii) sufficient alkalies, and (iii) a critical amount of reactive silica in the aggregate. Since most concretes are subsequently exposed to wetting, it will not usually be feasible to eliminate factor (i). Since all Portland cements contain alkalies to some extent, and some exposure conditions could contribute additional alkalies, it is not possible to eliminate factor (ii) and some uncertainty remains when measures are taken to limit concrete alkali content. Consequently, at first it seems logical to conclude that avoidance of potentially reactive aggregates is the only certain means of preventing ASR. However, that deduction is complicated by the difficulty of obtaining reliably representative samples for assessment and because of the absence of a predictive test procedure that is both reliable and universally applicable.

### 1.2. Aggregate sampling

All aggregate testing is influenced by the representiveness of the samples submitted to the laboratory (Soles 1979). This is particularly important in ASR assessment because the reactivity of an aggregate is often dependent upon a minor constituent which may be non-uniformly distributed within the source. In igneous rocks, for example, veination may vary in concentration and in mineralogy; gravel deposits typically exhibit systematic or random variations in petrography.

Most UK aggregate testing is carried out on samples of processed material taken in accordance with BS 812 (1984). Individual ASR assessments based upon such samples are of limited application and cannot be extrapolated with any confidence to future deliveries from the same source during any significant period of production. Some suppliers have repeated assessments at intervals to compile a more complete record of the resource being worked. Dredged aggregates supplied for one major UK construction in recent years were subjected to such a systematic survey by Messrs.Sandberg.

Some UK authorities have advocated geological quarry assessments to improve the representiveness of subsequent laboratory testing for ASR. Although fieldwork may recognise future large-scale variations in the source, it is doubtful whether smaller-scale diversity, affecting the minor constituents which sometimes cause ASR, could be adequately evaluated by site investigation . Quarry assessments by ASR specialists might be effective, but could not be economically justified.

## 1.3. Visual recognition procedures

The types of silica that sometimes react with alkalies in concrete have been established and can be identified by petrographical examination. Disordered forms of silica, such as opal, are the most reactive, whereas unstrained quartz is the least reactive. Other forms of silica are potentially reactive, including chert, chalcedony, recrystallised quartz and strained quartzitic material. Siliceous volcanic glass is also found sometimes to be reactive (Dolar-Mantuani 1983).

Petrographical examination should be carried out at the outset of any assessment of aggregates for ASR, partly because this may obviate the need for further testing and partly because knowledge of aggregate composition will facilitate selection of further tests and interpretation of the results (Sims 1981, Grattan-Bellew 1983a).

## 1.4. Chemical test methods

Tests for ASR have been reviewed by many authors (Sims 1981, Grattan-Bellew 1983b, Heck 1983).The chemical methods include the ASTM C289 (1981) test, the gel-pat test (BRS 1958) and the DAS (1974) test in Germany.

The ASTM C289 chemical test was originally published in 1952. The test appears to be effective at detecting potentially reactive silica and there is reported to be a linear relationship between the 'dissolved silica' test value and the proportion of reactive silica in the sample (Heck 1983). The test is, however, insensitive to 'pessimum', whereby expansion is maximised at a certain (often minor) content of reactive silica in the aggregate. A paradox may be envisaged whereby the ASTM C289 test could indicate an 'innocuous' classification for an aggregate combination containing a 'pessimum' proportion of reactive silica, whilst indicating 'potentially deleterious' for the same constituents combined so that the'pessimum' was substantially exceeded.

This limits the usefulness of the ASTM C289 test for UK aggregates. A majority of the aggregates available in the densely populated South-East and Midlands regions of England contain chert ('flint' variety) and sometimes also meta-quartzites. These rock types would usually be classified as 'deleterious' or 'potentially deleterious' by ASTM C289. Expansion has usually occurred in structures only when flint is present as a minor aggregate constituent, and ASTM C289 would have recorded a misleading result for many of these aggregates.

### 1.5. Expansion test methods

The ASTM C227 (1981) mortar-bar test was first published in 1950. It is now recognised that the mortar-bar test is not necessarily suited for all types and combinations of aggregates and can produce misleading results. In the UK the mortar-bar test has not predicted any aggregate combination to be potentially alkali-reactive, including those involved in known cases of ASR. It is possible that the mortar-bar test is best suited to identifying aggregates which will prove deleterious in most circumstances, but is insensitive to those circumstances encountered in the UK which depend upon the occurrence of a critical combination of constituents and conditions.

Some authorities have instead considered a concrete-prism test, and one method is described by CSA (1977). A draft concrete-prism method is currently being considered by BSI. Although there remain some uncertainties regarding the test parameters, experience to date suggests that the method identifies those combinations of UK aggregates which give rise to expansion in structures (Nixon & Bolinghaus 1983). Figure 1 indicates the apparent reliability of concrete prism testing.

Expansion tests, including ASTM C227, are subject to some control by petrography. The BS concrete-prism test method will probably require confirmatory microscopical examination of expanded specimens.

### 1.6. Effectiveness of petrographical screening

Hawkins (1983) advises that "consideration of the composition of an aggregate may enable a decision to be made as to whether an aggregate is unlikely to be reactive, or contains constituents which are sometimes found to be reactive". Petrography may thus be applied as an initial screening method and in many cases this may obviate the need for further testing.

In one study of 225 aggregate samples from the Middle East (Sims & Poole 1980), 70% of the samples examined initially, mainly using petrographical examination, could be exempted from further testing. Another study by Messrs.Sandberg of samples from around eighty aggregate sources in one region of Europe, enabled 86% to be assessed as 'unlikely to be alkali-reactive', largely on the basis of petrographic composition (Table 1).

### 1.7. UK method for petrographical examination

At present there are no BS test procedures for ASR, although a working group is currently assessing some methods. Since both DTp (1984) and Hawkins (1985) have considered specifying aggregates by composition as one measure for minimising the risk of ASR, priority has been given to a standardised procedure for the detailed and quantitative petrographical examination of aggregates.

The procedure is similar in principle to the guidance in ASTM C295 (1985). The UK method will usually not require individual sieve fractions to be quantified separately. The method calls for the constituent particles to be identified and separated into appropriate petrographic groups;

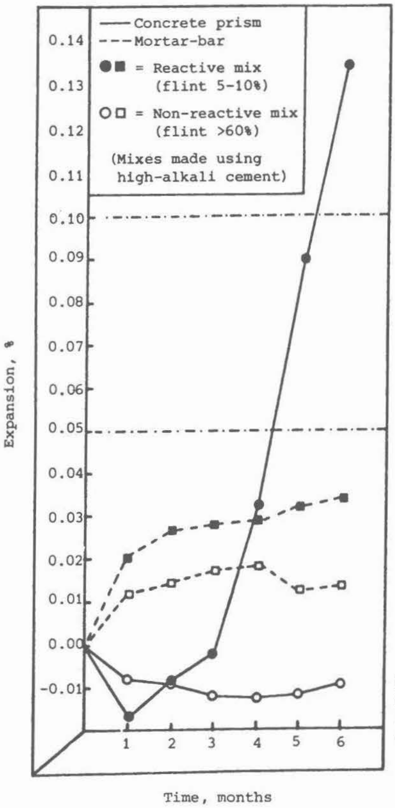

Figure 1. Mortar-bar and concrete prism test results for comparable reactive and non-reactive UK aggregate combinations.

| Aggregate type | Reactive | Potentially reactive | Unlikely to be reactive |
|---|---|---|---|
| | % of samples examined | | |
| Siliceous | Nil | 18 | 82 |
| Carbonate | Nil | 7 | 93 |
| Overall | Nil | 14 | 86 |

Table 1. Summary of conclusions for samples from around 80 sources, mainly based upon petrographical examination.

hand-separation being employed for coarse aggregates and visual-separation being used for fine aggregates, variously by point-counting, grain-counting or by visual estimation using sediment models. Thin-sections are prepared of selected coarse aggregate particles, or groups of particles, wherever needed to verify rock type or to investigate fine-grained constituents (such as volcanic rocks) or optically distinctive characteristics (such as strained quartzitic material).

The minimum test portion quantities depend upon the proportional contents of the constituents concerned and the required precision of the determination. The minimum sample quantities stated by the method are calculated assuming a constant accuracy level of ±10% relative, and statistical guidance is provided for establishing the larger quantities demanded by requirements for improved accuracy.

## 1.8. Some remarks concerning UK interpretation

### 1.8.1. Opaline silica

Aggregates containing any detectable opal or opaline silica should be regarded as being potentially alkali-reactive. Opaline silica can occur in almost any rock type and may be sporadically distributed in veins or vughs. Significant quantities of opaline silica in chert or flint will reduce the density noticeably, as found in some Danish and German flints, but small proportions may be difficult to identify without instrumental techniques. UK flint aggregates are not usually analysed for opaline silica.

### 1.8.2. Chert and flint

The cases of ASR in the UK have mostly involved aggregates containing flint or chert particles, usually when these formed a minor constituent of the sand and when that sand was combined with a non-reactive coarse aggregate. Examination of concrete from affected structures, supported by some laboratory experimentation (Nixon 1985) has indicated that reactions have occurred when the flint or chert content amounted to less than 40% of the total aggregate. Hawkins (1985) has suggested (in a draft) that many aggregate combinations containing more than 60% flint should thus be classed as non-reactive.

The lower limit of the 'pessimum' range for chert or flint is less clear. Estimates of the flint contents of total aggregates contained within concrete samples from England and Wales have suggested that expansion has occurred in some cases apparently containing lower than 10% flint. Consequently, it is suggested that UK aggregate combinations containing 5% or more chert or flint must be regarded as being potentially alkali-silica reactive (unless the content is more than 60%). In making such tentative judgements, the imprecision of the determination must be taken into account. In marginal cases, the aggregate supplies could be monitored for future variations in chert or flint contents.

### 1.8.3. Strained quartzitic rocks

Gogte (1973) suggested that quartz strain could be measured under the microscope to indicate ASR potential and further investigations have been carried out in North America (Dolar-Mantuani 1981, Buck & Mather 1984). No confirmed examples of damaging ASR involving strained quartzitic rocks have been reported in the UK, although some concrete samples exhibiting reaction sites associated with chert particles have also contained aggregate particles comprising variably strained quartzite.

The literature seems unclear concerning the relevance of discrete quartz particles which exhibit relatively high 'undulatory extinction angles'.

Rocks containing strained quartz grains, such as meta-quartzites, are likely also to exhibit high-energy grain boundaries and these boundary zones may be significantly more reactive than the main parts of the quartz grains. It therefore seems improbable that liberated strained quartz grains would prove to be comparable in reactivity to similarly strained grains of quartz within a quartzitic rock.

Buck and Mather (1984) have suggested minimum criteria for recognising aggregates containing potentially reactive strained quartz as being 20% strained quartz with an average 'undulatory extinction angle' of 15°. This 15° criterion is uncertain as Buck (1983) previously did not refer to the 25° discussed by Dolar-Mantuani (1981). Notwithstanding these apparently precise guidelines, the reactivity potential of UK strained quartzitic rocks is difficult to evaluate at present. Application of Buck and Mather's criteria to UK aggregates would lead many materials in routine usage to be classified as potentially reactive.

### 1.8.4. Glassy volcanic rocks

The reactivity of glassy volcanic rocks depends upon the glass composition and the proportion of glass in the rock. International experience suggests that glassy 'acid' rocks (e.g. rhyolite) are more reactive than glassy 'basic' rocks (e.g. basalt), although examples of the latter have been reported (Gudmundsson & Asgeirsson 1975). No examples of damaging ASR involving glassy volcanic rocks have been reported in the UK.

Only limited information is available on which to base criteria for assessing aggregates containing glassy volcanic rocks. Mielenz (1954) suggested a 3% limit for glassy acid to intermediate rocks, but in fact experiences seem to have been extremely varied and in many cases this restriction may be too cautious. It is suggested that rocks containing more than 5% glass could be termed 'glassy' and that aggregates containing a significant proportion of glassy volcanic rocks (say >10%) should be regarded, in the absence of other test data, as being potentially reactive.

## 2. EXAMINATION OF CONCRETE FOR EVIDENCE OF ASR

### 2.1. Introduction

The many similarities between rocks and samples of hardened concrete have caused the term 'petrography' to be adapted for the systematic visual examination of concrete.

UK mainland examples of structural damage caused by ASR were first identified in the mid-1970's and now more than 100 cases have been identified (Hawkins 1985). The earlier examples were subjected to extensive petrographical study by several consultants and research organisations, but later some mis-diagnoses occurred as the result of reliance upon the observation of comparatively large-scale features, such as map-cracking, without subsequent confirmation by petrography. Microscopical examination of concrete samples is probably the only unequivocal means of identifying or discounting the occurrence of ASR.

However, it is difficult reliably to demonstrate a definite causal link between microscopic evidence of ASR and signs of damage observed on the structure. The establishment of ASR as the cause of any damage can only be achieved by careful appraisal of all the evidence accumulated both by an organised site inspection and by the experienced laboratory examination of concrete specimens obtained through an adequate and selective sampling programme (C&CA 1985).

### 2.2. Samples and specimens

Study of samples taken from affected UK structures often indicates that evidence of ASR is not uniformly distributed within the concrete material. Some samples from severely affected concrete units do not exhibit any definite signs of ASR; other samples contain an amount of evidence that is apparently inconsistent with the scale of damage. To ensure that any evidence that would confirm the occurrence of ASR is reliably identified, it is necessary to select samples from positions where conditions conducive to ASR are maximised and/or from locations where surface damage is the most severe. Also, to overcome the uneven distribution of the evidence of reaction, a sufficient number of samples must be recovered. Often it is preferable to take a greater number of small samples, rather than a limited number of large samples.

The samples, usually cores, are returned to the laboratory for preliminary inspection. In UK examples, 'sweaty patches' are sometimes apparent on the outer core surfaces, sometimes associated with particular aggregate particles. These 'sweaty patches' are observed on many concrete samples and should not be regarded as other than indicative.

Specimens for microscopical examination normally comprise large-area thin-sections, but some petrographers also use polished slice specimens and/or examine the surfaces of irregularly-broken portions of the concrete. The concrete must be examined at various depths beneath the outer surface; although external water is essential for damage to occur, concrete at greater depths can sometimes exhibit more abundant evidence of ASR.

### 2.3. Microscopical examination procedure

A method for petrographical examination of concrete is given in ASTM C856 (1983). Guidance on microscopical examination for ASR diagnosis is being prepared by a C&CA Working Party (1985).

### 2.4. Suggestions for the evaluation of microscopical findings

#### 2.4.1. Features reliably diagnostic of ASR

The microscopic features indicative of ASR comprise two categories: (i) features 'reliably diagonostic' of ASR, and (ii) features consistent with ASR but which could have other causes and are 'possibly indicative'.

There are two 'reliably diagnostic' features: reaction sites and alkali-silicate gel deposits. A 'reaction site' is a position in the concrete where interaction between an aggregate particle and the surrounding paste is occurring, with associated gel product and resultant crack propagation. Sometimes a 'reaction rim' may be a reaction site, but this is not always the case.

Alkali-silicate gel, which is distinctive within thin-sections, has usually been considered to be 'reliably diagnostic' of ASR (Gutt & Nixon 1979). However, secondary ASR gel deposits must not be confused with secondary re-deposited cement hydrate gel, which is a non-deleterious feature of some concretes. Indications of abundance should be provided avoiding undue emphasis upon very minor proportions of gel-like material.

#### 2.4.2. Features possibly indicative of ASR

Petrographical examination of concrete enables the aggregate compositions to be established and any potentially reactive constituents to be recognised. The presence of such aggregates does not prove that reaction has or will occur, but, conversely, 'reliably diagnostic' features are difficult to explain in the absence of any identifiably reactive aggregate constituents. Potentially reactive particles might be discoloured, internally fractured, surrounded by possible 'reaction rims' or associated in an apparently passive way with ASR gel deposits which have migrated along peripheral cracks. None of these observations could be other than 'possibly indicative' of ASR.

Micro-cracking of concrete is a characteristic feature of ASR, but, unless cracks are linked to a 'reaction site', it is not possible to demonstrate that such micro-cracking is necessarily caused by ASR. Micro-cracks are present to some extent in the matrix of most concretes as the result of normal shrinkage. Secondary deposits of ettringite may be caused by leaching or sulphate attack, but ettringite has been reported from concrete affected by ASR (Pettifer & Nixon 1980).

### 2.5. Some suggestions regarding UK evaluation

The primary role of petrography in the diagnosis of ASR in concrete structures is to establish whether or not representative samples of concrete exhibit definite evidence of ASR, and not whether that ASR could have caused the degree of damage affecting the structure. That causal link can only be inferred, with varying degrees of certainty dependent upon the total evidence available from both site and laboratory investigations. It is usually possible to decide if ASR was one of the main causes of damage.

Petrography can only demonstrate that ASR has definitely occurred in a concrete if 'reliably diagnostic' microscopic features have been identified in the samples. ASR cannot be confirmed on the basis of 'possibly indicative' features alone, however abundant these might be within the samples. The confidence of the assessment depends upon the variety and abundance of the features identified, although there is typically only a poor correlation between the severity of ASR damage to structures and the incidence of features indicative of ASR within corresponding concretes.

### 2.6. Concrete core expansion testing

Information on the potential for further expansion of concrete in structures has been obtained in some cases by core expansion tests and one test procedure is being developed by the C & CA Working Party (1985).
Wood (1985) has reported some correlation between core expansions and the severity and rate of development of cracking in structures, but it is not yet possible to make accurate predictions by this method. Significant core expansions should not be accredited to ASR unless and until petrographical examination has confirmed ASR to be the cause.

## 3. SUMMARY

The representiveness of samples is particularly important in the ASR assessment of aggregates. Petrographical examination should be carried out at the outset and further testing may not become necessary. The ASTM C289 chemical method is of limited use for UK aggregates. Concrete-prism testing is now preferred to the ASTM C227 mortar-bar method.

A new petrographical examination method is being devised in the UK. Any opal is potentially alkali-reactive. Contents of from 5% to 60% chert or flint in UK aggregate combinations are potentially alkali-reactive. The reactivity potentials of strained quartzitic and glassy volcanic rocks are difficult to evaluate at present.

Microscopical examination of representative concrete samples is the only unequivocal means of identifying or discounting the occurrence of ASR. It is difficult to demonstrate a definite causal link between microscopic evidence of ASR and damage affecting the structure. Laboratory samples must be selected from structures to ensure that any evidence of ASR is identified.

Only reaction sites and alkali-silicate gel should be regarded as 'reliably diagnostic', with other features being only 'possibly indicative' of ASR. The confidence of the petrographic assessment depends on the variety and abundance of the microscopic features identified. The potential for further expansion might be indicated by core expansion tests.

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