This article is a continuation of the "What's This Report For?" series, based on a technical session sponsored by ACI Committee E702, Designing Concrete Structures. In keeping with ACI's mission to provide knowledge and information for the best use of concrete, the articles will be posted on the ACI Web site (**www.concrete.org/education/edu_online_CEU.htm**) and, along with sample reports and multiple-choice questions, be used for educational materials.

The Petrographic Report

What the designer needs to know

BY RICHARD D. STEHLY AND ADAM J. BREWER

It's safe to say that the most contentious report in the concrete industry is a petrographic report—a report that's usually requested because a concrete did not perform as expected. A petrographic report can be associated with litigation, adding a special level of importance to the work. Unlike a simple test method such as for compressive strength, petrography is not one single technique or set procedure, and the result—the report—does not comprise simple data that can be readily understood or compared with other test results.

Rather, petrography uses a suite of techniques, primarily employing optical microscopy, and requires professional judgment in selecting the locations from which to extract cores, selecting the sample from a core for detailed examination, determining appropriate specimen preparation and storage techniques, obtaining data and observations, and interpreting the results. Much of the information obtained is qualitative or semi-quantitative, making it sometimes difficult to compare reports made by different petrographers on cores taken from the same location.

WHY DO PETROGRAPHIC STUDIES?

In the broadest terms, petrography is a branch of geology that focuses on detailed descriptions of rocks. For this article, we're going to focus on the man-made rock we know as concrete.

Petrographic techniques often require more time for the preparation and examination of specimens than can be accommodated in construction quality assurance. Because they often require hours of highly skilled labor, they may be too expensive for routine testing. Thus, they are used mostly for dealing with problems, often in the context of litigation. They are also highly informative in research projects, as they provide very detailed information about the concrete itself and any deterioration that may have taken place.

ASTM C856, "Standard Practice for Petrographic Examination of Hardened Concrete," describes the techniques that may be used. The petrographer will select appropriate techniques based on the questions he or she is trying to answer and the capabilities of the laboratory. The information that could be obtained includes the type of aggregates and whether they have reacted with anything; the air-void system parameters (using ASTM C457); the quality of the cement paste; the presence and estimated quantity of supplementary cementitious materials (SCMs); the estimated water-cementitious material ratio (*w/cm*); the presence and possible causes of cracks; the presence and identification of deposits in cracks and voids; and evidence (which may or may not be conclusive) suggesting the cause(s) of such deterioration as spalling, cracking, scaling, dusting, blisters, or delamination.

WHO CAN BE A PETROGRAPHER?

As previously indicated, petrography requires a good deal of judgment. While a proper foundation of education and experience is essential for a petrographer, you can't obtain a university degree in concrete petrography. ASTM C856 requires that "the supervising concrete petrographer shall have college level courses that include petrography, mineralogy, and optical mineralogy, or 5 years of documented equivalent experience, and experience in their application to evaluations of concrete-making materials and concrete products in which they are used and in cementitious-based materials." Typically, the courses would have been part of a degree program in geology with emphasis in mineralogy and optical microscopy—that is, in the application of optical microscopy to the study of rocks.

Although concrete is essentially artificial rock, there are differences between it and natural rock that will affect everything from preparing the thin sections to interpreting the observations. To learn about concrete, the geologist needs to work alongside an experienced concrete petrographer, preferably as part of a team of other professionals in related disciplines. It's also helpful if the petrographer gains some experience at the job site, as this provides the context for the detailed work of examining specimens in the laboratory.

Similarly, petrographers are not specifically licensed as such by state licensing boards. Some states issue licenses to geologists with certain credentials and experience. We believe the work should be conducted under the supervision of a licensed professional, whether a geologist or an engineer.

HOW CAN I GET THE MOST OUT OF A PETROGRAPHIC REPORT?

Communication

Many people make the mistake of sending the petrographer a core (or worse, simply a random piece of concrete) obtained at the site. They provide no real information about the sample or the site, yet they expect the petrographer to produce a meaningful report.

Keep in mind that this is a report for which you will be paying hundreds of dollars per sample and for which you could be waiting several weeks. You want it to be as informative as possible. The more information the petrographer has to begin with, the better the context for conducting the examination. Just as you wouldn't go to your doctor for a diagnosis without saying anything about the symptoms you're experiencing, you shouldn't send a core to a petrographer with no further information.

The kind of information you should provide includes whatever "symptoms" you observed—cracking, say—and when you first noticed them. You need to provide whatever information you have about the history of the project, the exposure conditions, relevant dates (for example, when the concrete was placed and when it first showed signs of distress), the location of the project, and any available documentation. Such documents as the concrete mixture design submittal, project specifications, and concrete delivery tickets could all prove useful.

Because you probably don't know—though you may suspect—what the problem is, you should err on the side of giving too much information rather than too little.

"Be sure to take a sample that includes the problem you're concerned about as well as a sample from a comparable area that doesn't have the problem."

Photographs can be helpful, although sometimes sketches—particularly when you are trying to find the cause(s) of cracking—are more useful. It's also good to include a drawing of the site or the structure showing where the photographs and the sample(s) were taken. If you are concerned about cracking, map the cracks on a drawing of the structure, slab, or pavement.

Generally, the petrographer will make a standard set of observations on each sample. In some laboratories, the petrographer will routinely conduct these observations before receiving any information about the context; in other cases, the information will come in before the examination begins or while it's going on. Any of these practices is acceptable so long as the petrographer's report is written in light of the contextual information.

Sampling

Ideally, an engineer or experienced field technician should decide where and how to take the samples for examination. Because of the cost of the tests, very few samples are taken compared to the amount of concrete they represent. It behooves you to make sure they capture the information of concern. There are no universal rules about where and how to take the samples, but there are some guidelines. Be sure to take a sample that includes the problem you're concerned about as well as a sample from a comparable area that doesn't have the problem. For example, if you are investigating the cause(s) of cracking, take a core centered on a crack and one nearby.

If you're investigating the delamination of a concrete overlay, take one core near the edge of a hollow-sounding area and one where the overlay seems well bonded to the substrate, to provide a potentially helpful comparison. In any case, document where you took the cores, preferably by sketching the approximate location on a drawing of the area and with photographs.

The samples you take will nearly always be cores rather than broken pieces found at the site. Fractured surfaces will necessarily represent the area that was weakest or where the stress was highest, not the typical material. Also, if there was something in the crack, it may fall out, become contaminated, or react with something in the air or the water. It's better protected within a more or less intact core.

Make sure the samples are large enough to do the tests you have in mind. It's not uncommon to conduct multiple types of tests on cores from the same site. Ideally, you won't do petrographic analyses on cores that have already been used for compressive strength testing, but if the cores are long enough you could cut slices of them before doing the compressive strength tests. In some cases, the only specimen available has already been used for compressive strength testing. If necessary, it could be stabilized with epoxy and examined petrographically. It will, of course, contain cracks induced by the testing. ASTM C457 and C856 have requirements for minimum sizes of specimens for examination.

Properly label and wrap the cores. The label should be clear, unequivocal, indelible, and preferably informative (not just a sequential number or letter). Write directly on the core (but not on a surface you plan to examine) and/or on the plastic bag you are using to hold the core. A core that is cracked or scaled or otherwise fragile should be taped (duct tape is ideal) on the outside of the bag to hold it together; don't put tape on the core itself. Another good way to protect the core is to put it into a cylinder mold of the correct size so that it doesn't rattle around; seal it with tape to keep it closed. If you aren't hand carrying the cores to the laboratory, you will need to pack them carefully to make sure they aren't damaged.

Be sure to include enough information with the samples themselves that the recipient knows what they are, where they were taken, what needs to be done with them, and who to contact. If the cores pertain to litigation or there is reason to believe that they may be involved in litigation at some point, the package should also include chain of custody forms.

Often, petrographic studies are not the only test methods being used to determine the cause or causes

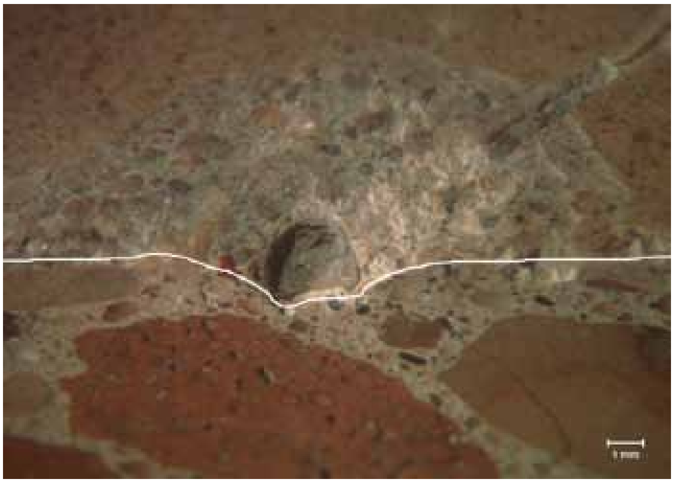


Fig. 1: Popout due to alkali-silica reaction (photographed at an angle). The white line delineates the boundary between the top surface (above line) and the polished surface perpendicular to it (below line). The offending shale particle can be observed in the base of the popout

of distress in the concrete. If other tests are being conducted, the petrographer should be informed. Sometimes the petrographer can cut the core in such a way as to allow the same core to be used for more than one test—for example, allowing sections on opposite sides of a diametral cut to be used for chemical analysis and petrography. Coordination between the petrographer and those conducting other testing is very helpful in keeping everyone informed and resolving any apparent contradictions in findings.

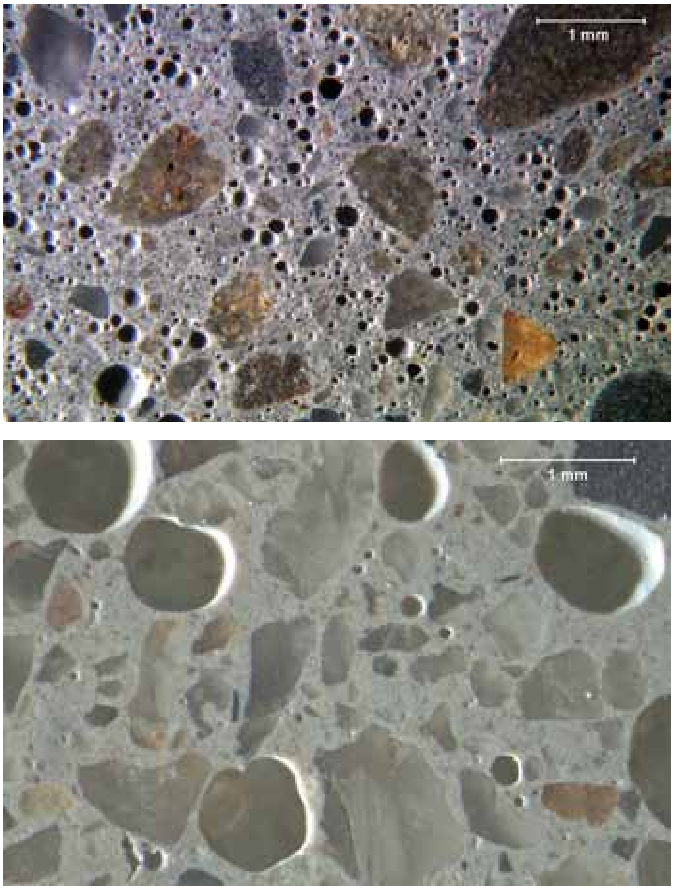


Fig. 2: The upper photograph shows a concrete with fine, well-distributed air voids consistent with freezing-and-thawing durability; the lower photograph shows a concrete with a few coarse air voids

WHAT'S IN THE REPORT?

Although the format and even some of the specific content of a petrographic report depend on the person or laboratory that produces it, the reports generally have similar contents. The background or introduction covers what the sample represents, where and when it was obtained, client information, and any other information supplied by the person who submitted the samples. Sometimes this section will indicate why a sample is being examined. Some laboratories include the main findings early in the report.

The report generally includes observations on overall sample dimensions—usually just length and diameter, but if there are two or more distinct layers they should be separately dimensioned; surface condition—intact, rough, smooth, deteriorated, coated, and any notable features observed, such as scaling or aggregate popouts (Fig. 1); reinforcement—whether any reinforcing bars or fibers are visible; and general physical condition.

Coarse and fine fractions of aggregates are usually described separately. Other observations on aggregates can include:

- Mineral types identified;
- Maximum size (coarse aggregate only)—note that this is based on observation of a cut surface, usually along a diameter, and may not capture the full size of the largest aggregate particle;
- Grading—this will be a qualitative observation that the aggregate appears well graded, gap graded, very fine, or very coarse;
- Angularity; and
- Distribution—whether the coarse aggregate appears to have segregated or is more or less evenly distributed within the concrete.

Observations on paste generally include:

- Air content (Fig. 2)—this could be visually estimated or, if ASTM C457 was performed on the same core, details of the air-void system parameters may be presented. If the durability to cycles of freezing and thawing is at issue, the full ASTM C457 analysis should be performed;
- Estimated proportion by volume—percent of the sample that is paste (not aggregate);

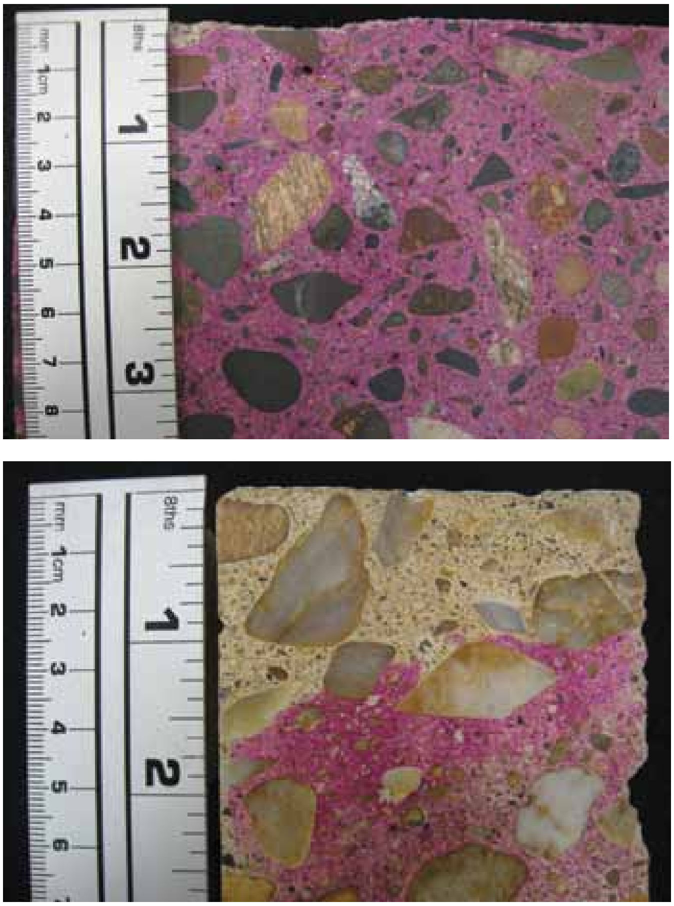


Fig. 3: Phenolphthalein turns deep pink if the pH is above about 9.5. The upper photograph shows a concrete with negligible carbonation, whereas the lower photograph shows a concrete that is heavily carbonated

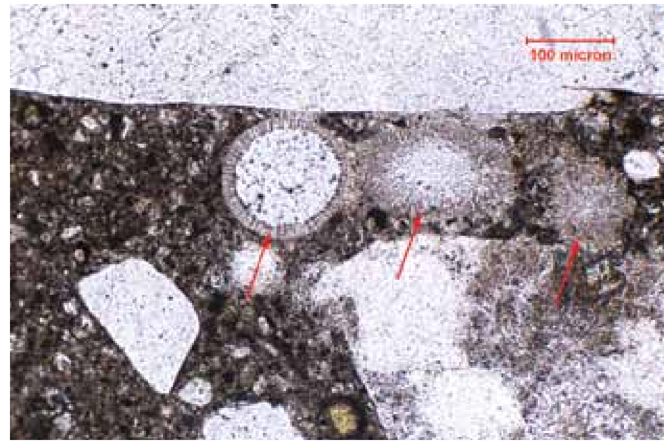


Fig. 4: Needle-shaped ettringite deposits line the air voids (indicated by red arrows)

- Carbonation—depth of carbonation and whether it varies near cracks. Carbonation is the reaction of calcium hydroxide in the hydrated cement paste with carbon dioxide in the atmosphere to form calcium carbonate. The pH of carbonated concrete is 8.5 or less[1]—much lower than that of uncarbonated concrete (which has a pH of 12 or more). The usual test method is to wet the cut surface of the concrete with phenolphthalein indicator, which turns a deep pink when it's in basic (high pH) solutions (Fig. 3). Carbonation depths can be an indication of the quality of the concrete—if the concrete is known to be relatively young and carbonation has proceeded well into the surface, it could be poor-quality concrete. It could also be an indication of the exposure conditions. Carbonation depths near cracks that are new relative to the age of the concrete may be significantly less than near those that formed early in the life of the concrete;
- SCMs—fly ash and slag cement are visible under the optical microscope; if present, there should be an estimated volume as a percent of the cement paste. Individual silica fume particles are too small to see under optical microscope, but agglomerations of particles may be visible;
- Paste-aggregate bond—whether the bond appears to be strong or weak; presence of bleed water voids or air-void clusters under coarse aggregate particles;
- Paste color—may suggest the presence of SCMs. In general, concrete with a higher *w/cm* is lighter than similar concrete with a lower *w/cm*. Uneven color could indicate insufficient mixing, multiple-stage batching, or retempering with water at the site;
- Hardness—qualitative indication of the strength of the paste;
- Microcracking—microcracks perpendicular to the original exposed surface indicate something about the quality of the curing. Other microcracks could indicate stresses or signs of deterioration, depending on their location and orientation;
- Deposits (Fig. 4 and 5)—if there are deposits in the cracks or voids, they should be noted and identified. Deposits of ettringite (Fig. 4) or calcium hydroxide indicate that the concrete was saturated with water at some point. Alkali-silica gel (Fig. 5) indicates the presence of reactive silica (generally from a susceptible aggregate) and saturation with water, probably over an extended time. Deposits of other materials indicate that some dissolved materials infiltrated from the environment;
- Bleed-water channels—indicate that the concrete experienced bleeding before setting;
- Estimated *w/cm*—by comparing a thin section of the concrete with a library of thin sections of concrete of known composition, the petrographer can estimate the *w/cm* within a reasonable tolerance (which should be

Fig. 5: Alkali-silica gel (red arrows) in voids near reactive gneiss particle

indicated in the report); typically it would be expressed as "estimated at 0.40 to 0.45"; and

- Degree of hydration—expressed as a percent. Three weeks of moist curing at temperatures between 20 and 35°C (68 and 95°F) would result in a degree of hydration of roughly 70%.[2]

All test methods used should be briefly described with reference to ASTM or other standards. If the methods are unique to that laboratory or company, they should be described in more detail. Other information might include the type of coolant (water or oil) used in the laboratory saw, whether thin sections were made, or whether electron microscopy was used to supplement the optical microscopy.

Some laboratories don't allow the petrographer to draw conclusions, leaving that to the engineer. Sometimes the evidence obtained by petrography is definitive on its own; sometimes it suggests more than one possibility that would require additional testing by other methods to pin down. Any conclusions should be well supported by the evidence presented. It's particularly helpful if the report includes photographs that support the conclusion.

SUMMARY

Petrographic methods can be among the most informative ones used in an investigation, whether that investigation is being conducted to solve a construction problem, conduct research, or help an expert witness formulate an opinion to present in court. To get the most out of the petrographic report, you need to provide as much information about the site and the history of the project as you can, obtain representative samples large enough for the anticipated tests, and properly label and pack them. You should also make sure the petrographer knows what issue is of concern and whether litigation is involved or expected.

Typically, a full petrographic examination can take several weeks, and the laboratory may have a considerable backlog of work ahead of yours. If you need an answer right away, let the petrographer know; it may be possible to take a quick look and give you a call, then follow up with the detailed report later. Sometimes, the quick look is enough to tell you what you need to know to make the correction or repair at the job site and move on with the work. When the full report comes in, you can decide what caused the problem and assign costs accordingly.

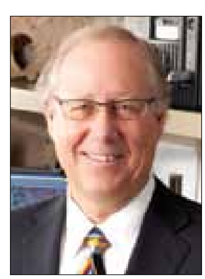
References

1. Taylor, H.F.W., *Cement Chemistry*, second edition, Thomas Telford Publishing, London, UK, 1997, 459 pp.

2. Kjellsen, K.O., and Detwiler, R.J., "Reaction Kinetics of Portland Cement Mortars Hydrated at Different Temperatures," *Cement and Concrete Research*, V. 22, No. 1, Jan. 1992, pp. 112-120.

Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors.



Richard D. Stehly, FACI, was Principal of American Engineering Testing, Inc., based in Minneapolis, MN, and was a licensed civil engineer in Minnesota and Wisconsin. He received his BS in civil engineering from the University of Minnesota. A member of ACI since 1980, he was elected President of the Institute in March 2010. He passed away suddenly September 18, 2010. During his short time as President, he championed several ACI initiatives in sustainable development. He served on the ACI Board of Direction, the Executive Committee, and numerous technical committees. He was also an officer of the ACI Foundation and Creative Association Management, ACI's for-profit subsidiary, and he served on the Editorial Review Panel of the U.S. Green Concrete Council.

ACI member **Adam J. Brewer** is a Petrographer at American Petrographic Services, Inc., based in Saint Paul, MN. He received his BA in geology from the University of Minnesota-Duluth in 2007. He is a member of the American Institute of Professional Geologists and the Minnesota Concrete Council.