The Power of Petrography

By Laura J. Powers

Concrete used in modern construction can be a very complicated material. It is becoming increasingly rare for a modern construction project to specify a simple concrete mixture – one consisting of sand and gravel (or crushed rock), portland cement, and water. Today, it is much more common to encounter concrete mixtures that contain a variety of organic admixtures, supplementary cementitious materials, manufactured aggregates, specialty cements, and various types of fibers. These materials are often added to improve the durability of the concrete, enhance its performance, or control specific properties, such as setting time, heat of hydration, shrinkage, and workability. Such materials have introduced considerable complexity into modern concrete mixtures, and increased the opportunities for problems to occur. The consequences can be costly, and can range from merely inconvenient to disastrous.

As expectations for concrete performance grow, it is necessary to exert greater control over the properties of the concrete mixtures and the individual concrete components, and of all aspects of the placing, finishing, and curing operations. We assume that quality control and quality assurance practices have eliminated most of the opportunities for problems to occur in the early stages, and we assume that placing, finishing, and curing operations will go smoothly and that weather conditions won't have an adverse effect on the construction. Sometimes things don't go as planned.

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Problems with concrete can occur at any time. The behavior of the concrete might lead you to suspect problems with the concrete components, or problems with placing and finishing the concrete. You might notice distress or even failure that tells you the concrete is not performing as intended. What went wrong? Concrete petrography has the power to provide answers to many of your questions.

What is Concrete Petrography?

Petrography is a specialized field of study within the geological sciences that deals with the description and systematic classification of rocks, usually through the use of microscopes and thin sections. Thin sections are preparations made from slices of material that is attached to a glass slide, and then ground to a thickness of about 0.0008 to 0.0012 inch. These preparations allow the petrographer to identify the mineral

Figure 1: A thin section of concrete is shown on the stage of the petrographic microscope

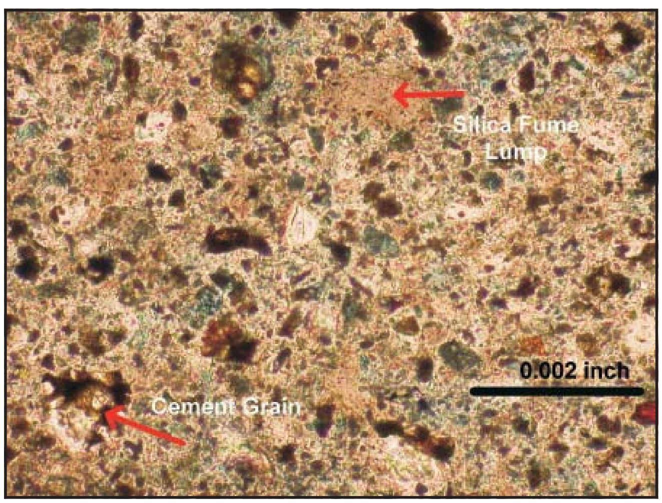

Figure 2: The constituents of the paste portion of the concrete are easily studied in a thin section. Examples of unhydrated cement and lumps of silica fume are shown with arrows.

Table 1 Common Tasks Performed in Petrographic Examinations

Measure	Identify	Estimate	Evaluate
1. Sample dimensions 2. Depth of paste carbonation 3. Aggregate top size 4. Size of embedded items 5. Air-void system parameters (ASTM C 457) 6. Paste content 7. Crack widths	1. Cementitious components (portland cement, fly ash, slag, thermally processed clay, hydrated lime, and finely ground limestone) 2. Aggregate rock types, mineralogy and textures 3. Potentially harmful mineral constituents 4. Products of adverse reactions such as alkali-silica reaction, alkali-carbonate reaction, and sulfate attack 5. Evidence of thermally-induced damage such as delayed ettringite formation 6. Contaminants 7. Secondary deposits 8. Intentionally added items such as fibers 9. Crack orientation and relationship to other features	1. Air content 2. w/c or w/cm 3. Extent of cement hydration 4. Paste volume 5. Aggregate volume	1. Paste-aggregate bond 2. Paste hardness, color and luster 3. Consolidation 4. Condition of embedded items 5. Aggregate gradation 6. Distribution of components 7. Joints and other discontinuities 8. Evidence of distress (cracks, microcracks, secondary deposits)

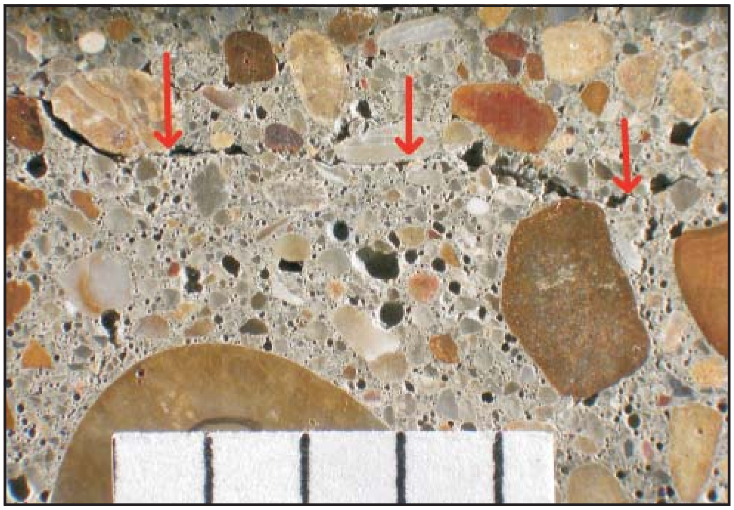

Figure 3: Finishing concrete too soon or too late can cause surface defects such as this horizontal delamination crack shown on a polished section of core

constituents and estimate their proportions, measure crystal size, and examine the relationships between the various constituents. The application of geological petrography requires special knowledge of rocks and minerals, and of how each forms.

The methods used in concrete petrography have been borrowed from geology and supplemented with techniques used in other materials-related fields. The application of concrete petrography requires special knowledge of concrete components, and knowledge of how concrete is mixed, placed, finished, and cured. The concrete petrographer must also know how concrete is affected by its service environment.

The petrographer makes detailed observations of the concrete using microscopes (*Figure 1*), while using a variety of tools and solutions to test specific properties of the concrete and its components. The aggregates rock types are identified and their mineral constituents are evaluated. The components of the paste, which can include hydration and reaction products as well as small particles of unreacted portland cement, fly ash, slag, and agglomerates of silica fume, and other materials, are identified and evaluated (*Figure 2*). The petrographic studies reveal in great detail how well the concrete was mixed, whether it was proportioned properly, whether there were difficulties in placing and finishing the concrete, whether the concrete was adequately cured or experienced excessive drying, how it has behaved since it was placed, and whether it contains contaminants or materials that are likely to cause problems later. *Table 1* lists some of the tasks performed in typical petrographic studies.

The petrographer may also perform supplemental studies to investigate certain features that are not readily studied using the microscopes. Two fundamental investigative tools include:

- X-ray diffraction (XRD), to identify crystalline substances that are too fine-grained for identification with the microscope;
- Scanning electron microscope with an energy dispersive spectrometer (SEM/EDS), to study materials at high magnifications and identify elements present in reaction products and contaminants.

Petrographic studies of concrete are performed in accordance with two ASTM standards: C 856 and C 457. C 856 is a standard practice providing guidelines for examining hardened concrete. C 457 is a standard test method for measuring air content and air-void system parameters.

When Do I Need to Consider Petrography?

Concrete petrography is most often performed to determine the cause of failure or distress. The line between distress and failure is sometimes blurred; however, both terms imply that the concrete is not performing as expected. If you see signs of distress in the concrete, such as cracking or discoloration, you should consider petrography. You should also consider petrography if you experience problems with the behavior of the young concrete, such as setting times that are too slow or too fast, early age cracking, strength problems, and finishing problems. Operations such as handling and manipulation of concrete leave behind tell-tale signs that the petrographer can detect with the microscope. For example, finishing difficulties can result in microscopic tears and shallow delamination just below the surface (*Figure 3*).

Petrographic examination can be used to investigate the composition and condition of concrete of all ages, and it is used to study construction materials other than concrete. A partial list of materials that are routinely studied includes mortar, grout, plaster, stucco, brick, shotcrete, concrete masonry units, terracotta, dimension stone, cast stone and cultured stone, and the aggregates that are used in concrete.

What Can Petrographic Examination Tell You About Your Concrete?

The petrographer's observations are used to evaluate such properties as the proportioning of the concrete, the effectiveness of mixing, consolidation, and curing practices, segregation, and evidence of specific distress.

Composition and Properties of Concrete

In the course of a typical petrographic examination, the petrographer will determine the rock and mineral types in the concrete aggregates, and evaluate whether the aggregates are physically and chemically

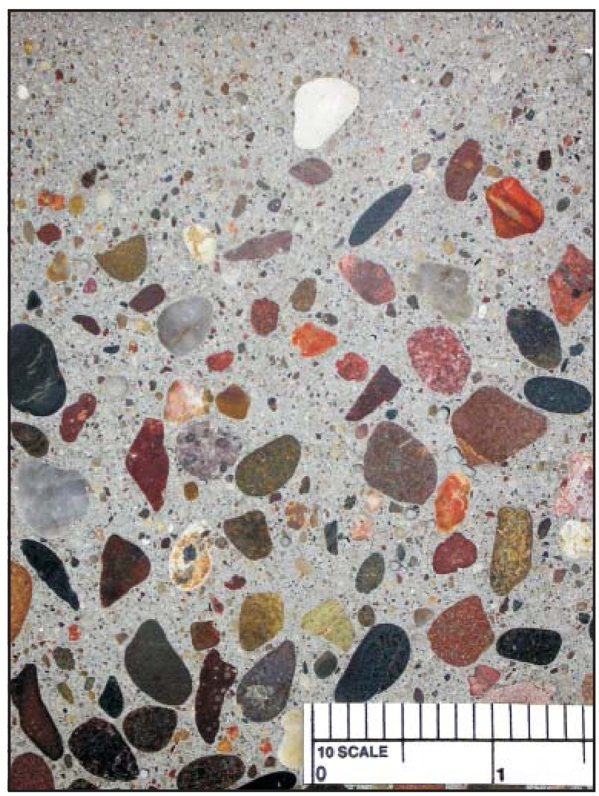

Figure 4: Concrete that is too fluid may experience segregation of its components, as shown on this polished section made from a core sample

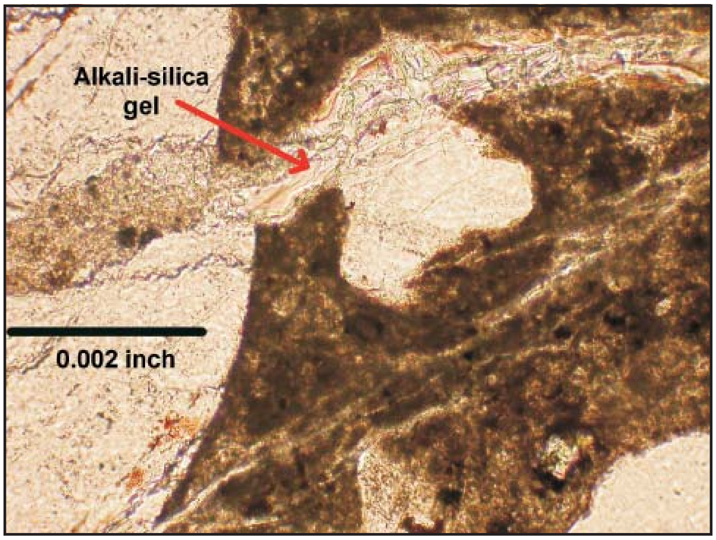

Figure 5: Reactive aggregates can cause cracking deterioration. The main crack shown and the narrower parallel cracks are filled with expansive reaction product.

stable. The bond of the aggregates to the paste is judged. The volumes of paste, aggregates, and air are estimated. The characteristics of the air-void system tell the petrographer whether the concrete contains air-entraining admixture. Qualities of the paste, such as color, hardness and luster are evaluated. The petrographer identifies the cementitious components in the paste and estimates the relative amounts of cementitious constituents that have not yet hydrated or reacted. Observations pertaining to paste properties are used to estimate water-to-cement ratio (w/c) or water-to-cementitious materials ratio (w/cm). The results of the examination can be compared against a concrete mix design or project specifications if these are available. The petrographer can perform a modal analysis of the concrete using point-count procedures if a more detailed analysis of proportions is needed.

Segregation of Constituents

In segregated concrete, the larger and denser aggregates settle to the bottom and the paste and air collect at the top (*Figure 4*). Segregation is usually caused by mixtures that are too fluid, or by over-vibration. In cases of over-vibration, the concrete often contains vibrator trails. Mixtures that are too fluid generally contain either too much water or too much plasticizer. Petrography can determine if the water content was high enough to cause segregation, but other tests are needed to determine whether the concrete contained too much plasticizer.

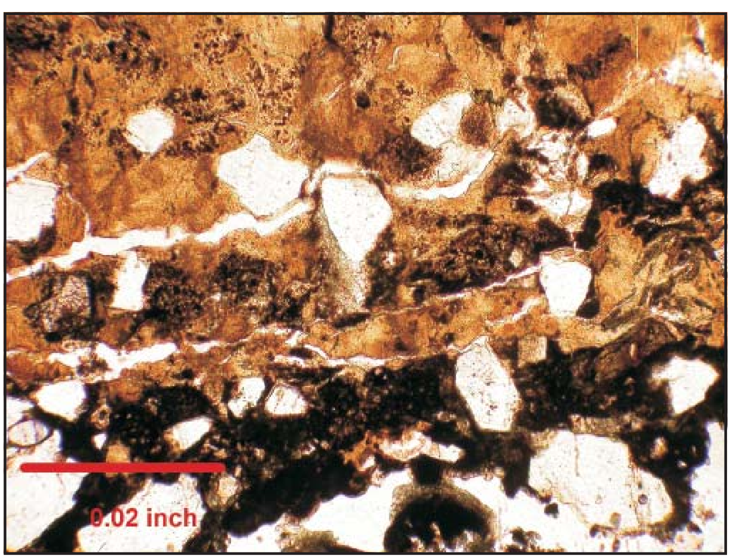

Figure 6: Exposure conditions can cause concrete to deteriorate from the outside surface inward. This concrete was placed in sulfate-rich soils in a cold moist environment.

Effectiveness of Curing

The aim of curing is to provide the necessary temperature and moisture to promote hydration of the portland cement and reaction of the supplementary cementitious materials. Carbonation is typically limited to a thin layer at the surface of properly cured, young concrete. The petrographer measures the depth of paste carbonation and other paste properties to judge the effectiveness of curing. Ineffective curing promotes excessive shrinkage.

Causes of Distress

Distress includes behavior such as cracking, spalling, crumbling, and staining that is not normally expected. The causes of distress, especially cracking, are varied. The petrographer first must determine whether the cause is internal or external. If the cause of distress is internal, it might be isolated to a particular component such as a reactive aggregate (*Figure 5*). If the cause is external, the petrographer will look for evidence of interaction between the concrete and its environment (*Figure 6*).

Air Content Determination

The petrographer measures the air content and air-void system parameters of concrete to determine whether it is adequately protected against damage caused by cyclic freezing and thawing in a particular service environment. Concrete should generally contain an air-entraining admixture if it is placed in an environment where it will be exposed to moist, freezing conditions, especially if deicers are used. During freezing, the entrained air bubbles (*Figure 7*) provide space for ice crystals to grow so that the paste will not be disrupted.

Problems with Aggregate Performance

In the course of a routine study, the petrographer will identify the rock types and the mineralogy of the coarse and fine aggregates in the concrete and evaluate the general characteristics of the aggregates. Some rock types are not durable in concrete. Some rock types contain minerals that are chemically reactive in concrete. The presence of these non-durable and reactive aggregates can cause distress or premature failure of the concrete.

Getting More from a Petrographic Study

The major keys to success in resolving problems using petrography examination are reliable information and good samples. The better the information the petrographer has to work with, the better his or her interpretations of the observations will be. Some information the petrographer finds useful includes:

- Concrete mix design
- Batch and/or delivery tickets
- Results of previous laboratory tests
- Mill certificates for cement
- Product data for admixtures
- Inspection reports
- Construction records
- History and photos of the distress

The samples needed for a reliable analysis must be suitable for the objectives of the study. The petrographer usually works with cores, although fragments and saw-cut sections will do. The number of samples will generally depend on the size of the project, the range of conditions represented by the concrete, and the nature of the problem with the concrete. If the objective is to address a specific problem, such as cracking, cores should be taken over the cracks and outside of the area of cracking for comparison. The petrographer can tell you what types of samples are needed, how they should be labeled, and how to protect the samples during shipment. In some situations, the petrographer should visit the site to make observations and measurements, take photographs, and select the locations for samples.

What If Petrography Doesn't Find The Answer?

Although petrography can determine the cause of many of the problems encountered in concrete construction, it can be less than definitive, even with proper samples and reliable background information. Some problems are difficult to solve solely by petrography, and require additional studies, such as those listed below, to supplement the petrographic examination.

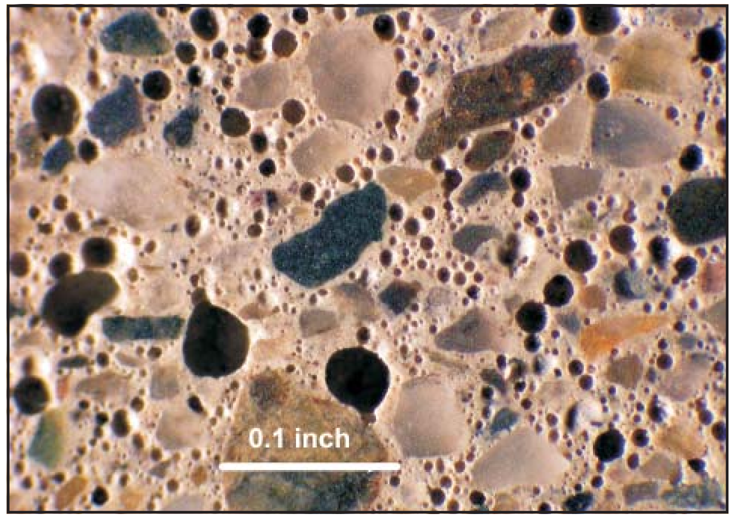

Figure 7: Entrained air voids are typically small, spherical, and well dispersed throughout the paste

- Thermal analysis (TGA, DCS, DTA) to identify and determine amounts of various hydration products;
- X-ray fluorescence analysis (XRF) to determine bulk chemistry;
- Infrared (IR) analysis to identify organic components;
- Chemical analysis for chloride content to evaluate the potential for corrosion of steel in concrete;
- Compressive strength and physical tests to evaluate the engineering properties of the concrete.

In troubleshooting distressed concrete, the petrographer can usually narrow the range of possible causes of a problem even when a specific cause cannot be named, and can state whether individual components of the concrete have deficiencies that might contribute to the problem. The petrographer might also recommend a site investigation by a materials engineer to provide more insight into the problem.

Finding a Petrographer

Many engineering consulting firms, materials testing laboratories, governmental agencies, some concrete suppliers, cement companies, and admixture producers, employ petrographers. A few petrographers work with only one aspect of concrete, such as air-void system analysis, while others work in a laboratory setting with access to sophisticated equipment. Most crucial, is their experience level and familiarity with concrete and concrete technology, concrete-making materials and other materials used in construction. Although it sounds trite, the time to find a petrographer is before you need one.▪

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