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## Standard Practice for Petrographic Examination of Hardened Concrete<sup>1</sup>

This standard is issued under the fixed designation C856; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This practice outlines procedures for the petrographic examination of samples of hardened concrete. The samples examined may be taken from concrete constructions, they may be concrete products or portions thereof, or they may be concrete or mortar specimens that have been exposed in natural environments, or to simulated service conditions, or subjected to laboratory tests. The phrase “concrete constructions” is intended to include all sorts of objects, units, or structures that have been built of hydraulic cement concrete.

NOTE 1—A photographic chart of materials, phenomena, and reaction products discussed in Sections ~~7-12-8-13~~ and Tables 1-6 are available as Adjunct C856 (ADJCO856).

1.2 The petrographic procedures outlined herein are applicable to the examination of samples of all types of hardened hydraulic-cement mixtures, including concrete, mortar, grout, plaster, stucco, terrazzo, and the like. In this practice, the material for examination is designated as “concrete,” even though the commentary may be applicable to the other mixtures, unless the reference is specifically to media other than concrete.

1.3 Annex A1 outlines an uranyl acetate method for identifying locations where alkali-silica gel may be present. It is a requirement that the substances in those locations must be identified using any other more definitive techniques, such as petrographic microscopy.

1.4 The purposes of and procedures for petrographic examination of hardened concrete are given in the following sections:

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1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units in parentheses are provided for information purposes only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* A specific hazard statement is given in ~~5.2.10-16.2.10.1~~.

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.65 on Petrography.

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TABLE 1 Visual Examination of Concrete (1)<sup>6</sup>

Coarse Aggregate	+ Fine Aggregate	+ Matrix	+ Air	+ Embedded Items
<i>Composition:</i>				
Maximum dimension, <sup>A</sup> in. or mm, in the range > <i>d</i>	Type:	color, by comparison with National Research Council <i>Rock Color Chart</i> (1963)	more than 3 % of total,	Type, size, location; kinds of metal; other items
1 Gravel 2 Crushed stone 3 Mixed 1 and 2 4 Other (name) 5 Mixed 1 + /or 2 + /or 4 If Type 1, 2, or 4, homogeneous or heterogeneous	1 Natural sand 2 Manufactured sand 3 Mixed 4 Other (name) 5 Mixed 1 + /or 2 + /or 4 If Type 1, 2, or 4, homogeneous or heterogeneous	color distribution: 1 mottled 2 even 3 gradational changes	predominantly in spherical voids? less than 3 % of total, abundant nonspherical voids? color differences between voids and mortar?	
Lithologic types Coarse aggregate more than 20, 30, 40, or 50 % of total			voids empty, filled, lined, or partly filled	
<i>Fabric:</i>				
—Shape —Distribution —Packing —Grading (even, uneven)	distribution particle shape grading preferred orientation	— as perceptible	distribution	shape distribution grading (as perceptible) parallelism of long axes of
—Shape —Distribution —Packing —Grading (even, uneven) excess, or deficiency of size or sizes) Parallelism of flat sides or long axes of exposed sections, normal to direction of placement + /or parallel to formed and finished surfaces <sup>B</sup>	distribution particle shape grading preferred orientation	— as perceptible	distribution	shape distribution grading (as perceptible) parallelism of long axes of irregular voids or sheets of voids: with each other; with flat sides or long axes of coarse aggregate
				voids below horizontal or low-angle reinforcement voids below horizontal or low-angle reinforcement
<i>Condition:</i>				
Does it ring when hit lightly with a hammer or give a dull flat sound? Can you break it with your fingers? Cracks? How distributed? Through or around coarse aggregate? With cores or sawed specimens, did the aggregate tear in drilling or sawing? Crack fillings? Surface deposits? If air dry, are there unusually wet or dry looking areas? Rims on aggregate?				clean or corroded? Are cracks associated with embedded items?

<sup>A</sup> A substantial portion of the coarse aggregate has maximum dimensions in the range shown as measured on sawed or broken surfaces.

<sup>B</sup> Sections sawed or drilled close to and parallel to formed surfaces appear to show local turbulence as a result of spading or rodding close to the form. Sections sawed in the plane of bedding (normal to the direction of placement) are likely to have inconspicuous orientation. Sections broken normal to placement in conventionally placed concrete with normal bond tend to have aggregate knobs abundant on the bottom of the upper piece as cast and sockets abundant on the top of the lower piece as cast.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

- C125 Terminology Relating to Concrete and Concrete Aggregates
- C215 Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens
- C227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)<sup>3</sup>
- C342 Test Method for Potential Volume Change of Cement-Aggregate Combinations
- C441 Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
- C452 Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate
- C457 Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete
- C496/C496M Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
- C597 Test Method for Pulse Velocity Through Concrete
- C803/C803M Test Method for Penetration Resistance of Hardened Concrete
- C805 Test Method for Rebound Number of Hardened Concrete
- C823 Practice for Examination and Sampling of Hardened Concrete in Constructions
- C1012 Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
- C1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

**TABLE 2 Outline for Examination of Concrete with a Stereomicroscope (1)**

NOTE 1—*Condition*—When it is examined at 6 to 10× under good light, the freshly broken surface of a concrete in good physical condition that still retains most of its natural moisture content has a luster that in mineralogical terms is subtranslucent glimmering vitreous.<sup>A</sup> Thin edges of splinters of the paste transmit light; reflections appear to come from many minute points on the surface, and the quality of luster is like that from broken glass but less intense. Concrete in less good physical condition is more opaque on a freshly broken surface, and the luster is dull, subvitreous going toward chalky. A properly cured laboratory specimen from a concrete mixture of normal proportions cured 28 days that has shown normal compressive or flexural strength and that is broken with a hammer and examined on a new break within a week of the time that it finished curing should provide an example of concrete in good physical condition.

Under the same conditions of examination, when there is reasonable assurance that the concrete does not contain white portland cement or slag cement, the color of the matrix of concrete in good physical condition is definitely gray or definitely tan, except adjoining old cracks or original surfaces.

Coarse Aggregate	Fine Aggregate	Matrix	Voids
Lithologic types and mineralogy as perceptible	Lithologic types and mineralogy as perceptible	Color	Grading
Surface texture	Shape	Fracture around or through aggregate	Proportion of spherical to nonspherical
Within the piece:	Surface texture	Contact of matrix with aggregate:	Nonspherical, ellipsoidal, irregular, disk-shaped
Grain shape	Grading	close, no opening visible on sawed or broken surface; aggregate not dislodged with fingers or probe;	Color change from interior surface to matrix
Grain size extreme range observed, mm	Distribution	boundary openings frequent, common, rare	Interior surface luster like rest of matrix, dull, shining
Median within range _ to _ mm		Width	Linings in voids absent, rare, common, in most, complete, partial, colorless, colored, silky tufts, hexagonal tablets, gel, other
Textureless (too fine to resolve)		Empty	Underside voids or sheets of voids uncommon, small, common, abundant
Uniform or variable within the piece		Filled	
From piece to piece:		Cracks present, absent, result of specimen preparation, preceding specimen preparation	
Intergranular bond		Mineral admixtures <sup>C</sup>	
Porosity and absorption <sup>B</sup>		Contamination	
If concrete breaks through aggregate, through how much of what kind?		Bleeding	
If boundary voids, along what kind of aggregate? All? All of one kind? More than 50 % of one kind? Several kinds?			
Segregation			

<sup>A</sup> Dana, E. S., *Textbook of Mineralogy*, revised by W. E. Ford, John Wiley & Sons, New York, N. Y., 4th ed., 1932, pp. 273–274.

<sup>B</sup> Pore visible to the naked eye, or at × \_\_, or sucks in water that is dropped on it.

<sup>C</sup> Dark solid spheres or hollow-centered spheres of glass, or of magnetite, or some of glass and some of magnetite, recognizable at magnification of × 9 on sawed or broken surfaces. Other mineral admixtures with characteristic particles visible at low magnification are recognizable. Ground surface of concrete containing portland blast-furnace slag cement are unusually white near-free surfaces but retain greenish or blue-greenish patches, and slag particles can be seen with the stereomicroscope or polarizing microscope.

### E3 Guide for Preparation of Metallographic Specimens

### E883 Guide for Reflected Light Photomicrography

#### 2.2 ASTM Adjuncts:

Adjunct C856 (ADJCO856) A chart of 27 photos<sup>3</sup>

<https://standards.iteh.ai/catalog/standards/sist/7f3ba5b-e96d-41c6-a93d-22d1b9bd1378/astm-c856-11>

### 3.

#### 3. Terminology

##### 3.1 Definitions:

For definitions of terms used in this practice, refer to Terminology C125.

#### 4. Qualifications of Petrographers and Use of Technicians

##### 3.1

4.1 All petrographic examinations of hardened concrete described in this practice shall be performed by or under the technical direction of a full time supervising petrographer with at least 5 years experience in petrographic examinations of concrete and concrete-making materials. 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. A resume of the professional background and qualifications of all concrete petrographers shall be available.

3.2A4.2 A concrete petrographer shall be knowledgeable about the following: concrete-making materials; processes of batching, mixing, handling, placing, and finishing of hydraulic-cement concrete; the composition and microstructure of cementitious paste; the interaction of constituents of concrete; and the effects of exposure of such concrete to a wide variety of conditions of service.

3.4.3 Sample preparation shall be performed by concrete petrographers or trained technicians pursuant to instructions from and under the guidance of a qualified concrete petrographer. Aspects of the petrographic examination, such as the measurement of

<sup>2</sup> Available from ASTM International Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Request Adjunct No. ADJCO856.

<sup>3</sup> Available from ASTM International Headquarters. Order Adjunct No. ADJCO856. Original adjunct produced in 1995.

**TABLE 3 Effects of Fire on Characteristics of Concrete**

Characteristic	Causes and Effects	Ways of Investigation								
<i>Surface hardness</i>	Dehydration to 100°C removes free water; dehydration is essentially complete at 540°C; calcium hydroxide goes to CaO at 450–500°C. Paste expands with thermal coefficient effect and then shrinks, cracks, decrepitates, and becomes soft (4).	Beneath the softened concrete, which can be tested in accordance with Test Method C805, the concrete is probably normal if it has not undergone color change. Establish by coring for compressive tests, by wear tests (CRD-C 52) (4), and by scratching with a knife.								
<i>Cracking</i>	Perpendicular to the face and internal, where heating or cooling caused excess tensile stresses. In some new concrete, resembles large-scale shrinkage cracking; may penetrate up to 100 mm but may heal autogenously (4).	Examination of the surface, ultrasonic tests, coring, petrographic examination (4).								
<i>Color change</i> —When concrete has not spalled, observe depth of pink color to estimate the fire exposure.	Concrete made with sedimentary or metamorphic aggregates shows permanent color change on heating. Color normal to 230°C; goes from pink to red from 290 to 590°C; from 590 to 900°C color changes to gray and then to buff (4). For temperatures up to about 500°C temperature distribution is little affected by using carbonate rather than siliceous aggregate (5). At 573°C low quartz inverts to high with 0.85 % increase in volume, producing popouts. Spalling over steel to expose one fourth of the bar at 790°C; white powdered decomposed hydration products at 900°C. Surface crazing about 290°C; deeper cracking about 540°C.	Color change is the factor most useful to the investigator; permits recognizing how deeply a temperature of about 300°C occurred (5).								
<i>Aggregate behavior</i> —Aggregate behavior affects strength, modulus, spalling, cracking, surface hardness, and residual thermal strains (4).	Aggregates differ in thermal diffusivity, conductivity, coefficient of expansion. Heat transmission decreases from concrete made with highly siliceous aggregate, sandstone, traprock, limestone, lightweight aggregates (4).	Changes on heating are often accompanied by volume change (4).								
<i>Spalling</i>	Occurs subparallel to free face; followed by breaking off saucer-like pieces especially at corners and edges (4).									
Note: Compressive strength and elastic modulus. For concrete at least 1-year old, strength will increase after cooling from 300°C if design strength was attained (5).	Reduction in strength of concrete containing siliceous gravel after heating, then cooling and testing:	Determinations by compressive tests and static modulus of cores; Test Method C805 for qualitative determination; Test Method C597 (4).								
	<table border="1"> <thead> <tr> <th>Heated to Temperature ° C</th> <th>Reduction, %</th> </tr> </thead> <tbody> <tr> <td>180</td> <td>25</td> </tr> <tr> <td>370</td> <td>50</td> </tr> <tr> <td>570</td> <td>80</td> </tr> </tbody> </table>	Heated to Temperature ° C	Reduction, %	180	25	370	50	570	80	
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sample dimensions, photography of as-received samples, staining of sample surfaces, that do not require the education and skills outlined in 3-14.1, shall be performed by concrete petrographers or by trained technicians pursuant to instructions and under the guidance of a qualified concrete petrographer. The analysis and interpretation of the features that are relevant to the investigation and evaluation of the performance of the materials represented by the sample shall be made solely by concrete petrographers with qualifications consistent with those outlined in 3-14.1.

3.4A.4.4 A concrete petrographer shall be prepared to provide an oral statement, written report, or both that includes a description of the observations and examinations made during the petrographic examinations, and interpretation of the findings insofar as they relate to the concerns of the person or agency for whom the examination was performed. Supplementary information provided to the petrographer on the concrete and concrete materials, conditions of service, or other features of the concrete construction may be helpful in interpreting the data obtained during the petrographic examinations.

3.5This 4.5 This practice may form the basis for establishing arrangements between a purchaser of the consulting service and the consulting petrographer. In such cases, the purchaser of the consulting service and the consulting petrographer should together determine the kind, extent, and objectives of the examinations and analyses to be made, and may record their agreement in writing. The agreement may stipulate specific determinations to be made, observations to be reported, funds to be obligated, or a combination of these and other conditions.

#### 4.5. Purposes of Examination

4.5.1 Examples of purposes for which petrographic examination of concrete is used are given in 4.2-4.5.2-5.5. The probable usefulness of petrographic examination in specific instances may be determined by discussion with an experienced petrographer of the objectives of the investigation proposed or underway.

#### 4.2

#### 5.2 Concrete from Constructions :

4.5.2.1 Determination in detail of the condition of concrete in a construction.

**TABLE 4 Outline for Examination of Concrete in Thin Sections**

Coarse and Fine Aggregate	Relict Cement Grains and Hydration Products	Characteristics of Cement Paste
<p>Mineralogy, texture, fabric, variable or homogeneous.</p> <p>Grading; excess or deficiency of sand sizes is to be judged after examination of a series of thin sections. Grain size and nature of internal boundaries in aggregate. Classification of coarse and fine aggregate.</p> <p>Natural mineral aggregate or crushed stone; natural or manufactured fine aggregate.</p> <p>Bond with matrix; peripheral cracks inside the borders of aggregate grains; internal cracks. General microfractures if one can establish that they existed before thin-sectioning.</p> <p><i>Alkali - carbonate reactions</i>—If the coarse aggregate is a carbonate rock or rocks, are there rims or partial rims depleted in calcium hydroxide? Partly dolomitic rocks that have reacted sometimes are bordered with paste free from calcium hydroxide along the dolomitic portion while the paste along the limestone portion is normal. See other comments in Column 3.</p> <p><i>Alkali - silica reaction</i>—Does the aggregate contain particles of types known to be reactive (chert, novaculite, acid volcanic glass, cristobalite, tridymite, opal, bottle glass)? If quartzite, metamorphosed subgraywacke, argillite, phyllite, or any of those listed in the sentence above, are there internal cracks inside the periphery of the aggregate? Has the aggregate been gelatinized so that it has pulled off during sectioning leaving only a peripheral hull bonded to the mortar? (This last phenomenon also occurs in concrete with air-cooled slag aggregate, where it indicates reaction between cement and slag.) Cracks that appear to be tensile and to narrow from the center toward the border of the particle are also evidence of alkali - silica reaction (6).</p>	<p>In concrete over 2 years old and normally cured, the only residual cement grains are those that were largest, which may be composed of several constituents or be of alite or belite (substituted <math>C_3S</math> and <math>C_2S</math>). The latter two may be bordered by one or two layers of gel having different indexes of refraction, or by a layer of calcium hydroxide. The largest relict grains may be truly unhydrated and retain the low (dark gray) birefringence of alite in distorted quasihexagonal sections and the visible birefringence to first-order yellow of the lamellar twins in rounded grains of belite. Interstitial aluminoferrite appears as prismatic grains ranging in color from brown to greenish brown to reddish brown and having a high refractive index and pleochroism masked by the color of the grain. Tricalcium aluminate is usually not recognized in thin section because the cubic form is isotropic or because it hydrates early in the hydration history of the concrete forming submicroscopic ettringite or tetracalcium aluminum sulfate hydrate or other tetracalcium aluminum hydrates with or without other anions. These may be visible in voids in older concrete but are best discriminated by X-ray diffraction.</p> <p>Cements from different sources have different colors of aluminoferrite and the calcium silicates have pale green or yellow or white shades. It should be possible to match cements from one source.</p>	<p>Normal cement paste consists in plane transmitted light of pale tan matter varying somewhat in index of refraction and containing relict unhydrated cement grains. In concrete sectioned at early age or not adequately cured, the paste contains unhydrated cement grains ranging down to a few micrometres in maximum size with an upper limit as large as 100 <math>\mu\text{m}</math> in maximum diameter if the cement was ground in open-circuit mills or was deliberately ground to low surface area to reduce the heat of hydration. With crossed polars, normal paste is black or very dark mottled gray with scattered anhedral poikilitic crystals or small segregations of calcium hydroxide and scattered relict grains of cement. In concrete of high water - cement ratio and siliceous aggregate, the calcium hydroxide crystals are as large as the maximum size of residual cement grains, about 100 <math>\mu\text{m}</math>. In concrete of lower water - cement ratio, higher cement content, and either siliceous or carbonate aggregate, the maximum size of calcium hydroxide crystals is considerably smaller. Regardless of water - cement ratio and type of aggregate, calcium hydroxide crystals occupy space tangential to the undersides of aggregate particles. Where all the aggregate is carbonate rock the maximum size of calcium hydroxide is smaller than in comparable concrete with siliceous aggregate. (Calcium hydroxide is probably epitaxial on calcite.)</p> <p>Cement paste in concrete that has been subjected to prolonged acid leaching is low in calcium hydroxide which is present as recrystallized virtually anhedral grains precipitated near the exterior surfaces.</p> <p>In concrete over 2 or 3 years old made with Type I, II, or III cement, some ettringite is to be expected as rosettes in air voids. This is a normal phenomenon; to demonstrate sulfate attack it must be established chemically that the <math>SO_3</math> content of the concrete is greater than would be supplied by the original sulfate content of the cement. Ettringite in voids is not ettringite that has damaged concrete although it may accompany submicroscopic ettringite in the paste that has damaged the concrete.</p>

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- 45.2.2 Determination of the causes of inferior quality, distress, or deterioration of concrete in a construction.
  - 45.2.3 Determination of the probable future performance of the concrete.
  - 45.2.4 Determination whether the concrete in a construction was or was not as specified. In this case, other tests may be required in conjunction with petrographic examination.
  - 45.2.5 Description of the cementitious matrix, including qualitative determination of the kind of hydraulic binder used, degree of hydration, degree of carbonation if present, evidence of unsoundness of the cement, presence of a mineral admixture, the nature of the hydration products, adequacy of curing, and unusually high water - cement ratio of the paste.
  - 45.2.6 Determination whether alkali - silica or alkali - carbonate reactions, or cement - aggregate reactions, or reactions between contaminants and the matrix have taken place, and their effects upon the concrete.
  - 45.2.7 Determination whether the concrete has been subjected to and affected by sulfate attack, or other chemical attack, or early freezing, or to other harmful effects of freezing and thawing.
  - 45.2.8 Part of a survey of the safety of a structure for a present or proposed use.
  - 45.2.9 Determination whether concrete subjected to fire is essentially undamaged or moderately or seriously damaged.
  - 45.2.10 Investigation of the performance of the coarse or fine aggregate in the structure, or determination of the composition of the aggregate for comparison with aggregate from approved or specified sources.
  - 45.2.11 Determination of the factors that caused a given concrete to serve satisfactorily in the environment in which it was exposed.
  - 45.2.12 Determination of the presence and nature of surface treatments, such as dry shake applications on concrete floors.
- 4.35.3 *Test Specimens from Actual or Simulated Service*—Concrete or mortar specimens that have been subjected to actual or simulated service conditions may be examined for most of the purposes listed under Concrete from Constructions.

**TABLE 5 Characteristics of Concrete Observed Using Microscopes**

Characteristic	Type of Microscope		
	Stereomicroscope	Petrographic	Metallographic
<i>Aggregate:</i>			
Shape	X	X	X
Grading	X	...	...
Distribution	X	...	...
Texture	X	X	X
Composition	X	X	...
Rock types	X	X	...
Alteration	X	X	...
degree	X	X	...
products	X	X	...
Coatings	X	X	...
Rims	X	X	X
Internal cracking	X	X	...
Contamination	X	X	...
<i>Concrete:</i>			
Air-entrained or not	X	X	X
Air voids	...	...	...
shape	X	X	X
size	X	X	X
distribution	X	...	...
Bleeding	X	...	...
Segregation	X	...	...
Aggregate-paste bond	X	X	X
Fractures	X	X	X
Embedded items			
size	X	...	...
shape	X	...	...
location	X	...	...
type	X	...	...
Alteration			
degree and type	X	X	X
reaction products			
location	X	X	X
identification	X <sup>A</sup>	X	...
Nature and condition of surface treatments	X	X	...
<i>Paste:</i>			
Color	X	X	...
Hardness	X	...	X
Porosity	X	...	X
Carbonation	X	X	...
Residual cement			
distribution	...	X	X
particle size	...	X	X
abundance	...	X	X
composition	...	X	X
Mineral admixtures	X <sup>B</sup>	X	X
size	...	X	X
abundance	X	X	X
identification	X	X	X
Compounds in hydrated cement	X <sup>C</sup>	X	X
Contamination			
size	X	X	X
abundance	X	X	X
identification	...	X	X <sup>D</sup>

<sup>A</sup> Secondary ettringite can sometimes be recognized by crystal habit and silky luster.

<sup>B</sup> Fly ash can be detected by color and shape when dark spheres are present. In concrete that has not oxidized the presence of slag may be inferred from the green or blue color of the paste.

<sup>C</sup> Ettringite and calcium hydroxide in voids may be recognized by their crystal habits.

<sup>D</sup> Magnesium oxide and calcium oxide should be identifiable in polished section.

#### 4.4

##### 5.4 Concrete Products:

45.4.1 Petrographic examination can be used in investigation of concrete products of any kind, including masonry units, precast structural units, piling, pipe, and building modules. The products or samples of those submitted for examination may be either from current production, from elements in service in constructions, or from elements that have been subjected to tests or to actual or simulated service conditions.

45.4.2 Determination of features like those listed under concrete from constructions.

45.4.3 Determination of effects of manufacturing processes and variables such as procedures for mixing, molding, demolding, consolidation, curing, and handling.

45.4.4 Determination of effects of use of different concrete-making materials, forming and molding procedures, types and