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Chapter 11—Petrographic Examination

Petrography is the scientific description of the composition and texture of rock, including the systematic classification of rocks. Petrographic examination of hardened concrete—a man-made rock—is the examination of concrete by the techniques used in petrography to determine the formation, composition, and internal structure of the concrete and to classify it as to its type, condition, and serviceability.

This paper is intended to show that petrographic examination provides information useful in evaluating hardened concrete, to note the problems inherent in its use, to outline what it involves, to describe the kinds of information that it can produce, and to show how this information can be applied.

The questions that materials testing and evaluating tries to answer are: (*a*) "How will this material behave in use?", (*b*) "Why did this material behave in use in the way it did?", and (*c*) What can be anticipated as to the future service of this material?" The first question is never answered unequivocally, except after-the-fact, by determining how the material did behave in use. The most useful method for developing practical information upon which to make decisions that depend on prediction of probable behavior of materials is the study of why materials behaved in use as they did.

Testers of materials are unable to compress time or to anticipate and reproduce the environment that the material will experience. Generally, they use standardized procedures not directly related to the specific environment or that do not determine the particular properties relevant to performance in the specific instance. Thus, testing construction materials amounts to obtaining certain kinds of information about certain samples in specified conditions and extrapolating to the conditions of intended use insofar as they can be predicted.

Petrographic examination of hardened concrete is included among the subjects in this volume because it helps to improve the extrapolation from test results to performance in use. It offers direct observational information on what is being tested and what is in the structure, giving another way of appraising the relation between samples being tested and materials in use and judging how similar the two are.

Communication Problems

A petrographic examination of concrete ordinarily begins and ends with a problem of communication between the person who requests the examination (usually an engineer) and the person who makes it (usually a petrographer). Unless the two succeed in producing a clear, mutually understood statement of the problem, they cannot expect a clear, useful answer to be obtained economically. In nearly all cases, the engineer who asks for an examination of a particular concrete suspects that the concrete is unusual; the more clearly he defines the features prompting his interest, the more he directs the petrographer toward the important aspects. The engineer may not be familiar with the techniques that the petrographer may use or with his approach; the petrographer may not realize the engineer's responsibility for decision and action, may not find out all the engineer could tell him about the concrete, and may not realize which petrographic findings are useful and relevant. The petrographer should not expect petrographic results to be taken on faith; the rationality of the techniques producing them should be demonstrable. Both should remember that the essentials of petrographic examination of concrete are practiced anytime anyone looks intelligently at concrete either in a structure or as a specimen and tries to relate what he can see to the past or future performance of the concrete. On this basis, it is clear that many of the most useful petrographic examinations are made by inspectors, engineers, chemists, physicists—anyone concerned with the production or use of concrete. No one should hesitate to examine concrete with all available means; all, from novice to expert, should question the indicated conclusions and verify them in as many ways as possible.

Methods—Standardized and Described

There is a recommended practice for petrographic examination of concrete aggregates, namely ASTM Recommended Practice for Petrographic Examination of Aggregates for Concrete (C 295). ASTM Recommended Practice for Examination and Sampling of Hardened Concrete in Constructions (C 823), which was adopted in 1975, [2] gives guidance for the examination of concrete in constructions for many purposes in addition to petrographic examination of the samples taken. Steps to be taken before examination and preliminary investigations are outlined; the desirability of assembling reports and legal documents concerning the construction is pointed out, as well as

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the usefulness of interviews with contractors and others connected with the construction and with the owners, occupants, and users of the constructions. Procedures for detailed investigations of the concrete in place in constructions are described. Sampling hardened concrete is discussed, with the preparation of appropriate sampling plans and selection of the number and size of samples. Information needed to accompany samples is described. It is the hope of the subcommittee by which the recommended practice was prepared that it will be useful not only to petrographers but also to engineers and others who have reason to examine constructions.

ASTM Recommended Practice for the Petrographic Examination of Hardened Concrete (C 856) was adopted in 1977. It turned out to be a more complicated document than was expected, because the purposes differ for examining concrete from constructions, from specimens in field exposure, from specimens in simulated service, from specimens in laboratory tests, and from specimens after laboratory curing. What may be recognized as features produced in field exposure, simulated service, laboratory tests, and laboratory curing may be features interesting and revealing in themselves in laboratory experiments. The features may also make more comprehensible similar or related features of concrete from constructions. The subcommittee hopes that this recommended practice will serve the engineers who buy a petrographic examination and then want more understanding of what they are getting and why; that it will also serve petrographers approaching the examination of concrete for the first time; and that it will remind concrete petrographers of things that they may have forgotten or neglected. The illustrations appear in ASTM Adjunct C 856.

In 1976, Evaluation of Methods of Identifying Phases of Cement Paste [*1*][2] was published. It will be helpful to those who wish to determine alite and belite residues in paste, examine hydrated cement by X-ray diffraction, differential thermal analysis, or infrared absorption spectroscopy. Pastes of three cements, a Type I, a white cement, and a cement containing no tricalcium aluminate (C_3A), were examined at ages to one year; a number of pure phases were synthesized and examined by the methods listed above. Another publication relevant to the petrographic examination of hardened concrete is Guide to Compounds of Interest in Cement and Concrete Research [*2*]. Other publications of interest are found in the volumes of the Fifth International Symposium on the Chemistry of Cement [*3*] and those of the Sixth International Symposium on the Chemistry of Cement [*4*]. One of the most stimulating serial publications came into being in 1971, *Cement and Concrete Research, an International Journal* [*5*]; it appears bimonthly and covers a wide field of cement and concrete topics and has the advantage of being truly international since the editorial board and the contributing authors do come from most of the centers in various parts of the world where cement and concrete research is carried out.

Before the production of ASTM Recommended Practice C 856, petrographic techniques for the examination of hardened concrete had been described and discussed but not standardized. In 1966 I wrote:

> At present I know of no laboratory where petrographic examinations of concrete are made that is equipped to use all the methods that have yielded useful information and no one person who has digested the available approaches and developed the ability to choose the particular combination of techniques best suited to each problem encountered. Concretes are more complex than most rocks used as aggregates; their constituents are less well known; concretes change through time more rapidly than most aggregates. All of these circumstances combine to make each petrographic examination of concrete unique and thus to make the methods harder to generalize and standardize. Each examination presents some new facet for the petrographer who is willing to learn.

In 1977 there is more sophisticated equipment in more laboratories but the number of laboratories may have diminished. More people are using sophisticated equipment and techniques in the study of cement hydrates and even of concrete, and that is good and highly desirable, and may bring about a breakthrough by orders of magnitude in our ability to interpret the behavior of concrete in constructions. This real and exciting probability brings with it dangers of losing touch with the importance of the very great range in scale, from constructions with dimensions in hundreds of metres (kilometres in the case of pavements), to core samples with dimensions in hundreds of millimetres that can be examined with great advantage at low magnification by a stereomicroscope on a large stand, to thin sections with scales ordinarily about 800 mm^2 by 15 to 30 μm thick, to X-ray diffraction samples which may be milligrams of material hand-picked under the stereomicroscope or a few grams of paste concentrated by hand-picking the aggregate from carefully broken concrete, to scanning electron microscope specimens that may be 200 mm^3 or much smaller and thinner, to single crystals a few micrometres cubed that are examined by microprobe and to the nanometre-sized material examined by the transmission electron microscope. Few cases will be found in which all the steps in scale listed above will be used, but the determining steps are looking at the constructions, looking at the samples from it with the eye and the stereomicroscope, and usually then forming one or more working hypotheses that indicate to the petrographer how to make the transition from the macroscale to the microscale most economically in knowledge gained for each unit of effort, and preferably using more than one method so as to obtain an independent verification. Proper caution is needed so that proper sampling is done at all levels of scale. For example, samples should be taken from deposits in several cracks and voids in several cores, paste concentrates are made from several cores, and so a sensible sampling plan is carried from the macro- to the microscale.

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[2] The italic numbers in brackets refer to the list of references appended to this paper.

One should also bear in mind the straw that broke the camel's back theory of concrete deterioration, which says that unless the concrete was hit by a truck or a large object from outer space, it is highly probable that evidence of more than one deteriorative mechanism (or what appears to be such evidence) will be present in any sample of deteriorated concrete. Sorting out the major cause or causes from the minor causes or secondary effects of deterioration requires the exercise of the petrographer's best judgment.

The history of the construction and its behavior is of great importance, and for this kind of information the petrographer should consult engineers, inspectors, and contractor's personnel who have been present during construction and those who have later inspected or occupied the construction.

The newer techniques offer an opportunity to understand in much more detail than previously the chemical reactions that have gone on in a concrete, because it will be possible to characterize the hydration and reaction products more clearly and consequently the chemical reactions of normal hydration or abnormal deterioration, or both, in the concrete, and to evaluate, with much more certainty than is possible without identification of the reaction products, the relative roles of chemical attack and physical attack in producing deterioration. The goal of relating better established and more familiar techniques in petrographic examination of hardened concrete to the more intimate and detailed insights made possible by the newer techniques remain to be achieved completely and while progress since 1966 is considerable, the task is not yet complete.

Purpose and Approach

Purpose

A petrographic examination attempts to answer two general objective questions: "What is the composition?" and "How is it put together?" The first question refers to the recognizable individual constituents present on the scale at which they are considered. The second question refers to structural fabric, that is, the articulation or packing in space of the component elements making up any sort of external form [*6*] or heterogeneous solid body. Both questions may be answered on any useful scale by choice of technique or techniques of appropriate resolving power. The resolving power needed differs depending on the specific questions to be answered.

Approach

Step one, in any case, is to define the problem in order to find and ask the right questions, those that need to be answered to solve the problem that caused the examination to be requested. These right questions should be answered insofar as they can be in the context, limited as it will be by money, time, instrumentation, and the state of the art. The best petrographic examination is the one that finds the right questions and answers them with maximum economy in minimum time, with a demonstration clear to all concerned that the right questions were answered with all necessary and no superfluous detail. The approach to the ideal varies depending on the problem, the skill with which the questions are asked, and the skill of the petrographer. One measure of the petrographer's skill, is knowing when to stop, either because the problem is adequately solved, or, in some cases, because it has been shown to be unsolvable under the circumstances.

Fabric and Composition

Fabric—the packing of component elements in space—is the heterogeneity obvious as one looks at a weathered concrete structure or at a broken or sawed surface of concrete. Fabric includes all of the structural elements, ranging in scale from gross to atomic, and comprises both structure and texture as those terms are used in rock description. The fabric appears on the scale of the lift or course or batch or the structural crack, on the scale of the coarse aggregate, on the scale of the sand grains or the air voids in the mortar or the "microcracks," on the scale of the residual unhydrated cement or the calcium hydroxide crystals, on the scale of the hydrous calcium aluminates and the scale of the almost amorphous crystalline hydrous calcium silicates in the hydrated cement paste, or on the scale of the atomic structure of any crystal forming a part of any of the structural components. The closest naturally occurring analogue among rocks to the fabric of concrete is graywacke conglomerate with abundant matrix. The closest naturally occurring analogue to hardened cement paste is silty clay.

Fabric and composition together define, characterize, and form the basis for descriptive classification of solid multicomponent substances. Composition and fabric are so closely interrelated in concrete that they cannot be separated clearly.

One important decision in a petrographic examination is the decision whether the request for the petrographic examination was made because of problems created by the physical structure of the concrete or because of problems created by its chemical composition. Problems arising from the physical structure or fabric include inadequacies in mixing or consolidation and inadequacy of the air-void system to provide frost resistance. Problems arising from the chemical composition include those resulting from errors in batching, reactions between cement and aggregate, reactions between a contaminant and cement paste, and reactions between cement paste and solutions from external sources. Were the construction practices employed suitable for producing concrete capable of giving satisfactory service in the particular environment and exposure? Were the materials that were chosen susceptible to participation in chemical reactions that have deleterious consequences? Was there a failure to modify the environment, for instance, by improving the drainage so as to increase the ability of the concrete to survive the chemical or physical character of the environment? Usually several causes have interacted, but one is probably the originator; if it can be identified, the appropriate techniques are pointed out more clearly.

Investigating composition and fabric provides a specific, unique definition of what is being examined. The standard tests do not always supply information that permits discrimination between one piece of concrete and another, but direct observation on the relevant scale does. There are *n* possible concretes all having 50-mm (2-in.) slump, with air content of 5 percent, with 31-MPa (4500-psi) compressive strength at 28 days, but the No. 2 cylinder in the set of three broken on Day A in Laboratory B is unique and different, perceptibly and logically, from Nos. 1 and 3 and from all the members of the other possible sets, and its top is different from its bottom as cast. The salient lesson from the study of composition and fabric of concrete is the individuality and uniqueness of each structure or part of a structure, of each specimen and each thin section; this individual combination of fabric and composition reflects the history and forecasts future performance of the concrete. What is investigated at any time is particular concrete, not concrete in general. Each structure and each part of a structure is unique in terms of composition, fabric, history, and exposure.

Comparisons

To say that each structure and specimen is unique does not mean that comparisons are useless or impossible; they are essential, and concretes can be grouped rationally and compared usefully within classes and between classes, if the basis for the grouping is objective. Each comparison leaves out of account some characteristics of the things compared, so that it is necessary to bear in mind that the accidentally or deliberately omitted factors may prove to be important. Paste, mortar, or concrete of known proportions, materials, age, and curing history offers the logical basis for comparison and extrapolation; laboratory specimens made to be examined or salvaged just after having been tested for strength provide a good source of such comparative material. Specimens exposed to laboratory air outside the moist room or curing tank for more than a few hours are much less suitable, because specimens that are cracked or that have slender cross sections sometimes carbonate very rapidly. Specimens exposed to simulated weathering tests, or wetting and drying cycles, or prolonged drying are not to be considered as representative of normally cured or of naturally weathered concretes. Natural weathering differs from part to part of a structure, as well as from climate to climate, elevation to elevation, and subgrade to subgrade.

Interpretation of Observations

Normal Concrete

For this discussion, "normal" constituents and fabrics are defined as those present in serviceable concrete of the class and age in the region. "Serviceable" is used instead of "undeteriorated" because it is possible to tell whether concrete in a structure is serving as it was intended to but the criteria that distinguish inevitable chemical and physical changes from deterioration in concrete 20 or 50 years old have not been well established.

The most valuable information that can be obtained by petrographic examination of concrete comes from the examination of normal concrete; only by comparison with the range of constituents and fabrics in normal satisfactory concrete can that which differs from the normal be recognized and its differences specifically defined. Unless it can be demonstrated that the constituents, or the proportions of constituents, or the fabric, depart from those found in serviceable concrete of the age and class in the region, there is no logical basis for assuming any connection between constituents, or proportions, or fabric, and service behavior. Even when it can be shown that a concrete has a peculiar service record and some unique feature or features not shared by a dozen others of comparable class, age, and provenance, it remains to be seen whether the known unique feature and the peculiar service record are connected causally, or whether both are related to some third or *n*th factor that is the effective cause of the abnormal behavior.

Class of Concrete

The restriction to concrete of one class is necessary because changes in cement content, water/cement (w/c) ratio, and maximum size of aggregate large enough to change the class entail such large changes in properties that no close comparison will be significant. If, for example, the criteria for paving concrete are applied to mass concrete, all mass concrete appears very inferior, which it is not for the purpose it is intended to serve. Class of concrete is important in the definition as it implies relative homogeneity in mixture proportions, particularly in w/c ratio, cement content, and maximum size of aggregate. It is possible by microscopic methods to sort mass concretes that are fairly homogeneous in cement content and w/c ratio in order of increasing age, or it is possible to sort mass concretes fairly homogeneous in age in order of increasing cement content. In terms of the ability to sort mass concrete microscopically, "fairly homogeneous" in cement content and w/c ratio means a maximum difference in cement content between concretes of about 30 kg/m^3 (50 lb/yd^3), and 0.1 by weight in w/c ratio.

Age of Concrete

Some restriction on the ages of concretes compared is necessary unless age is the variable being studied. Unless the age is known or unless one has younger and older concretes of otherwise comparable characteristics so that the age of the unknown may be estimated in relation to the knowns, it may be impossible to judge the significance of observations. For example, in one case calcium sulfoaluminate was found in many voids as far as 130 mm (5 in.) from the outer surfaces of a concrete pavement of high flexural and compressive strength and of unknown age. In other field concrete from the region, calcium sulfoaluminate is commonly present in concrete over 5 years old made with Type I or Type III cement, but it is not abundant and is confined to voids near outer surfaces. If the concrete of unknown age is in fact 5 or 7 years old, it differs conspicuously from others of comparable age and class in the region and the difference probably justifies some concern about its future; if it is 15 years old, it is peculiar, but the peculiarity is probably of less practical importance.

Provenance of Concrete

Restriction of an investigation to one region assists in rational comparison from several points of view. The aggregates economically available in an area are determined by the regional geology and consequently show some homogeneity of composition resulting from similarity of origin and history. In a particular region, cements and aggregates economically available are used in making concrete which is exposed to the climate characteristic of the region—the prevailing temperature range and temperature frequency distribution and the characteristic amount and sequence of precipitation. The extent of a region of comparable concrete may vary from a few square miles to many thousands, depending on variation in: (*a*) regional geology—as it determines quantity and uniformity of aggregate supply; (*b*) topography—a region of low relief and generally uniform slope such as the Great Plains, or the Atlantic or Gulf Coastal Plain, has widespread, essentially comparable range and distribution of temperature and precipitation, but in a region of high relief and broken slopes, temperature varies considerably with altitude, and precipitation with orientation to prevailing winds, making important differences in exposure over short distances; and (*c*) patterns of distribution of aggregates and cement from competitive sources—in some areas, only one type of natural sand and gravel is available; no manufactured aggregate is produced, and synthetic aggregate sources are not common. Metropolitan marketing areas served by water transportation usually have available a selection of natural coarse and fine aggregates, manufactured coarse aggregates, and synthetic aggregates. All variations between the two extremes just mentioned can be found in availability of aggregates.

Cement plants per state range from none in New Hampshire and Vermont to 19 in Pennsylvania [*7*]. Ports and coastal areas may be served by overseas and domestic cement sources.

An additional influence that may appear is a prevailing engineering opinion, in an organization placing concrete in a large area, on what is desirable in mixture proportions or methods of placing or consolidation. The existance of satisfactory structures built in many different ways underlines the need to define "normal" concrete in objective and restricted terms.

Normal and Unusual Concrete

Although the most important kind of petrographic examination of concrete is the examination of normal concrete, usually the concrete that a petrographer is asked to examine has behaved in an unexpected way. Before and during the early stages of the examination, the information on the history and behavior should be considered and the following questions asked: 1. What process or processes could produce the described results? 2. What observable traces could the process or processes leave in the concrete? 3. Would such traces be unique and specific evidence of what is supposed to have happened?

Reconstruction of History of Field Concrete

To pass from consideration of simple petrographic examination to the petrographic examination of concrete that has aged and perhaps deteriorated in service introduces two important new unknowns—time and the precise environment of the structure. The effects of the passage of relatively short periods of time on the constituents present in several cement pastes of known w/c ratio stored under laboratory conditions have been investigated, but anomalies remain in the results, although both the composition of the pastes and the nature of the environments were known and controlled far more thoroughly than the composition and environment of any field concrete.

Composition

If the changes in composition of cement paste with time in laboratory conditions were known for a representative number of cement compositions and w/c ratios, effects of both cement-aggregate interactions and of environmental influences would be easier to recognize and could be interpreted more usefully.

Environment

Why do exposed vertical walls of chert-gravel concrete in the vicinity of St. Louis, Mo., generally have fewer popouts than apparently similar walls in the vicinity of Memphis, Tenn.? The winters are colder in St. Louis, but the mean annual rainfall is lower; and in Memphis a larger proportion of the higher mean annual rainfall occurs in winter. The difference probably is that the chert gravel in the Memphis walls is more likely to be critically saturated when it freezes. The Weather Bureau's climatological data for the location are a valuable source of information that can assist in many petrographic examinations of hardened concrete.

The discovery in Mississippi of several highway pavements and associated structures affected by sulfate attack and by combined sulfate and acid attack [*8*] emphasizes the need to make use of available information on the composition of foundations and subgrades.

Thus, the examination of samples of field concrete after extended service involves an increase in complexity, a decrease in available information, and a decrease in the confidence that may be placed in the answer, as compared to examinations of laboratory test specimens of hardened concrete.

It does not belittle the petrographer to admit that he cannot make bricks without straw; neither can the chemist, the physicist, or the engineer; sometimes the petrographer can recover evidence not accessible by other approaches. Several reasons make reconstruction of the history of deteriorated field concrete difficult; in any particular instance it may be important and yet impossible in the present state of our knowledge to decide what weight belongs to each.

Deteriorated field concrete that is submitted to a laboratory or to a petrographer is almost never concrete that has performed abnormally for one single obvious cause; such simple cases usually can be and are explained on the spot to the satisfaction of those concerned. The field concrete that is examined by a petrographer is concrete that has worried some responsible person enough to make the effort and expense of sampling and testing appear justified. There is thus a build-in bias in the sampling process. Normally the concrete that a petrographer sees as part of his assigned duties is controversial concrete sent in by organizations with alert conscientious concrete technologists or concrete that has become the subject of controversy under other situations. In practice, this generally means that he sees only the poor concrete produced under conditions where a degree of control was intended. Concrete produced where there was little intent for control to be exercised, that is, the worst concrete, rarely is sampled and sent to a petrographer; good concrete is rarely controversial.

Furthermore, the older the concrete the less information is likely to be available about materials, proportions, conditions of placing, and the characteristics that undeteriorated comparable concrete would have. Although one can deduce from the concrete that w/c ratio was high or low, and usually that cement content was high or low or medium, and the general quality of the workmanship, one cannot reconstruct the alkali content of the cement. Aggregate sources, particularly of natural sand and gravel, can be located from their composition—the constituents present and their size distribution are diagnostic of the region and sometimes of the particular source.

Finally, deteriorated field concrete usually shows superimposed traces of several processes, with at least one in an advanced stage. The most advanced process may conceal the evidence of others that was more important in effect. Frequently the most conspicuous process is carbonation of other surfaces and along the borders of old cracks.

Laboratory test exposures are simplified compared to natural exposures by the exclusion of some factors and the regulation of those retained and often are "accelerated" by altering some factor so as to remove it from the range possible in nature. Consequently, a laboratory procedure often results in symptoms different from symptoms encountered in a field example of the process the test is intended to simulate.

Samples of field concrete, when examined using light microscopy, frequently are found to contain secondary calcium carbonate near their outer surfaces, along old cracks, and sometimes in the interior. Such calcium carbonate, when examined by optical methods, is generally found to be calcite, rarely aragonite, and almost never vaterite, the form-birefringent spherulitic calcite with interstitial water. Vaterite, however, was found by optical methods to be common on mortar bars that had been tested according to ASTM Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227) and had been found on concrete specimens tested for resistance to freezing and thawing according to ASTM Test for Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water (C 666). The use of X-ray diffraction to examine cement-paste concentrates from field concrete has revealed that vaterite, not recognized by optical methods, is frequently a major constituent of the secondary calcium carbonate [*9*], especially on samples from seawater exposures or from other wet environments. Vaterite is known to persist for several months in laboratory specimens stored in room conditions. The sequence from poorly crystallized vaterite, calcite, and aragonite to well-crystallized calcite in the carbonation of pastes and mortars has been clarified by Cole and Kroone [*10*], and vaterite is now known as a natural mineral [*11*].

Accelerated freezing and thawing in water according to ASTM Method C 666, Procedure A, produces a characteristic loss of surface skin and loss of mortar, which is not like the condition of specimens exposed on the mean-tide rack at Eastport, Maine [*12*]. Field concrete that is not air-entrained and is deteriorated by natural freezing and thawing develops sets of subparallel cracks normal to the placing direction of the concrete or deteriorated regions parallel to the nearest free surface. These phenomena are not reproduced in accelerated freezing and thawing in water.

Field concrete that has deteriorated primarily because of the alkali-silica reaction usually has much more advanced and conspicuous internal symptoms of this reaction than are found in mortar bars of expansive combinations examined after test according to ASTM Method C 227. On the other hand, some field concrete regarded as undeteriorated has shown a range of evidence of alkali-silica reaction.

Alkali-carbonate and alkali-silica reactions exist together in varying degrees of development in some concretes, and inconspicuous degrees of reaction may be the only recognizable peculiarities in cases of unsatisfactory service with possibly expensive consequences. The several alkali-carbonate reactions are described in other papers in this volume, as is alkali-silica reaction.

Closure

"Things which are seen"—concrete and mortar—"were not made of things which do appear" [*13*] to the eye and to the light microscope. The use of X-ray diffraction, electron microscopy, differential thermal analysis, and thermogravimetry, with the electron probe and infrared spectroscopy, in conjunction with the observing eye and the light microscopy, still offers the chance of sorting out the qualitative and quantitative differences in hydration products and in submicroscopic fabric that are related to serviceable and deteriorated concrete.

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