

A code of practice for the petrographic examination of concrete

Applied Petrography Group

SR2, July 2010

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DISCLAIMER

The recommendations contained within this Code of Practice are intended only as a general guide and, before being used in connection with any report or specification, they should be reviewed with regard to the full circumstances of such use. Although every care has been taken in the preparation of this document, no liability for negligence or otherwise can be accepted by the author, the officers or members of the Applied Petrography Group, their advisers or their agents

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1 INTRODUCTION

This Code of Practice is intended to provide guidance on the minimum requirements for a full petrographic report on concrete samples and other cementitious construction materials containing Portland cement and calcium aluminate cements such as HAC. Suggested procedures are given for the preparation of thin sections and for the techniques of examining thin sections with the petrological microscope. It is assumed that the user of this Code of Practice is experienced in the petrographic examination of concrete and associated materials. The health and safety aspects of the methods described for the preparation of thin sections are outside the scope of this Code of Practice. A brief Glossary of common terms used in the petrographic examination of concrete is provided in the Appendix.

Depending on the precise objectives of a particular investigation some sections of this guide may not be required while others may require more elaborate investigation.

2 EQUIPMENT

2.1 *Equipment for concrete thin section preparation*

(i) *Diamond saws*

Two diamond saws are desirable, one with a large diameter cutting wheel (~500mm diameter) and one with a small diameter cutting wheel (<300mm diameter). A narrow bladed (<1mm thick) oil-lubricated precision trim saw is also useful for cutting fragile specimens and for cutting off flattened concrete specimens mounted onto glass slides.

(ii) *Vacuum impregnation equipment*

A vacuum chamber capable of containing large concrete samples up to 5kg and means of introducing epoxy resin after the sample is evacuated is required.

(iii) *Polishing, lapping and grinding equipment*

A very wide range of grinding and polishing equipment is available. The following types of grinding and polishing equipment are in common use in the UK but other equally suitable types of equipment are in use elsewhere in Europe and the USA. A petrographic preparation laboratory will require an appropriate combination of the following items of equipment:

- High-speed vertical spindle grinding wheel with diamond abrasive bonded in brass. This can be oil or water lubricated. This can be used for rapid grinding and fine diamond grinding wheels lubricated with oil are suitable for flattening impregnated concrete specimens prior to polishing.
- Lapping machines fitted with resin-bonded diamond abrasive pads. These can be used in the same way as the high-speed vertical-spindle grinding wheel and the coarser grades are suitable for rapid stock removal and the finer grades are suitable for polishing. They can be used with either oil or water abrasive.
- Lapping machines with cast iron lapping plates and with a controlled abrasive slurry feed. Common abrasives would include

carborundum and aluminium oxide. Suitable grinding medium would be oil or water. The water-lubricated laps are suitable for the production of large-area polished plates and the oil lubricated laps can be used to flatten impregnated concrete specimens prior to mounting on glass for thin sectioning.

- Vacuum chucks such as those manufactured by Logitec to be used in conjunction with an oil-lubricated lapping machine for the controlled grinding of thin sections to thicknesses of down to about 40µm.
- Plate glass sheet to be used for final hand finishing of thin sections using an oil/carborundum abrasive slurry.
- Polishing machines with felt pads for use with abrasive diamond pastes for polishing to a mirror finish suitable for reflected light examination and for quantitative SEM microanalysis.

(iv) *Ovens*

Elevated temperatures of curing are required for some types of epoxy resin. The curing of such resins should be carried out at temperatures not exceeding 45⁰C. Ovens of this type are also suitable for drying specimens prior to their vacuum impregnation with epoxy resin.

(v) *Cleaning equipment*

An ultrasonic cleaning bath is useful for the cleaning of impregnated and polished surfaces ¹.

(vi) *Consumables*

Common materials used in the UK for the preparation of the concrete thin sections would include the following:

- Low viscosity epoxy resin for vacuum impregnation of concrete. Some cure exothermically and need to be kept cool during curing if used in large volumes. Some need slightly elevated temperatures (no more than 45⁰C to cure.
- Fluorescent dye that can be dissolved in epoxy resin.
- Coloured dyes that can be dissolved in epoxy resin.
- Solvents for cleaning purposes such as petroleum spirit, acetone and methylated spirits.
- Coolant other than water such as cutting oil.
- UV-Curing adhesive for mounting and covering of thin sections.
- Carborundum abrasive of various grades. One of the most commonly used grades would be 600-grade.

2.2 *Equipment for the petrographic examination of concrete samples*

(i) *Essential equipment*

These items are indispensable and need to be of high quality:

- A zoom stereo binocular microscope.
- A high quality petrological photomicroscope fitted with a digital camera.
- A point counting stage for the petrological microscope to enable point counting of thin sections².

¹ Note - the use of ultrasonic cleaners should be avoided in unimpregnated samples because of the risk of loosing materials such as ettringite or gel from voids and cracks.

(ii) *Recommended equipment*

For more detailed petrographic studies, the following equipment is desirable:

- A petrological microscope with appropriate filters and light source allowing the ability to carry out fluorescence observations to be carried out in either reflected or transmitted light.
- A petrological microscope with the facility to work in reflected as well as transmitted light
- Point counting equipment for the measurement of the air content of hardened concrete in accordance with ASTM C457

(iii) *Specialist equipment*

The following equipment can be used in conjunction with more conventional petrographic techniques to investigate some of the more detailed aspects of concrete composition and deterioration:

- A scanning electron microscope with X-ray microanalysis capability for examining uncovered thin sections, broken surfaces or specially prepared polished surfaces. This equipment can be used to quantify GGBS or PFA contents in hardened concrete and can be used to investigate chemical attack, chloride penetration and alkali-silicate gel composition.
- X-ray diffraction equipment is useful for identifying the reaction products of chemical attack and identifying deleterious materials in aggregates.
- An infra-red spectrometer can be used to determine the presence of some types of concrete admixtures.

3 SAMPLING

The ideal method of sampling concrete is by diamond core drilling. Large lump samples may also be of use but damage during sampling can limit investigations into causes of cracking. Sampling locations should be chosen to represent the variation in the condition of the concrete on site. In many cases it is useful to be able to examine samples of undamaged as well as damaged concrete in order to establish the original quality of the concrete. A photographic record of the core sample locations should be taken. If the surface concrete is too weak to be core sampled as is sometimes the case with sulphate attack it is advisable to obtain samples of surface concrete by hand and bag these separately to be included with deeper cored samples.

The core samples need to represent not only the surface concrete but also the concrete at depth and should be ideally no less than 70mm in diameter and 200mm long. Where smaller diameters are unavoidable two or more cores may be needed to represent each sampling location.

The samples obtained should be labelled, their orientation clearly marked and wrapped in cling film as soon as practicable after sampling. The samples should be accompanied by a sampling certificate giving details of the sample locations and the specific objectives of the petrographic examination.

² Note, this equipment may be replaced by computer image analysis methods.

4 METHODS FOR THE PREPARATION OF CONCRETE SAMPLES FOR PETROGRAPHIC EXAMINATION

4.1 *Large-area polished surfaces/plates*

Large area polished plates can be conveniently prepared using water lubricated diamond saws and lapping machines fitted with cast iron lapping plates. The plates would typically be finished using 600-grade carborundum or finer. On completion of the preparation of the plates the plates should be stored in a damp environment in order to allow any gel that has formed within the concrete to migrate on to the polished surface.

4.2 *Thin sections*

(i) *Introduction*

This section provides a description of a possible method for thin section preparation³. This method of preparation is commonly employed in the UK, however it should be noted that many other procedures and types of equipment are available. However, for all methods employed it is essential that the following precautions be taken:

- Excessive heating is avoided during the preparation of the thin sections: Excessive heating means temperatures of >45°C.
- Exposure to air should be minimised as carbonation can take place very rapidly in freshly ground and polished concrete surfaces and carbonation results in the loss of much valuable information in the finished thin section.
- Exposure to water should be kept to a minimum in order to avoid the occurrence of secondary hydration and the loss of water soluble compounds from the cement paste.

(ii) *Preliminary impregnation and cutting*

In most cases it is possible to carry out initial cutting using a water-lubricated large diameter diamond saw. However, in the case of very weak or friable samples such as those affected by fire damage or sulphate attack, it is essential that the concrete surface be vacuum impregnated with resin in order to consolidate the concrete surfaces prior to any cutting being carried out.

It is desirable that the final states of cutting be carried out using a precision small-diameter saw in order to minimise the amount of damage in the cut surface that needs to be removed prior to mounting on to glass microscope slide.

(iii) *Impregnation*

In order to produce high quality polished surfaces from concrete – particularly if the concrete is very porous – it is essential that the concrete be vacuum impregnated with a low viscosity epoxy resin prior to polishing and grinding. The use of a fluorescent dye is recommended in order to assist in the determination of porosity and microcracking. Coloured dyes may also be employed for this purpose. The most effective means of impregnation is to place the sample in a vacuum chamber and evacuate prior to the introduction of the impregnating resin.

³ It is assumed that the petrographer will have examined the original samples and will have selected the areas from which thin sections are to be prepared.

(iv) *Initial lapping*

Prior to mounting the concrete specimen on to a glass slide, it is necessary to remove the damage introduced into the surface of the sample during cutting. This is generally done using a combination of grinding and lapping to produce a high quality optically flat surface that can be bonded on to a glass microscope slide.

(v) *Mounting onto glass slides*

The flattened specimen should be fully cleaned – preferably using an ultrasonic cleaning bath and a solvent such as petroleum spirit. The polished surface should then be wiped over with a soft tissue using a solvent such as methylated spirits or acetone. The cleaned surface is then bonded on to a frosted glass slide using a UV-curing adhesive. It is important in mounting the specimen on to the glass that the thickness of the bond is of a controlled thickness and is kept to a minimum under the specimen.

(vi) *Removal of excess material*

Once bonded on to glass the specimen is then ready for the excess concrete to be cut off. This is done using a precision oil lubricated diamond saw and when complete should leave a section thickness of the order of 1mm.

(vii) *Final lapping*

The thin sample is then ground down in stages to a thickness of approximately 150 to 200µm using diamond surface-grinding equipment lubricated by oil. Further lapping using a precision vacuum chuck is used to take the section to a thickness of about 40µm. If it is to be hand finished. With some types of equipment it is possible to take the thin section down to its final thickness using very fine diamond grinding wheels.

(viii) *Hand finishing*

Using a petrological microscope to measure the thickness of the thin section the section can be hand finished down to its final thickness of 25 - 30µm⁴. The birefringence of quartz particles present in the sample often provide a convenient way of judging the thickness of the thin section during hand finishing.

(ix) *Covering*

It is important that on completion the final section be thoroughly cleaned and then covered using a glass cover slip. This is to prevent carbonation and damage to the sample after its preparation and is also important to reduce light scattering during the examination of the thin section.

5 PETROGRAPHIC EXAMINATION

5.1 *Recording of results*

It is recommended that the petrographic data be collected systematically in tables similar to those given in Section 7 of this code of practice. A separate discussion of the findings of the petrographic observations should ideally be included together with recommendations for further work if appropriate.

⁴ If the slice is too thick details of the structure of the cement grains can be hard to resolve.

A glossary of terms for use in the description of the samples is included in Section 9 of this code of practice.

5.2 *Preliminary macroscopic examination:*

The samples should be examined with a binocular microscope as received and their dimensions and main features should be recorded using photographs and drawings. The features observed should include the following.

- (a) The presence and position of reinforcement.
- (b) The extent to which reinforcement is corroded.
- (c) The nature of the external surfaces of the concrete.
- (d) The features and distribution of macro and fine cracks.
- (e) The distribution and size range and type of the aggregate.
- (f) The type and condition of the cement paste.
- (g) Any superficial evidence of deleterious processes affecting the concrete.

5.3 *Polished surfaces:*

Large-area polished surfaces typically can be examined with a binocular microscope to obtain valuable information about the concrete and are relatively quick and inexpensive to prepare compared to thin sections. They should provide as large a section of the sample as is possible – ideally representing the full length of the core and include the parts of the sample not examined in thin section. The method of polishing is described in ASTM C457 and would typically involve the use of glass or cast iron lapping plates and an abrasive slurry finishing with a surface ground and polished using 600-grade carborundum or finer. The features recorded should include the following items.

- (a) The size, shape and distribution of coarse and fine aggregate.
- (b) The coherence, colour, and porosity of the cement paste.
- (c) The distribution, size, shape, and content of voids.
- (d) The composition of the concrete in terms of the volume proportions of coarse aggregate, fine aggregate, paste and void.
- (e) The distribution of fine cracks and microcracks. Often the surface is stained with a penetrative dye, so that these cracks can be seen. Microcrack frequency may be measured along lines of traverse across the surface and the orientation of the traverses recorded.
- (f) The relative abundance of rock types in the coarse aggregate is assessed.
- (g) The sample, after a period of storage of at least 24 hours in humid conditions should be examined with the aid of a binocular microscope for the possible presence of gel or other exudations.

5.4 *Thin sections:*

At least one thin section and preferably more depending on the specific objectives of the investigation should be prepared for each sample as appropriate and each thin section should measure at least 45mm x 70mm. . The location and number of thin sections required should be decided by the petrographer during the preliminary macroscopic examination of the samples. However it is often advantageous that at least one section be made from a plate cut at right angles to the external surface of the concrete, so that the outer 70 mm or so of the concrete are included in the section. Sometimes it may be more appropriate to make the section from inner parts of the concrete. This might be appropriate where specific problems for example such as AAR are being investigated for example.

The microscope employed should have a calibrated graticule or similar device for measuring crack widths and the dimensions of other features of interest.

The features observed using the thin sections should include the following:

- (a) Details of the rock types present in the coarse and fine aggregate and in particular structures seen within those rocks and the degree of weathering.
- (b) Details of the aggregate properties can be measured such as the degree of strain in quartz⁵.
- (c) The size, distribution and abundance of phases in the cement paste are assessed including, for example, the occurrence of calcium hydroxide and the amount of residual unhydrated clinker.
- (d) The presence of cement replacement phases such as slag or PFA can usually be recognised (though the amounts of these phases cannot be quantified accurately). The presence of high alumina cement can be detected and the type of cement clinker can often be identified.
- (e) Any products of processes of deterioration of either the cement paste or the aggregate can be recognised.

5.5 *Broken surfaces:*

After the specially prepared surfaces and sections are completed, the remainder of the core should be examined with the binocular microscope. In particular, the pieces should be broken to produce fresh surfaces. These surfaces allow the contents of voids to be studied and the nature of aggregate surfaces or crack surfaces to be investigated.

5.6 *Composition (optional):*

(i) Measurement of volume proportions

The composition of the sample should be measured where the sample is of appropriate size using either the polished slice and/or the thin section(s), depending on the size of the sample and on details of the aggregate type and paste. The thin section is preferable, for example where large quantities of dust are present. The volume proportions can be conveniently measured by the method of point counting using a mechanical stage as described in the "Modified Point Count Procedure" in ASTM C457. The amount of coarse aggregate can also be assessed by this method if a distinction can be made between coarse and fine aggregate. The results obtained usually represent the sample with reasonable accuracy, but may not represent the concrete.

(ii) Water/cement ratio:

Water/cement ratio in hardened concrete may be measured petrographically. It is desirable that the determination be made using concrete control samples of similar composition and type to the sample under examination. It is important that the petrographer is aware of the many factors that may hinder an accurate measurement of water/cement ratio. Admixtures such as plasticisers may affect the quantities of unhydrated cement and portlandite crystal size and abundance. Leaching and other forms of concrete deterioration may affect paste porosity as well as portlandite and unhydrated cement grain abundance. Also low

⁵ Dolar-Mantuani, 1983 *(Note also:P.E.Grattan-Bellew1986 7TH ICAAR – who points out that strain is indicative of micro-crystalline quartz. at grain margins)

temperatures will slow setting times and reduce crystal size, reduction in strength and increase porosity. However despite the many complicating factors the advantage of carrying out this determination petrographically is that with experience it is usually possible to tell to whether or not there are any additional factors that may contribute to the uncertainty in the measurement of water cement ratio.

A petrographic assessment of the original water/cement ratio of a concrete should be based on the following types of information:

- Comparison with reference concrete samples made with a known water/cement ratio.
- Measurements of the amounts of unhydrated cement. The number and proportion of unhydrated cement clinker particles varies inversely with the original water/cement ratio.
- Measurement of the porosity of the cement hydrates. The porosity of the cement hydrates tends to increase with increasing water/cement ratio. With this method it is critical that impregnation with fluorescent dye is carefully controlled and that precautions are taken to avoid grinding away impregnated concrete prior to sectioning.
- The saturated surface-dry density of the concrete can be used to calculate the water/cement ratio of the concrete if the porosity of the aggregate can be reliably judged.
- The amount size and distribution of calcium hydroxide in the paste. Concretes with a low water/cement ratio tend to develop only limited amounts of coarsely crystalline calcium hydroxide. The extent to which calcium hydroxide is separated into layers on aggregate surfaces and occurs in voids and on void surfaces varies with the original water/cement ratio.
- An assessment of the extent to which the porosity and portlandite distribution of the concrete has been modified since its placement.

(iii) *Estimation of the composition of the concrete in terms of weight fractions:*

The amount of individual rock types present in the aggregate as a whole should be assessed and the saturated density of the sample is measured by the method of immersion in water using vacuum impregnation to ensure saturation. From this information and the volume proportions, the weight fractions of aggregate, cement and water can be calculated. An example of the method of calculation of the composition of hardened concrete is given in Section 8.

6 REPORTING OF RESULTS

The petrographic report should make reference to this code of practice.

The report should include a summary of the information provided by the client about the nature of the structure from which the samples were obtained. The report should list the requirements of the client / reason for the examination of the samples if advised.

The report should include the factual observations of the samples in tabular form using tables similar to those given in Section 7.

The report should include photographs of the samples as received with close-up photographs illustrating features of interest such as gel deposits or crack fillings. The report should also include photomicrographs of the thin sections illustrating the principal features of the samples.

The report should include a summary of the findings and recommendations for further work such as electron microscopy or the examination of additional samples. An interpretation of the findings should be given – particularly where the client is likely to unfamiliar with petrographic results. The interpretation might include the following points:

- An indication of the relative severity of deterioration if present
- A discussion of the causes of deterioration. The report should identify whether or not alkali-aggregate reaction, delayed ettringite formation, sulphate or other forms of chemical attack have occurred.
- A discussion of whether or not the deterioration is on-going
- Indication of concrete quality
- Approximate air/void and water/cement ratios
- Types of aggregate

7 EXAMPLE TABLES FOR THE COLLECTION OF PETROGRAPHIC DATA

Table 1: Macroscopic features

Laboratory ref.	
Sample ref.	
Sample orientation and location details	
Sample preparation details	
Sample dimensions:	
Core diameter (mm)	
Core length (mm)	
Number of pieces	
Description of outer surface	
Description of inner surface	
Paste colour	
Macrocracking: (>0.1mm wide)	
Fine cracking: (0.01-0.10mm)	
Carbonation:	
Typical depth (mm)	
Maximum depth (mm)	
Texture of carbonated paste	
Reinforcement:	
Diameter (mm)	
Depth (mm)	
Corrosion	
Coarse aggregate distribution:	
Voids:	
Entrained air voids abundance (voids <1mm in diameter)	
Maximum size (mm)	
Typical size (mm)	
Measured / estimated void content (%)	

Supplementary notes:

Table 2: Petrographic description of the aggregate

Laboratory ref.	
Sample ref.	
Coarse aggregate:	
Maximum size (mm)	
Typical shape	
Major rock types	
Minor rock types	
Trace rock types	
Fine aggregate:	
Grading (estimated BS 882 (fine-medium-coarse) grading classification)	
Maximum size (mm)	
Typical shape	
Major rock types	
Minor rock types	
Trace rock types	
Alkali-aggregate reaction:	
Gel on plate	
Gel in voids	
Gel in cracks	
Evidence for specific rock types involved in reaction	
Evidence for other forms of aggregate deterioration (e.g. unstable slag, pyrite)	
Aggregate surface details (include evidence for aggregate shrinkage, DEF or AAR)	

Table 3: Petrographic description of the paste

Laboratory ref.	
Sample ref.	
Cement type	
Cement replacement and estimated level of cement replacement	
Texture of carbonated paste (details of porosity, grain size and evidence for carbonate formation in voids)	
Portlandite (approx. vol.% of paste)	
Cement grains	
Unhydrated cement (grains/40mm of concrete)	
Pseudomorphically hydrated cement grains	
Mineralogy of unhydrated cement grains	
Porosity	
General level	
Porosity distribution	
Microcracking	
General microcracking level	
Microcracking at the surface	
Typical length (mm)	
Microcrack fillings	
Void fillings and abundance	
Petrographically assessed water/cement ratio	

Table 4: Compositional data (optional)⁶

Laboratory Reference	
Sample Reference	
VOLUME PROPORTIONS :	
Paste %	
Fine aggregate %	
Coarse aggregate %	
Void %	
Water / cement ratio (assessed petrographically)	
WEIGHT PROPORTIONS:	
Fine aggregate (kg/m ³)	
Coarse aggregate (kg/m ³)	
Cement (kg/m ³)	
Water (kg/m ³)	
Aggregate/cement ratio	

⁶ An example of the calculation of the composition of the concrete from point count data is given in Section 9 of this Code of Practice.

8 EXAMPLE OF THE METHOD OF CALCULATION OF CONCRETE COMPOSITION FROM VOLUME PROPORTIONS MEASURED BY POINT COUNTING

(i) *Results of point counting (excluding voids) and petrographic examination for water/cement ratio:*

- Coarse aggregate: 40%
- Fine aggregate 30%
- Paste: 30%
- Petrographically measured water/cement (w/c) ratio: 0.50

(ii) *Assumed densities*

These are based on the petrographic identification of the aggregate types.

- Coarse aggregate density (siliceous gravel): 2620 kg/m³
- Fine aggregate density (siliceous sand): 2620 kg/m³
- Cement density assuming Portland cement: 3140 kg/m³

(iii) *Calculation of aggregate contents*

The aggregate content in kg/m³ is given by:

- Aggregate content (kg/m³) = (aggregate density) * (vol. % of aggregate)

Using the above formula gives coarse and fine aggregate contents of 1048 and 786 kg/m³ respectively.

(iv) *Calculation of cement and water contents*

Cement content is given by the equation:

$$\text{Cement content (kg/m}^3\text{)} = \frac{10 * \text{paste vol. \%}}{\text{w/c} + (1000/\text{cement density kg/m}^3\text{)}}$$

The above example gives a cement content of 367 kg/m³

Water content is given by the equation:

$$\text{Water content (kg/m}^3\text{)} = \text{w/c ratio} * \text{cement content kg/m}^3$$

The above example gives a water content of 183 kg/m³.

9 DEFINITIONS ⁷

The following is a short list of technical terms in common use in the petrographic examination of concrete. ⁸

Alkali-aggregate reaction (AAR): This is a broad term encompassing both alkali carbonate reaction (ACR) and alkali silicate reaction and alkali-silica reaction (ASR). It refers to reactions between alkalies in usually derived from the cement in the cement paste and aggregate particles. Some forms of alkali-aggregate reaction such as ASR result in the formation of an alkali-silicate gel that is readily detectable in thin sections. Other forms of alkali-carbonate reaction such as ACR may not result gel formation.

Alkali carbonate reaction (ACR): This form of reaction is very rare in the UK and there is some debate over the precise mechanism of this reaction. Most documented cases of ACR involve argillaceous, dolomitic limestone. The reaction which is expansive is rarely associated with the formation of obvious gel deposits.

Alkali-silicate/silica reaction (ASR): This is by far the most common form of AAR and generally results from reactions between either microcrystalline, cryptocrystalline, or substantially strained quartz and associated microcrystalline quartz at grain margins and alkalies in cement paste. On rare occasions, ASR may result from the presence of highly reactive opaline silica in aggregate. Petrographic examination is the definitive method for the detection of this form of concrete deterioration. The reaction commonly results in the development of cracking that originates within reactive aggregate particles and continues into the surrounding paste and gel deposits are commonly associated with the occurrence of ASR.

Calcium aluminate cement (CAC): This is a general term that encompasses high alumina cement (HAC) as well as some of the more modern aluminate cements used in rapid setting concrete repair materials or some types of sprayed concretes and grouts.

Carbonation: Carbonation most commonly results from the exposure of concrete to atmospheric carbon dioxide and results in the conversion of portlandite to calcium carbonate and also affects some of the cement hydrate phases forming complex calcium silicate hydrate carbonate compounds. In damp conditions or in concrete exposed to moisture containing dissolved carbon dioxide, coarse-textured carbonation may develop and coarse crystals of calcium carbonate may develop within the cement paste. “Popcorn” calcite deposition (PCD) is one form of this type of carbonation.

Cracking: Cracks are classified using the following terms:

- **Macroscopic cracks:** These cracks are visible in the hand specimen or with the aid of a stereo binocular microscope and are typically >0.01mm wide.

⁷ See also the Glossary of Terms in the *Code of Practice for the Petrographic Examination of Building Materials* produced by the APG.

⁸ Taken from the full glossary document prepared by the APG document reference **SR3 (2008)**

- **Macrocrack:** These are cracks that are readily visible to the naked eye without the aid of a stereo binocular microscope and are typically >0.1mm wide.
- **Fine crack:** These are cracks that are only readily visible with a stereo binocular microscope or in thin section. Cracks of this type are typically between 0.01 and 0.10mm wide.
- **Microcracking:** These cracks cannot be detected with a stereo binocular microscope. They are typically <0.01mm wide and are most easily seen in petrographic thin sections containing fluorescent dye and by using fluorescent illumination.

Delayed ettringite formation (DEF): This term describes deleterious ettringite formation in concrete that has been cured at elevated temperatures, typically >65°C. Ettringite formation resulting from this process can be readily detected using thin sections and the ettringite tends to form in peripheral cracks around aggregate surfaces and sometimes within microcracks in the paste.

Drying shrinkage cracking: Drying shrinkage microcracks tend to develop radially around the surfaces of fine aggregate particles in concrete. Fine cracks and macrocracks caused by drying shrinkage tend to be parallel-sided cracks and orientated perpendicular to concrete surfaces.

Ettringite: This is a very common calcium-alumino-sulphate mineral. It occurs in most concretes where moisture ingress has occurred. Ettringite formation may be deleterious in the case of DEF or sulphate attack where it can give rise to a deleterious expansion and distinctive forms of cracking but in most cases secondary ettringite formation is non-deleterious.

Fine crack: See section on cracking

GGBS: Ground, granulated blast furnace slag. This material is commonly employed as a cement replacement material in concrete and can be easily recognised in thin section. The GGBS particles are typically angular and are composed almost entirely of glass.

High alumina cement (HAC): This is a form of cement manufactured from the fusion of limestone and bauxite. It is readily distinguishable in thin section from most other types of cement. Petrographic examination is the definitive method for the detection of carbonation in concrete containing HAC.

Macrocrack: See section on cracking

Macroscopic: This is a general term referring to features that are visible to the naked eye or with the aid of a stereo microscope.

Microcrack: See section on cracking

Microsilica: Well dispersed microsilica cannot be directly observed in thin sections. However, distinctive clots of undispersed microsilica are commonly present in concrete containing microsilica – even where most of the microsilica is well dispersed. Microsilica clots are isotropic, and tend to be spherical and are sometimes concentrically layered. They are typically <100µm in diameter.

PFA: Pulverised fly ash. This material is a by-product of coal burning power stations and can be readily recognised in thin sections, where it is visible as spherical glass particles, some of which may be hollow. Hollow PFA particles may be referred to as cenospheres. PFA is also commonly associated with small quantities of graphite particles that appear black in thin section.

Plastic shrinkage cracking: This form of cracking occurs in concrete prior to its hardening. It can be distinguished from many other forms of cracking in that it results in cracks that are generally restricted to the cement paste and are non-parallel sided. Cracks of this type typically appear on the concrete surface and commonly diminish in width rapidly with depth and the paste surrounding cracks of this type is commonly of locally high porosity reflecting the migration of moisture towards the cracks during the drying out of the concrete surfaces.

Popcorn calcite depositions (PCD): This term refers to coarse calcium carbonate crystals developed in cement paste in concrete exposed to groundwater containing dissolved carbon dioxide. It is a form of carbonation and in some cases may be associated with thaumasite formation and the thaumasite form of sulphate attack.

Porosity: This term is distinct from void content. It refers to microscopic pores within cement hydrates. Porosity is directly related to water/cement ratio, but is also strongly influenced by curing and many forms of concrete deterioration. Porosity is sometimes used as an indicator of water/cement ratio in hardened concrete.

Portland cement: Portland cement is the most common form of binder used in concrete and is manufactured from the burning of limestone and an aluminosilicate rock (clay or shale) at temperatures of up to 1500°C. There are many forms of Portland cement and it is commonly possible to distinguish sulphate-resisting and white Portland cement and ordinary Portland cement using petrographic thin sections.

Portlandite: Portlandite is calcium hydroxide and is one of the products formed during cement hydration. Portlandite is readily recognisable in thin sections and has a distinctively high birefringence that contrasts with the much lower birefringence of the hydrated cement phases.

Sulphate attack: This is a general term encompassing both conventional sulphate attack resulting in gypsum and ettringite formation, but also includes sulphate attack associated with thaumasite formation. Sulphate attack can be readily recognised in thin sections and commonly results in the development of surface-parallel cracks infilled with ettringite or thaumasite.

Thaumasite: This is a carbonate-sulphate calcium hydrate mineral with a complex composition. It is a common reaction product in concrete exposed to moisture containing both carbonate and sulphate ions. Thaumasite is most commonly encountered in concrete exposed to temperatures of <4°C. Some forms of thaumasite can be readily distinguished from ettringite and have a high birefringence. However, some forms of thaumasite have a much lower birefringence and can be difficult to distinguish from ettringite without recourse to SEM micro-analysis.

Void: This describes empty spaces present in concrete that are typically greater than about 5 micrometres in diameter. It encompasses both entrained air voids (spherical voids typically <1mm in diameter) as well as much larger entrapped air voids. It should be noted that it is possible for concrete to have a low porosity, but a high void content.