THINGS PETROGRAPHIC EXAMINATION CAN AND CANNOT DO WITH CONCRETE

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ABSTRACT

Petrographic examinations of concrete offer relatively rapid means of diagnosing most concrete problems. Presented is a brief overview of some types of features that can be expected to be revealed in a reasonably short period of time. Also discussed are some features that the petrographer is often asked to do which which cannot be determined petrographically during routine problem-solving examinations.
The emphasis is on practical applications.

SOMMAIRE

Les examens pétrographiques des bétons offres des manières des faires rapids relativements pour déterminer la plupart des problèmes des bétons. Présenté ici est un sommaire bref de quelques des caractères des traits comme on doit s'y attendre être révélés sous peu raisonnablement. Aussi discutés sont quelques des caractères qui le pétrographeur est demandé frequement à faire mais qui normalement ne peut pas se faires pétrographiquement pendant ces examens routines pour résoudre les problèmes.
On accentuons les applications pratiques.

INTRODUCTION

Petrographic examination of concrete-making materials ideally is a quality control or problem preventing operation. Components considered as likely to create distress or other problems when used in concrete can often be identified and additional testing recommended hopefully before marketed concrete is produced, shipped, and placed.

Generally, these examinations are allowed to proceed at some reasonable pace.

Petrographic examinations of hardened concrete, on the other hand, are most often concerned with "after-the fact" situations. The in-place concrete has deteriorated in some manner or someone has reasons to be concerned about its integrity or durability.

Only rarely then does the concrete petrographer have the luxury of a "reasonable pace". More likely than not his client needs answers the day before the cores were put into the mail.

Petrographic examinations of hardened concrete most often are problem-solving or "whose fault was it ?" situations. (No one ever sends good concrete to the petrographer, knowing it to be good beforehand).

An owner of a spalling bridge deck or map-cracked pavement is most likely to want to know, "why ?", "How bad is it ? ", "Can we live with it ?", or "how can we prevent it next time?". This latter point can be particularly delicate should the project owner be worrying that he might be pouring the same problem at the same time the petrographer is unpacking cores from previous projects.

Consequently, petrographic examinations of hardened concrete most frequently are expected to provide some definitive answers in rather limited time frames.

It is here that petrographic examinations are unexcelled among the various investigative choices available because a competantly-done petrographic examination can yield more information about a sample of concrete in much less time than is usually required by other approaches.

Without compromising accuracy or professional quality within about one day an experienced concrete petrographer, with adequate laboratory facilities, should develop enough information about a particular sample of concrete to provide some answers to the original question. If he does not then know the causes of the problem he certainly should know many things that were not related to the problem.(It should perhaps be added that to a petrographer committed to his client's interests nothing is sacred about an eight hour day).

CAN AND CANNOT

The concrete petrographer is frequently asked to identify things that can and cannot be expected from a petrographic examination alone. In setting up these two categories specific things have been listed which are considered to be determinable or not in the normal day-to-day problem-solving efforts of petrographic examinations of concrete. The issue here is the practical work as opposed to the academic or theoretical. "Can" and "cannot" here refer to practically-determinable issues- within a relatively short period of time.

A number of specific items are listed to illustrate each category. These are not listed in any particular order of priority. Many of these items will be illustrated by actual photographs.

Care should be taken not to take individual illustrations out of context.

Rarely does a single feature or criteria fully account for a particular concrete problem. Not uncommonly one finds evidence of excessively-high air entrainment, excessively-high water-cement ratios and inadequate curing in a single sample of concrete where low compressive strength was experienced. No one of these criteria in and of itself was singularly responsible.

Also, a single feature can be subject to different interpretations. Air void clusters are commonly associated with retempered air-entrained concrete. However, air void clusters can also be observed in poorly-mixed air-entrained concrete(particularly with late additions of air-entraining agent), associated with certain very vesicular aggregates which had been used at less than saturated-surface dry conditions,and are common with contaminants of gas -generating powders such as aluminum metal. Air void clusters also are sometimes observed when large doses of certain potent surface active chemical admixtures are added to previously mixed air-entrained concrete.

The whole concrete sample must be considered by evaluating all of its particular features collectively in order to arrive at conclusions relating specific observations to specific problems.

As a variety of features or criteria are presented this paper should be considered as a sort of overview intended to illustrate a rather wide range of subjects. Some are common while others are much less so. Most any one of these individual subjects could be singled out for more detailed study and individual presentation as a technical paper

PETROGRAPHIC EXAMINATIONS OF CONCRETE

CAN

1. Evaluate proportioning

Relative amounts of sand, coarse aggregate, air , and cement paste are readily recognized. Each can be determined quantitatively without having to destroy the sample. Quantitative measurements would be done by point count or by linear traverse methods(1). Note that the proportions of sand and coarse aggregate can be separately determined only if the two aggregates are lithologically different. The criteria is composition rather than particle size.

2. Evaluate mixing

Uniformity of composition indicates effective mixing of the ingredients. The presence of sand streaks, aggregations of coarser particles with very small amounts of mortar separating them, clusters of air voids, lumps or streaks of relatively unhydrated portland cement, or significant variations in density of the mortar are suggestive of inadequate mixing.

3. Evaluate compaction

Adequately-compacted concrete will contain only few areas occupied by large entrapped air voids and these are of small size. The concrete is homogeneous. Honeycombing, or excessive amounts of large open gaps, is commonly noted with poorly-compacted concretes.

4. Detect segregation/over-vibration

Concrete that has been segregated will show an accumulation of particles of coarse aggregate near the bottom with conspicuously less coarse aggregate above this. Severe segregation can be caused by over-vibration or by use of excessively wet concrete mixes (or both!). Where excessive vibration was a major factor the upper portions of the concrete commonly show conspicuously less air content and an enrichment of cement and aggregate fines near the surfaces of slabs.

5. Determine air content

Concrete air content is quantitatively determined by the point count or linear traverse methods on prepared slabs (2).

6. Determine parameters of the concrete air void system

This is an extension of the procedure used to determine air content and provides more useful data on the probable freeze-thaw durability of the concrete. Data derived from this determination frequently are adequate to explain why partieular concretes failed during freezing and thawing. The procedures are described in detail in reference (2).

7. Evaluate curing/carbonation

Well-cured concrete is characterized by the presence of a rather hard and relatively impermeable surface encrusted with a superficially-thin coating of calcium carbonate. Viewed microscopically, this coating most often appears as a glossy white or grayish film which uniformly covers the surface. It is well-bonded to the surface. Little,if any, of the cementitious matrix below this surface skin shows evidence of carbonation-or conversion of cement hydrates to calcium carbonate. The interior matrix is hard, of uniform color (usually grayish or pale yellowish), and shows a luster that is best described as sub-vitreous.

Poorly-cured concrete, on the other hand, is characterized by the presence of a soft, dusty surface, chalky-textured interior cementitious matrix, and abundant calcium carbonate in the matrix at depth. Where the concrete was allowed to dry out very quickly, and particularly in cold weather, one finds an unusual abundance of residual grains of unhydrated portland cement at depth and these grains are enclosed by a soft, chalky,and distinctly carbonated cementitious matrix. The color of such cementitious matrices is most often a pure white or yellow-white. Slow-setting concretes of low strength as a result of excessively high water contents are particularly apt to be extensively carbonated at depth with the cementitious matrix being distinctly chalky in texture. High water-cement concretes are much more permeable to ingress of atmospheric agents than are those of lower water-cement ratios.

Carbonation is a result of chemical combination of atmospheric carbon dioxide with cement hydrates and particularly so with calcium hydroxide released from portland cement during hydration. Carbonation is inevitable but in well-cured concretes it is largely restricted to the finished surfaces where it consists of the relatively impermeable coating noted above. In this case it is probably beneficial in helping to seal the concrete from destructive agents.

8. Evaluate water content

Concrete made with excessively-high water-cement ratios is petrographically characterized by the presence of but trace amounts of residual grains of unhydrated portland cement, and at relatively young age, a distinct white mottling aspect of the cementitious matrix (when examined microscopically at a magnification of about 50 diameters), relative abundance of fine microfractures randomly distributed throughout the matrix, conspicuous bleeding channels oriented at right angles to the surface of non air-entrained horizontal slabs, abundance of colorless to white hexagonal platelets(mica-like) of calcium hydroxide (portlandite) as secondary deposits in air voids and bleeding channels, chalky-textured white to very pale yellow cementitious matrix, and extensive carbonation of the matrix. Crazing and dusting of the concrete surface and abundance of drying shrinkage cracking are commonly associated with high water-cement ratio concretes. Portlandite deposits in air voids may be especially abundant in voids nearer the concrete surface. Another aspect of such concrete is an apparent low density which is often noted in hand specimens.

Concrete made with inadequately-low water-cement ratios (and these are <u>very</u> rare) are characterized by an abnormal abundance of residual grains of unhydrated portland cement, at a relatively late age, are friable (have sandy, poorly-cemented and harsh textures) and typically show considerable lack of compaction and homogeneity. Some "dry-packed" concretes and grouts show such features.

9. Evaluate degree of cement hydration

Unhydrated portland cement particles are readily recognizable in hardened concrete and their relative abundance can be evaluated. In addition to situations as noted above, concrete which is allowed to rapidly dry out (particularly so in cold weather) can show an abnormal abundance of unhydrated cement. Large overdoses of potent retarding chemical admixtures can yield the same characteristic.

10. Detect coarse-ground cement

Occasionally a low strength and excessive retardation problem can be traced to use of coarse-ground portland cement in the concrete. In these cases the cementitious matrix will show a distinct "black" mottling aspect when examined with a stereoscopic microscope at a magnification of about 50 diameters. The matrix appears as though it might have abundant grains of black pepper disseminated throughout it.

11. Identify aggregates as to rock and mineral composition

This is self-explanatory. It is the closest most concrete petrographers get to the petrography they studied in school.
Components for the most part can be identified "on sight" by an experienced petrographer during the course of examining prepared slabs of concrete. Small portions of aggregates can be scratched with a needle and powders so obtained then examined under transmitted light with the petrographic microscope to supplement visual observations. Thin sections are rarely of much use as a routine technique. The additional time and expense in preparing thin sections are rarely justified or needed. Obviously, in particular situations, thin section work may be required.

12. Detect use of lumpy cement

Concrete made with "old" cement pre-hydrated in storage so as to contain hardened lumps is likely to be described as having been "excessively retarded", experienced a "slow strength gain", or had developed unacceptably low values of compressive strength. Severe bleeding and workability problems may also have been reported. Use of such cement in concrete is petrographically recognizable by the presence of abnormally large aggregations of hardened cement particles scattered throughout the mortar. Most frequently these lumps are from about 3 to 6 mm in diameter although much larger masses are not rare. These lumps are usually dark gray in color but may also be of much lighter shades of gray where the hydrated cement was also carbonated in storage.

The presence of any substantial numbers of cement lumps in a prepared slab of concrete is symtomatic of a larger problem. As with the concrete problems described above most probably the lumps indicate hydration of the cement in bulk.

The lumps of cement here are not to be confused with lumps derived solely as a result of "pack-set". The pack-set lumps are much softer and less likely to survive breakdown during the concrete mixing operation.

13. Detect retempering

For a variety of reasons concrete may arrive at the jobsite too stiff to be placed. The concrete has already "set" to some degree. When water is added at the jobsite (or enroute) in amounts substantially greater than called for in the mix design, and that concrete is remixed to make it workable, it is said to be retempered. There are many gradations.

How stiff was the concrete ? How much extra water was added ? Was the re-mixing adequate to thoroughly break up and "re-plasticize" the concrete ? Clearly the concrete as placed can be quite different from the mix design previously selected and approved for the project at hand. The water-cement ratio alone is no longer that of the approved mix.

Petrographic evidence of retempering includes,the presence of dark gray coatings or "veneers" of mortar or portland cement paste on coarse aggregate particles, lumps of dark gray mortar or concrete scattered throughout a matrix of much lighter color, clustering of air voids in air-entrained concrete, and marked variations in density across the sample slabs being studied. Evidence of high water-cement ratio , as noted above, is commonly associated with one or more of these features. More often than not all of these features are present in a single sample of the concrete.

14. Detect presence or absence of fly ash

Fly ash is readily detected by examination of pulverized cement paste in transmitted light with the petrographic microscope. A magnification of about 400 diameters is ideal. Fly ash is characterized as distinctly spherical globules which are optically isotropic (amorphous; glassy) and which vary from colorless and transparent, through various shades of transparent yellows and browns, to black and opaque. The characteristic spherical form is unique among commonly-encountered concrete ingredients. Flocculent opaque particles of dark brown-black to black carbon are frequently associated with fly ash. The index of refraction of fly ash is probably too variable to be of much use as a diagnostic criteria.

15. Detect presence or absence of granulated blast furnace slag

Granulated blast furnace slag in concrete is recognizable as shard-like particles of glass (optically isotropic) when pulverized cement paste is examined in transmitted light with the petrographic microscope. As with fly ash, a magnification of about 400 diameters is ideal. Commonly, the particles vary from colorless and transparent to various shades of yellow and brown, most of which are also transparent. These particles are usually much larger in size than grains of unhydrated portland cement from the same concrete sample. Published data show a range in index of refraction of about 1.635 to 1.67 (3).

Granulated blast furnace slag fluoresces bright orange to orange-red when viewed in the dark under "short-wave" (ca 2537A) ultraviolet illumination, well-filtered to remove visible radiation. Fresh concrete containing substantial amounts of granulated slag in the cementitious matrix also show this same fluorecence. The particular color of fluoresence is quite diagnostic for granulated blast furnace slag. The fluorescence disappears as the concrete ages.

Concrete containing substantial amounts of granulated blast furnace slag in the cementitious system is commonly of a characteristic dark green or blue-green color, particularly seen on freshly-broken surfaces. These colors fade out and disappear altogether as the concrete ages.

Concrete containing substantial amounts of granulated blast furnace slag in the cementitious system emits the universally unmistakable odor of hydrogen sulfide when freshly broken or when wetted. This feature also disappears as the concrete ages.

Older stocks of granulated blast furnace slag, or of slag-cement mixtures, commonly show a substantial degree of devitrification of slag particles. This is recognizable as varying levels of birefringence when viewed under crossed polarizers with the petrographic microscope.

16. Detect use of ground limestone, etc, as cement extender

Many things are used to extend cement. The choice in some cases appears to be based largely on the type of materials which happen to be locally available at the time. Use of ground limestone in this manner is not uncommon outside of the United States. If the particular rock used has some distinctive petrographic feature, such as an abundance of well-crystallized calcite or dolomite rhombs, or oolitic grains, then it may be possible to identify its presence in cement paste. More often, however, limestone extenders are easily "lost" in the cement paste- and particularly so where the concrete also contains carbonate aggregates.

17. Detect cement alkali-aggregate reactions

Certain rocks, minerals, and artificial glasses can chemically react with the alkalis sodium and potassium as are released from hydrating portland cement. As a result of these reactions the affected aggregate particles expand in the hardened concrete resulting in severe fracturing. Extensively-affected concrete slabs are characterized by development of conspicuous map-cracking on exposed surfaces.

Given the "right" combination of aggregate, available alkalis, and moisture such concretes can in effect become self-destructive.

It is therefore particularly imperative that the concrete petrographer insure himself that he has identified cement alkali-aggregate reaction where it has occurred or the presence of aggregate components likely to be subjected to future such reactions.

Materials known to be potentially deleteriously reactive with cement alkalis include opal, chert (particularly those that are opaline), acidic volcanic glasses, artificial glasses, acidic to intermediate volcanic rocks with glassy or cryptocrystalline groundmasses, cristobalite, and tridymite.
Less-commonly evidence of alkali-aggregate reaction is observed with some phyllites, some gneisses, and some quartzites.

Some carbonate rocks are reactive with cement alkalis. Petrographic criteria for identifying reactive varieties are less well-defined than those for the materials shown above. Extremely fine-grained dolomites containing prominent amounts of acid insoluble residues are particularly suspect.

Other types of aggregate components are listed in published work (4).

Petrographic evidence of alkali-aggregate reactions include, presence of reaction rims (zones of lighter or darker color encircling particular types of aggregate. Care must be taken to distinquish these from weathering rims. Weathering rims normally completely enclose the aggregate particles while reaction rims may abruptly disappear at points where the aggregate comes into contact with air voids.), presence of alkalic silica gel as fracture fillings in aggregates, in the mortar, or as linings or fillings of air voids, or as exudations on the concrete surface, radial fracturing of specific varieties of aggregates, and open fractures within aggregates (not always associated with gel deposits). Certainly the most conclusive evidence is the presence of alkalic silica gel and particularly so when this can be traced to components known to be potentially reactive. It is not uncommon, for example, to trace alkalic silica gel deposits in air voids through fractures in the cement paste,and into fractures within opaline rocks.

Abundance of gel is a time dependant feature. It may not be evident in concrete of fairly young age. In cases where alkali-aggregate reaction is suspected but gel deposits are not evident, the following test may be helpful; the prepared concrete slab is placed on its side (one of the prepared sides) in a shallow tray. Water is added to the tray until about 75-80 percent of the slab is immersed. This set-up is allowed to stand undisturbed overnight. The slab is carefully removed from the water and excess water is removed by blotting with absorbent paper towels. The slab is then transferred to the stage of the stereoscopic microscope whereupon the air surface of the slab is examined(the surface above the water level). Evidence of alkali silica type reactions consists of tiny , fresh exudations of gel onto the dry surface of the concrete. These appear as miniature dimples on the surface and most frequently consist of gel that is soft (like semi-hardened candle wax), translucent, and white to yellowish in color. After drying in the lab air for some period the gel deposits usually become hard and porcelaneous in appearance. This test serves to mobilize gel already present in the cement matrix and bring it to the surface where it is readily recognized.

Alkalic silica gel is optically amorphous. As with most gels its water content is variable. As a result the index of refraction is variable. One publication shows a range of 1.46 to 1.53 (5).
Old gel deposits may show birefringence due to partial carbonation.

Fracturing of aggregate particles not associated with gel deposits, or with reaction rims, as is common with some reactive carbonate rocks, can be caused by means other than alkali-aggregate reaction. Freezing and thawing is a common cause, for example. It is more difficult to relate such simple fracturing to alkali-aggregate reaction than would be the case where other evidence of alkali-aggregate reaction also were present.
Testing of questionable aggregates in mortar bars,or by other direct means, is usually necessary to establish alkali-aggregate reactivity (6),(7).

18. Detect use of masonry cement

On occasion masonry cement gets into concrete either as the sole cement or as substantial replacements for portland cement. Concrete produced in such fashion usually is characterized by a very conspicuous white color, very high air content, presence of fly ash (in non- fly ash design concrete), and "superabundance" of portlandite crystals in air voids, fractures, and on exposed surfaces. No one of these features alone is specific for use of masonry cement but all taken together are strongly suggestive.

19. Detect freezing of plastic concrete

Concrete that freezes while it is still plastic will often develop ice crystals throughout the matrix. When this concrete hardens casts of ice crystals remain. They are typified as sub-radial clusters of linear "fractures". As they are of very shallow depth they are quite fragile and frequently are worn away. They persist, however, in sockets of large coarse aggregate particles and can be observed by carefully plucking out these particles. This is not particularly difficult as such concrete is apt to be quite fragile. Ice crystal casts are rarely observed in lean,sandy concretes.

20. Detect freeze-thaw distress of concrete matrix

Concrete damaged by repeated cycles of freezing and thawing usually will show scaling of the surface matrix together with an abundance of internal fracturing. Fractures are oriented sub-parallel to the finished concrete surface. The fractures are sharp-walled and generally pass around particles of coarse aggregate.
Inadequate air entrainment is the most common cause for such failures.

21. Detect freeze-thaw distress of aggregates

Certain finely-porous aggregates, as some weathered cherts for example, expand with such force during freezing and thawing,while in a critically saturated condition, as to fracture enclosing concrete. With particular aggregates this can take place with relatively few cycles of freezing and thawing. Where these particles are near the concrete surfaces popouts often result. In these cases the matrix is often fractured beyond the walls of the popout. Clay-ironstone concretions are common sources for such failures. Generally,weathered and porous aggregates are likely to fail during freezing and thawing.

On the surfaces of prepared concrete slabs evidence of freeze-thaw distress of aggregate commonly consists of a series of microfractures radiating out from affected particles into the enclosing mortar.

On the concrete finished surface each popout usually has some trace of the affected aggregate remaining in the bottom of the socket. Commonly,fresh fracture surfaces of cherts, clay-ironstone concretions, laminated argillaceous carbonate rocks, porous sandstones, or shales may be found in the popout sockets. Fragments of these aggregates may also be found lying loose on the concrete surface near the popout.

Air entrainment of concrete can not be expected to provide freeze-thaw durability if the concrete also contains aggregates which are not durable to freezing and thawing.

22. Recognize unsound shales

Some shales fail during freezing and thawing and others by simple wetting and drying. In the latter case the particles shrink away from the cement paste on drying. An open gap completely surrounding the particle is common. More often than not close examination of such particles will also reveal the presence of microfractures splitting the grains open and extending into the enclosing cement paste. Shales such as this are common in many sand aggregates in the United States. Small, sand-size popouts are common where these sands are used- even in advance of winter weather.

23. Detect sulfate attack

One of the most conspicuous features of concrete damaged by chemical attack of soluble sulfate salts is an abundance of ettringite crystals filling air voids and fractures. These secondary deposits usually consist of microscopic tufts of white, acicular or "silky" crystals. Clusters of ettringite crystals in air voids commonly appear like small tufts of cotton. Where the ettringite results from sulfate attack it is commonly associated with tiny colorless crystals of gypsum when sodium sulfate is involved, or of both gypsum and brucite where magnesium sulfate is involved.

Ettringite is ubiquitous in concrete. If one looks closely enough he is apt to find some ettringite in most any concrete, particularly as secondary deposits in air voids.Normally, these deposits are also associated with calcite and or portlandite. Neither gypsum or brucite are present.
In concrete extensively fractured by any cause ettringite may appear to be unusually abundant so as to imply possible sulfate attack.
A chemical analysis for sulfate content of such concretes may be helpful.

Concrete extensively attacked by sulfate salts commonly shows a soft, powdery cement paste with a distinctly chalky texture. Extensive fracturing is common.

24. Detect use of very dirty aggregate

Concrete made with very dirty aggregate usually shows a pale yellowish or brownish cast and dull luster. Careful removal of coarse aggregate grains will usually reveal pebble sockets containing dull,mud-colored coatings of clay minerals originally coating the aggregate. Coarse aggregate particles in such cases are usually poorly-bonded to the mortar and can readily be removed.

25. Detect severe bleeding

A slab sawn vertically (at right angles to the concrete surface) from horizontal concrete slabs which have experienced severe bleeding can be expected to show bleeding channels as narrow, open fissures concentrated alongside particles of coarse aggregate and oriented at right angles to the surface as cast. Large voids will be conspicuously oriented towards the surface. Both voids and fissures may contain secondary deposits of portlandite. These deposits tend to be conspicuously concentrated in the upper portions of the concrete.

Evidence of severe bleeding is common in excessively-wet non air-entrained concrete.

26. Detect contaminants

Although this is a near limitless category, certain contaminants that are not uncommon include lumps of free lime, CaO, or magnesia, MgO,associated with carbonate aggregates, plant fragments (woody or other vegetative trash commonly associated with uncleaned natural aggregates),and fragments or granules of aluminum metal. The lime and magnesia noted above can occur when carbonate aggregates are, for example, shipped in the same vessels which previously carried burned carbonates from the same source. These materials are very reactive (MgO can be unpredictably reactive) with water and substantially increase in volume when the corresponding hydroxides are formed. Aluminum contaminants are almost invariably enclosed with myriads of tiny gas voids formed from hydrogen gas evolved by the reaction of the metal with cement alkalis. Fragments of artificial glass are widely found intermixed with natural aggregates. Artificial glass may be deleteriously reactive with cement alkalis.

27.Detect adverse galvanic action

One still encounters cores of concrete which contain, in a single core, imbedded steel reinforcement, copper plumbing, and aluminum conduit. Though the steel and copper are very commonly imbedded, and apparently with success, it is another matter with aluminum.

Two dissimilar metals imbedded in an electrolyte and in electrical contact with each other at some point can induce galvanic corrosion- an electric cell is formed. The extent or severity of corrosion or failure is related to many factors which include, nature of the metals (their relative positions in the electromotive series of metals) , the conductivity of the electrolyte, and availability of moisture.

Where aluminum metal is involved galvanic corrosion results in a build-up of white to yellowish, gel-like deposits around the aluminum. The metal thus effectively "swells" in volume. Significant expansive forces can be developed.

28. Evaluate bonding in multi-course applications

Slabs taken from cores cut vertically through multi-course concrete floors often yield considerable information relating to bonding of each course. Evidence of poor preparation of the base course is indicated by the presence of an essentially flat surface, with little coarse aggregate projecting upwards into the upper course, and dessication of the cement bond coat or the underside of the upper course. The latter feature is common where the dry, absorptive base concrete was not saturated with water prior to application of the upper course, or topping.Failure of resin-type bond coats is evidenced by open gaps between either or both concrete courses, or extensive fracturing of the resin. The resin may also be found to consist of soft, waxy material not adequately polymerized.

29. Supplement chemical analyses

When most any type of failure,or sub-standard performance, of concrete occurs it is common for someone to request a chemical analysis of the concrete to determine if the cement content was in accordance with the mix design. Samples are collected, pulverized, and digested in acid in order to dissolve the cement. The original cement content is then calculated based on weights of recovered silica, SiO_2, or lime,CaO, or both.

Petrographic examination of portions of the same sample, prior to digestion, can often be helpful in such cases by identifying aggregate components which are likely to contribute soluble lime and or silica to these analyses. The chemist can then make appropriate corrections.

If the concrete was made with a cementitious system containing substantial amounts of fly ash or granulated blast furnace slag in lieu of some fraction of portland cement, these materials may also be decomposed by the acid digestion, in whole or in part, and contribute soluble silica and or lime to the analysis. Petrographic examination can identify the presence of these components in the concrete before digestion is begun.

Concrete containing substantial amounts of granulated blast furnace slag, will, on digestion with acid, liberate very odoriferous volumes of hydrogen sulfide, which the chemist should readily detect.

30. Evaluate discoloration or staining

A little iron can go a long way in discoloring concrete. Certain pyrites and marcasites are well-known to produce yellow, yellow-red, or deep rust-brown stains on concrete..Trace amounts of naturally-occurring bituminous or asphalt-like hydrocarbons are partially dissolved by cement alkalis, bleed to the concrete surface, and on weathering yield yellow to brown stains. Some carbonate aggregates contain bitumens which will be leached out as above and produce stains. The common practice of cutting post-tensioning steel cables with incandescent flames generates small air-born globules of metallic iron or iron oxides which readily attach themselves to nearby concrete surfaces. Small patches of yellow or rust-like staining then develop as these droplets weather and leave no trace as to the origin of the staining.

Use of air-cooled blast furnace slag as concrete aggregate often results in complaints about development of dark green or blue-green patchy areas on concrete surfaces. Apparently, such staining is to be considered normal and in time it will fade out. Petrographic advice in these instances can be useful in preventing needless replacement of such concrete and alleviating distress of the project owner(s).

PETROGRAPHIC EXAMINATIONS OF CONCRETE
"CANNOT"

1. Determine the type of portland cement used (ASTM C 150 Types 1,2,3,etc)

This is a question frequently asked of the concrete petrographer. An experienced concrete petrographer might, however, at least suspect use of Type 5 cement due to the unusually dark color characteristic with this particular one. Pozzolanic, fly ash, or granulated blast furnace cements can be recognized but the particular type of portland cement used with them cannot. The issue here is detection in hardened concrete.

2. Determine quantitative amounts of cement, water, fly ash, or granulated blast furnace slag

As regards the cement content a petrographic examination may indicate that it appears to be "low" but the weight actually used cannot be provided. Fly ash and granulated blast furnace slag, as previously noted, are detectable in hardened concrete by petrographic means but it must be considered that those particles so recognized are those that were not "consumed" in the hydration process. Even if a concrete petrographer felt confident that he could determine fly ash or granulated blast furnace content by, for example, a point count analysis of representative portions of the pulverized cement paste under the petrographic microscope,he is only counting the "non hydraulic" fraction. He cannot identify particles converted into hydrates, certainly not by most practical means.
Excessive water contents can only be recognized as "excessively high water-cement ratios", as noted earlier. Kilograms of mix water cannot be given.

3. Detect use of chemical admixtures

One may feel obliged to report that, for example, the presence of an apparent excess of unhydrated portland cement was due to an overdose of a particular chemical admixture, but the techniques he uses to prove this are not likely included in the usual petrographic repetoire.

4. Determine cause for excessive retardation of concrete

Exceptions would include cases where coarse-ground cement or excessive amounts of mineral admixtures were used. Again, simple cold weather alone is quite capable of retarding concrete and in the absence of ice crystal casts no reliable petrographic criteria are likely to be found in the concrete.

5. Determine who added that extra shot of water to the concrete that no one ever seems to know about.

This is self-explanatory. Retempered concrete is rarely documented but it happens nevertheless. Only the courts have the expertize of determining who did the actual deed.

6.Determine whyconcrete with 6% air at the plant only shows 1% air in the scaling core

One could write volumes on this subject. When a petrographic examination of hardened concrete determines only 1% or so air content the concrete petrographer can only conclude that the concrete was not air-entrained. The only air-entrainment that matters, where freeze-thaw durability is concerned, is that that winds up in the concrete in place. The concrete petrographer is not likely to have available to him a sample of the same concrete as it left the plant. If he has such a sample- and it is not impossible if someone just happened to have a test cylinder available- it is not unlikely that he finds the concrete produced at the plant also was not air-entrained.

If the concrete as mixed was, in fact, air-entrained as designed, and the concrete as placed was not, there are many possible explanations- none of which are likely resolvable by petrographic examination alone.

7. Determine type of air-entraining agent that was used

A petrographic examination can identify concrete as air-entrained or that is not air-entrained. By determining that the air void system parameters are in the range generally accepted as satisfactory for freeze-thaw durability he may also conclude that an effective air-entraining agent was used. He cannot, by petrographic means, determine the chemical identity of the air-entraining agent.

CLOSURE

An attempt has been made in this paper to illustrate some of the great variety of determinations that can be expected from examinations of concrete by an experienced concrete petrographer. No such paper can be all-inclusive. The next sample of concrete which the petrographer sees is sure to present some feature not described and perhaps never seen before. Consequently, no concrete petrographer is likely to feel confident that he already knows all that he may ever need to know in this field. The next sample is certain to prove him wrong.

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(2) ASTM Standard Practice for Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete, C 457-82, ASTM Annual Book of Standards, Part 14, Concrete and Mineral Aggregates, 1982.

(3) Lea, F.M., The Chemistry of Cement and Concrete, Third Edition, pp 465, Chemical Publishing Company, Inc., New York, 1971.

(4) ASTM Standard Practice for Petrographic Examination of Aggregates for Concrete, C 295-79, ASTM Annual Book of Standards, Part 14, Concrete and Mineral Aggregates, pp 220, 1982.

(5) ASTM Standard Recommended Practice for Petrographic Examination of Hardened Concrete, C 856-77, ASTM Annual Book of Standards, Part 14, Concrete and Mineral Aggregates, Table 6,pp 552, 1982.

(6) ASTM Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method), C 227-81, ASTM Annual Book of Standards, Part 14, 1982.

(7) ASTM Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method), C 586-69, ASTM Annual Book of Standards, Part 14, 1982.

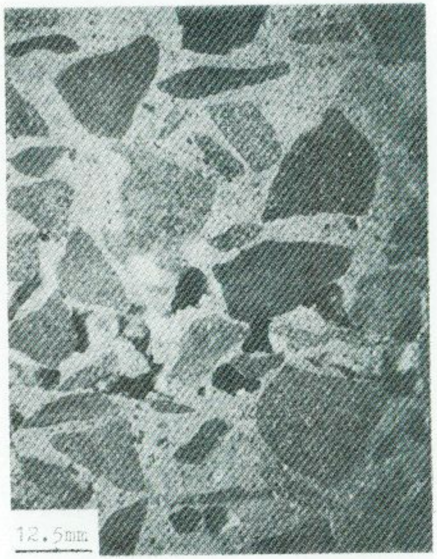

Figure 1
Poor Compaction."Honeycombed"

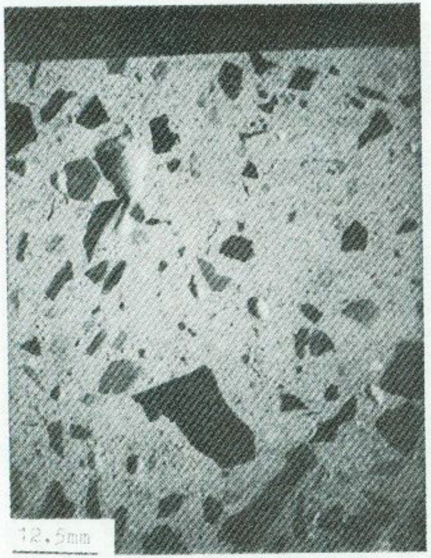

Figure 2
Segregation

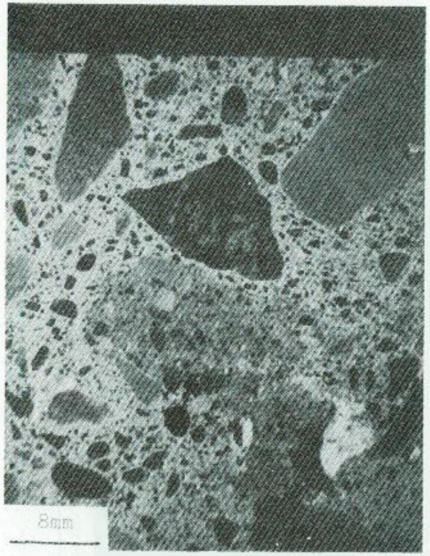

Figure 3

Retempered concrete. Note dark lump of mortar near center

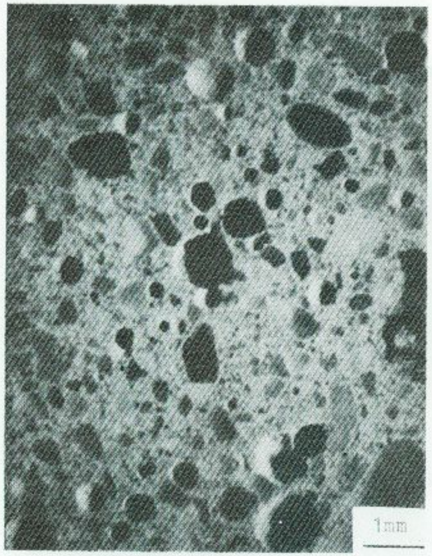

Figure 4

Retempered concrete.Air void clustering

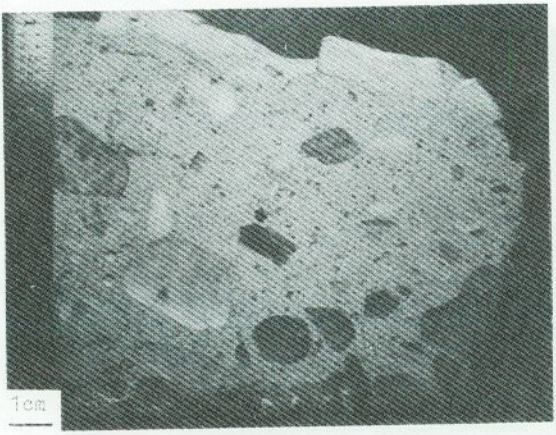

Figure 5

"Dusty" floor. Laitence is about 1.3 cm thick. Note also extreme segregation of coarse aggregate

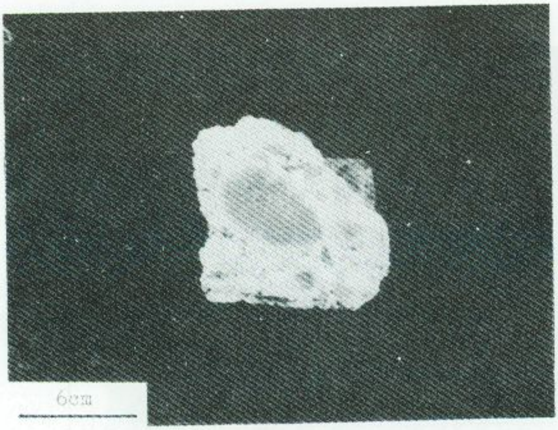

Figure 6

Concrete made with lumpy cement. Dark mass in center is a lump of cement.

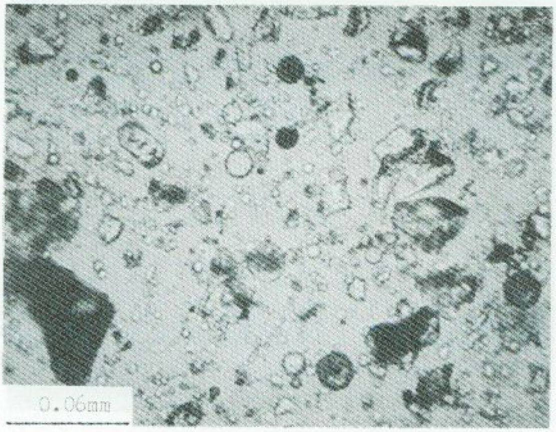

Figure 7

Fly ash in portland cement. Spheres are fly ash while angular grains are unhydrated portland cement

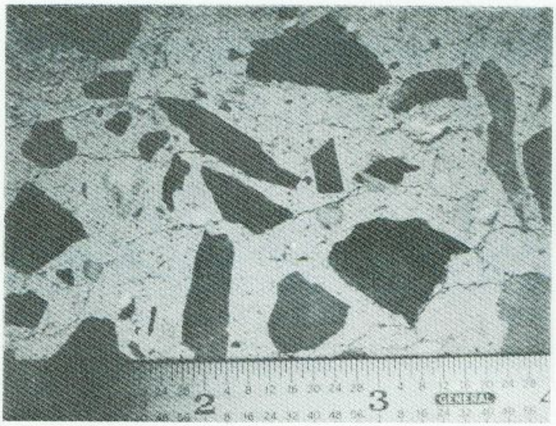

Figure 8

Freeze-thaw damage of concrete. Scale is in inches, Concrete was not air-entrained.

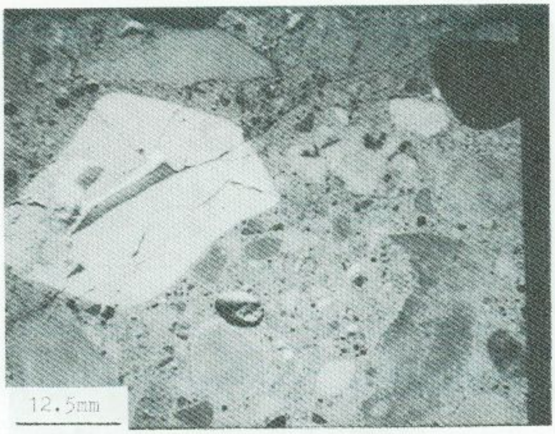

Figure 9

Freeze-thaw deterioration of aggregate. Large white grain at the left is extensively fractured with fractures extending into the cement matrix

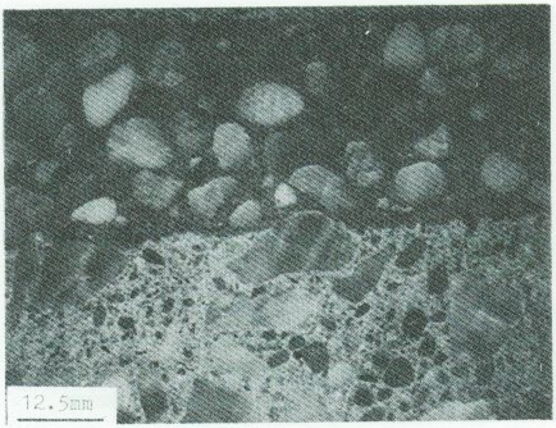

Figure 10

Two-course floor. Pea gravel topping on concrete base. Excellent preparation of surface of concrete base shown by penetration of its coarse aggregate into the topping.