INTERNATIONAL

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Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete[1]

This standard is issued under the fixed designation C457/C457M; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method describes procedures for microscopical determinations of the air content of hardened concrete and of the specific surface, void frequency, spacing factor, and paste-air ratio of the air-void system in hardened concrete. Three procedures are described:

1.1.1 *Procedure A*—Linear-traverse method.

1.1.2 *Procedure B*—Modified point-count method.

1.1.3 *Procedure C*—Contrast enhanced method.

1.2 This test method is based on prescribed procedures that are applied to sawed and lapped sections of specimens of concrete from the field or laboratory.

1.3 It is intended to outline the principles of this test method and to establish standards for its adequate performance but not to describe in detail all the possible variations that might be used to accomplish the objectives of this test method.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined..

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements see Note 9 *and* Note 12.

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C125 Terminology Relating to Concrete and Concrete Aggregates
C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C173/C173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C231/C231M Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C666/C666M Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
C672/C672M Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals (Withdrawn 2021)[3]
C823/C823M Practice for Examination and Sampling of Hardened Concrete in Constructions
C856 Practice for Petrographic Examination of Hardened Concrete
D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *American Concrete Institute Standards:*[4]

201.2R Guide to Durable Concrete
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

[1] This test method 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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[2] 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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, http://www.aci-int.org.

***A Summary of Changes section appears at the end of this standard**

3. Terminology

3.1 For definitions of terms used in this test method, refer to Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *average chord length* $(\bar{l})$, *n*—the average length of the chords formed by the transection of the voids by the line of traverse; the unit is a length.

3.2.2 *binary image, n*—formed by segmenting an image using only one threshold with the resulting image having only areas of black or white.

3.2.3 *digital image, n*—an image captured using a computer-based storage method where the information presented in the image can be seen visually, like a traditional photographic image, but can also be extracted in a numeric form that can be used for additional analysis.

3.2.4 *paste-air ratio (p/A), n*—the ratio of the volume of hardened cement paste to the volume of the air voids in the concrete.

3.2.5 *paste content (p), n*—the proportion of the total volume of the concrete that is hardened cement paste expressed as percentage by volume.

3.2.5.1 *Discussion*—When this parameter is calculated, it is the sum of the proportional volumes of the cement, the net mixing water (including the liquid portions of any chemical admixtures), and any supplementary cementitious materials present.

3.2.6 *pixel, n*—the smallest definable point of a digital image that has an assigned value representing the brightness of that component in an image.

3.2.6.1 *Discussion*—Typically a pixel will have the same aspect ratio as the overall image and will have an assigned integer value occurring in the range 0-255. Multiple pixels are arranged contiguously in two-dimensional arrays to form a digital image.

3.2.7 *segment, v*—the process of placing image pixels into classes or like-groupings using any number of thresholds.

3.2.8 *spacing factor* $(\bar{L})$, *n*—a parameter related to the maximum distance in the cement paste from the periphery of an air void, the unit is a length.

3.2.9 *specific surface (α), n*—the surface area of the air voids divided by their volume, expressed in compatible units so that the unit of specific surface is a reciprocal length.

3.2.10 *threshold, n*—a value used to discriminate pixels into more than one class or like grouping.

3.2.11 *void frequency (n), n*—voids per unit length of traverse; the number of air voids intercepted by a traverse line divided by the length of that line; the unit is a reciprocal length.

3.2.11.1 *Discussion*—The value for void frequency *(n)* cannot be directly determined by the paste-air ratio method as this value refers to the voids per unit measure of traverse in the total concrete (including aggregate).

3.2.12 *water void, n*—a space enclosed by the cement paste that was occupied by water at the time of setting and frequently found under an aggregate particle or reinforcing bar. A water-void is usually identified by its irregular shape or evidence that a channel or cavity has been created by bleed water trapped in the concrete at the time it hardened.

4. Summary of Test Method

4.1 *Procedure A, Linear-Traverse Method*—This procedure consists of the determination of the volumetric composition of the concrete by summing the distances traversed across a given component along a series of regularly spaced lines in one or more planes intersecting the specimen. The data gathered are the total length traversed (T_t), the length traversed through air voids (T_a), the length traversed through paste (T_p), and the number of air voids intersected by the traverse line *(N)*. These data are used to calculate the air content and various parameters of the air-void system. If only the air content is desired, only T_a and T_t need be determined.

4.2 *Procedure B, Modified Point-Count Method*—This procedure consists of the determination of the volumetric composition of the concrete by observation of the frequency with which areas of a given component coincide with a regular grid system of points at which stops are made to enable the determinations of composition. These points may be in one or more planes intersecting the specimen. The data gathered are the linear distance between stops along the traverse *(I)*, the total number of stops (S_t), the number of stops in air voids (S_a), the number of stops in paste (S_p), and the number of air voids *(N)* intersected by the line of traverse over which the component data is gathered. From these data the air content and various parameters of the air-void system are calculated. If only the air content is desired, only S_a and S_t need be determined.

4.3 *Procedure C, Contrast Enhanced Method*—This procedure consists of the determination of the volumetric composition of the concrete by summing distances measured in digital images of a prepared concrete surface using a series of regularly spaced lines in one or more digital images obtained from one or more planes intersecting the specimen. The specimen is prepared exactly as described for Procedures A and B with the additional steps of darkening the specimen surface and filling the air voids with a fine particle size white powder. The data gathered are the total length measured (T_t), the length measured through air voids (T_a), and the number of air voids intersected by the measurement lines *(N)*. These data are used to calculate the air content and various parameters of the air-void system, except the paste-air ratio and spacing factor that require determination of the paste content (T_p) as described in 16.1. If only the air content is desired, only T_a and T_t need be determined.

4.4 *Paste-Air Ratio Modification*—In some instances the specimen is not representative of the concrete as a whole, so T_t and S_t lose their significance and cannot be used as a basis for calculations. The most common examples are concrete with large coarse aggregate and specimens from the finished surface region, for both of which the examined specimen consists of a disproportionately large amount of the mortar fraction. In such instances the usual procedure must be changed, and the paste-air ratio modification must be used (see 5.5).

5. Significance and Use

5.1 The parameters of the air-void system of hardened concrete determined by the procedures described in this test method are related to the susceptibility of the cement paste portion of the concrete to damage by freezing and thawing. Hence, this test method can be used to develop data to estimate the likelihood of damage due to cyclic freezing and thawing or to explain why it has occurred. The test method can also be used as an adjunct to the development of products or procedures intended to enhance the resistance of concrete to cyclic freezing and thawing.

5.2 Values for parameters of the air-void system can be obtained by any of the procedures described in this test method. The selection of which one of the three methods to be used shall be subject to agreement of the user and provider of the determination

NOTE 1—Because Procedure C requires darkening the paste and aggregate, its use must occur after other tests if the analyst is also gathering petrographic data in addition to the measurements described in this test method.

5.3 No provision is made for distinguishing among entrapped air voids, entrained air voids, and water voids. Any such distinction is arbitrary, because the various types of voids intergrade in size, shape, and other characteristics. Reports that do make such a distinction typically define entrapped air voids as being larger than 1 mm in at least one dimension being irregular in shape, or both. The honey-combing that is a consequence of the failure to compact the concrete properly is one type of entrapped air void.

5.4 Water voids are cavities that were filled with water at the time of setting of the concrete. They are significant only in mixtures that contained excessive mixing water or in which pronounced bleeding and settlement occurred. They are most common beneath horizontal reinforcing bars, pieces of coarse aggregate and as channelways along their sides. They occur also immediately below surfaces that were compacted by finishing operations before the completion of bleeding.

5.5 Application of the paste-air ratio procedure is necessary when the concrete includes large nominal maximum size aggregate, such as 50 mm [2 in.] or more. Prepared sections of such concrete should include a maximum of the mortar fraction, so as to increase the number of counts on air voids or traverse across them. The ratio of the volume of aggregate to the volume of paste in the original mix must be accurately known or estimated to permit the calculation of the air-void systems parameters from the microscopically determined paste-air ratio.

NOTE 2—The air-void content determined in accordance with this test method usually agrees closely with the value determined on the fresh concrete in accordance with Test Methods C138/C138M, C173/C173M, or C231/C231M. However, significant differences may be observed if the sample of fresh concrete is consolidated to a different degree than the specimen later examined microscopically. For concrete with a relatively high air content (usually over 7.5 %), the value determined microscopically may be higher by one or more percentage points than that determined by Test Method C231/C231M.

SAMPLING AND SECTION PREPARATION

6. Apparatus and Materials for Specimen Preparation

6.1 *Apparatus and Materials for All Procedures—*

6.1.1 Apparatus and materials for the preparation of surfaces of concrete speciemens for microscopical observation are described in Practice C856; other apparatus may be equally suitable.

6.2 *Materials for Procedure C—*

6.2.1 *Opaque Permanent Black Ink,* wide felt-tipped marker, black ink stamp pad, or black ink roller, or similar.

6.2.2 *White Powder,* barium sulfate, wollastonite, or titanium dioxide with a median particle size of 2-3 µm, or similar.

6.2.3 *Light Oil,* light mineral oil, or similar.

NOTE 3—Apparatus for measurement of prepared specimens is described in the three following procedures.

7. Sampling (for all procedures)

7.1 Specimens of concrete can be obtained from concrete cast in the field or laboratory, or by coring, sawing, or otherwise removing concrete from structures or products. The procedure followed and the location from which the specimens are obtained will depend on the objectives of the program. In general, secure samples of hardened concrete in accordance with Test Method C42/C42M or Practice C823/C823M or both. Provide at least the minimum area of finished surface given in Table 1 in each specimen. A sample may be composed of any number of specimens.

7.2 For referee purposes or to determine the compliance of hardened concrete with requirements of specifications for the air-void system, obtain samples for analysis by this test method from at least three randomly selected locations over the area or

TABLE 1 Minimum Area of Finished Surface for Microscopical Measurement[A,B]

Nominal or Observed Maximum Size of Aggregate in the Concrete, mm [in.]	Total Area to be Traversed[C] for Determination of p,[D]A, α, or $\bar{L}$, min, cm^2 [in.^{2}] Based on Direct Measurement of: Total Air-Void Content	Paste-Air Ratio, p/A
150 [6]	1613 [250]	645 [100]
75 [3]	419 [65]	194 [30]
37.5 [1½]	155 [24]	97 [15]
25.0 [1]	77 [12]	77 [12]
19.0 [¾]	71 [11]	71 [11]
12.5 [½]	65 [10]	65 [10]
9.5 [⅜]	58 [9]	58 [9]
4.75 (No. 4)	45 [7]	45 [7]

[A] The indicated values refer to reasonably homogeneous, well-compacted concrete. The microscopical measurement shall be made on proportionately larger area of sections if the concrete is markedly heterogeneous in distribution of aggregate or large air voids. If more than one finished surface is taken from a single portion of the concrete, the finished surfaces shall be separated by a distance greater than one half of the nominal or observed maximum size of aggregate.

[B] See Section 3 for the interpretation of symbols employed.

[C] When performing a point count to determine p, A, α, or $\bar{L}$, the analysis points shall be distributed evenly over the area to be traversed.

[D] When p is determined, it shall be determined by analyzing the same area to be traversed for determination of A, α, or $\bar{L}$.