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# Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete[1]

This standard is issued under the fixed designation C1760; 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 covers the determination of the bulk electrical conductivity of saturated specimens of hardened concrete to provide a rapid indication of the concrete's resistance to the penetration of chloride ions by diffusion (See Note 1). The results of this test method can be related to the apparent chloride diffusion coefficient that is determined using Test Method C1556.

NOTE 1—The term "bulk" is used because the electrical conductivity is determined by measuring the current passing through all the phases of a test specimen (e.g., cement paste, sand, aggregate). This is accomplished using electrodes that cover the ends of the specimen. Other test methods that measure conductivity may use probes placed on the side surface of the specimen.

1.2 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *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.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to exposed skin and tissue upon prolonged exposure.[2])

## 2. Referenced Documents

2.1 *ASTM Standards:*[3]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field

C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C125 Terminology Relating to Concrete and Concrete Aggregates

C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

C1202 Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

C1543 Test Method for Determining the Penetration of Chloride Ion into Concrete by Ponding

C1556 Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion

## 3. Terminology

3.1 *Definitions:*

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

## 4. Summary of Test Method

4.1 This test method measures the electrical current through a saturated concrete specimen with a potential difference of 60 V dc maintained across the ends of the specimen. Test specimens can be 100 mm diameter by 200 mm long molded cylinders or nominal 100 diameter cores with length ranging from 100 to 200 mm. The apparatus and specimen conditioning procedures are the same as described in Test Method C1202, except that the side of the specimen does not have to be sealed. The current is measured 1 min after the voltage is first applied. The measured current, the applied voltage, and the specimen dimensions are used to calculate the bulk electrical conductivity of the concrete.

## 5. Significance and Use

5.1 This test method measures the bulk electrical conductivity of concrete, which has a theoretical relationship to the diffusion coefficient of chloride ion, or other ions, in the concrete (**1, 2**).[4] Experimental data confirm that there is a correlation between the apparent chloride diffusion coefficient measured by Test Method C1556, or similar method, and the bulk electrical conductivity (**3, 4**).

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[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.66 on Concrete's Resistance to Fluid Penetration.

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[2] See section on Safety Precautions, *Manual of Aggregate and Concrete Testing*, *Annual Book of ASTM Standards*, Vol. 04.02.

[3] 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.

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

5.2 A number of factors are known to affect electrical conductivity of concrete: water cementitious materials ratio, the type and amount of supplementary cementitious materials, presence of polymeric admixtures, admixtures that contain soluble salts, specimen age, air-void system, aggregate type, degree of consolidation, degree of saturation, and type of curing. Different curing methods are used in this test method depending on whether the concrete contains supplementary cementitious materials. Use the same method and duration of curing when comparing mixtures.

5.3 This test method is suitable for evaluation of concrete mixtures for proportioning purposes and for research and development. Specimens must be sufficiently saturated for measured electrical conductivity to provide an indication of the resistance of the concrete to chloride ion penetration. Because the electrical conductivity depends upon the degree of saturation, specimens are vacuum saturated before testing to ensure a common reference state for comparison purposes. If the specimen is tested in a partially saturated, or "as delivered" state, it shall be noted in the test report.

5.4 This test can be used to evaluate the electrical conductivity of concretes in structures for applications that may require such information, such as the design of cathodic protection systems.

5.5 The type of specimen and conditioning procedure depends on the purpose of the test. For evaluation of concrete mixtures, specimens are 100 mm diameter molded cylinders that are moist cured up to the time of testing. For evaluation of concrete samples taken from structures, specimens are 100 mm diameter cores that are vacuum saturated before performing the test.

5.6 Age of the test specimen may have significant effects on the test results, depending on the type of concrete and the curing procedure. Most concretes, if properly cured, become progressively and significantly less conductive with time.

5.7 Measured electrical conductivity can be used as a basis for determining the acceptability of a concrete mixture.

NOTE 2—Because the method and duration of curing of test specimens affect the test results, the acceptance criteria will need to specify the curing procedure and test age.

## 6. Interferences

6.1 This test method can produce misleading results if one is comparing concrete mixtures with and without soluble chemical admixtures such calcium nitrite (See Note 3). Calcium nitrite increases greatly the conductivity of the pore solution. For two concrete samples with the same microstructure, the electrical conductivity of concrete made with a calcium nitrite admixture will be greater than that of the same concrete without calcium nitrite. This could be interpreted falsely as a lower resistance to chloride ion penetration. Long-term chloride ponding tests indicated that concretes with calcium nitrite were at least as resistant to chloride ion penetration as the control mixtures (See Note 4).

NOTE 3—Procedures are available for estimating the pore solution conductivity from the concentration of ionic species present in the solution (**5**).

NOTE 4—Other admixtures that provide large quantities of ions might affect results of this test similarly. Long term ponding tests using Test Method C1543 or diffusion testing using Test Method C1556 are recommended if an admixture effect is suspected.

6.2 Because the test results are a function of the electrical resistance of the specimen, the presence of reinforcing steel or other embedded electrically conductive materials, including some types of aggregates, may yield unrepresentative results, as these will result in higher conductivity than a concrete of similar quality but with no embedded conductive material. Therefore, the test is not valid for specimens containing reinforcing steel.

## 7. Apparatus

7.1 *Vacuum Saturation Apparatus*—As described in Test Method C1202.

7.2 *Movable Bed, Water-Cooled Diamond Saw or Silicon Carbide Saw*—For trimming test specimen to test length, if required.

7.3 *Applied Voltage Cells*—As described in Test Method C1202.

7.4 *Voltage Application and Data Readout Apparatus*—As described in Test Method C1202.

7.5 *Jaw Caliper, Micrometer or Diameter Tape*—For measuring specimen diameter, readable to at least the nearest 0.1 mm. Depth of jaw for a jaw caliper shall be at least 70 mm.

7.6 *Jaw Caliper*—For measuring specimen length, with a measuring range up to at least 250 mm and readable to at least the nearest 0.1 mm.

## 8. Reagents and Materials

8.1 *Sodium Chloride Solution*—3.0 % by mass (reagent grade) in distilled water.

8.2 *Specimen-Cell Sealant*—As described in Test Method C1202. Needed if rubber gaskets are not used to seal test specimen in voltage cells.

8.3 *Filter Paper*—No. 2, 90-mm diameter. This is not required if rubber gaskets are used to seal test specimen in voltage cells.

## 9. Test Specimens

9.1 *Molded Cylinders*

9.1.1 Prepare 100 mm by 200 mm cylindrical specimens in accordance with Practice C192/C192M or Practice C31/C31M, whichever is applicable. The method of final curing depends on whether the concrete contains supplementary cementitious materials. Unless otherwise directed by the specifier of tests, moist cure specimens in accordance with 9.1.2 for concrete mixtures containing only portland cement. For concrete mixtures containing supplementary cementitious materials, moist cure in accordance with 9.1.3 or 9.1.4 as directed by the specifier of tests. If no specific instructions are provided, cure mixtures containing supplementary cementitious materials in accordance with 9.1.3.

9.1.2 *Basic Moist Curing*—Cure test specimens for 28 days in accordance with Practice C192/C192M for specimens prepared in the laboratory or in accordance with the standard curing procedure of Practice C31/C31M for specimens prepared in the field. During final moist curing, free water must be present on the surfaces of the test specimens. If the moist room is not able to maintain this condition, cure the specimens in water storage tanks in accordance with Specification C511.

9.1.3 *Extended Moist Curing*—Cure test specimens for 56 days in accordance with Practice C192/C192M for specimens prepared in the laboratory or in accordance with the standard curing procedure of Practice C31/C31M for specimens prepared in the field. During final moist curing, free water must be present of the surface of the test specimens. If the moist room is not able to maintain this condition, cure the specimens in water storage tanks in accordance with Specification C511.

NOTE 5—The 56-day moist curing period is to allow for some supplementary cementitious materials to develop potential properties because of their slower rate of reaction. Concrete containing supplementary cementitious materials may continue to show reductions in conductivity beyond 56 days. In some cases, the specifier of tests may require testing at later ages, such as 3 months.

9.1.4 *Accelerated Moist Curing*—Provide 7 days of standard curing in accordance with Practice C192/C192M for specimens prepared in the laboratory or in accordance with Practice C31/C31M for specimens prepared in the field. After 7 days of standard curing, immerse the specimens for 21 days in lime-saturated water at 38.0 ± 2.0 °C.

NOTE 6—The accelerated moist curing procedure has been found useful in providing an earlier indication of potential property development with slower reacting supplementary cementitious materials (**6**). The extended moist curing method and accelerated curing method may not provide the same results. The curing method will be selected by the specifier of tests so that it is in agreement with the established acceptance criteria.

9.2 *Cores*

9.2.1 Take cores using a water-cooled coring drill equipped with a 100-mm inside diameter diamond-dressed core bit. Drill cores in accordance with Test Method C42/C42M Mat locations indicated by the specifier of tests.

9.2.2 After drilling, wipe the surface of the core with a wet rag and place the core in a sealable plastic bag or container. It is not necessary to allow the surface water to evaporate before placing the core in the bag or container.

9.2.3 Transport cores to the laboratory in the sealed bags or container. If cores must be shipped, they shall be packed so as to be protected from freezing and from mechanical damage during transit.

9.2.4 If the concrete surface where the core is taken has been modified, for example, by texturing or by applying curing compounds, sealers, or other surface treatments, trim off that surface using a water-cooled diamond-dressed saw appropriate for the task.

9.2.5 If the core is not a full depth core, cut off the fractured end, using a water-cooled diamond-dressed saw, so that the cut end is approximately perpendicular to the core axis. Unless otherwise specified, the trimmed length of the core shall be between 100 and 200 mm, and shall be at least three times the nominal maximum size of aggregate.

NOTE 7—As the specimen length decreases, it is expected that there will be more variability in replicate test results because of variability in aggregate content within the specimen. The exact effect of specimen length on the variability of measured conductivity is not known. The specifier of tests may require more replicate tests if cores are less than 100 mm long.

## 10. Conditioning

10.1 Before testing, condition core specimens in accordance with the conditioning procedure in Test Method C1202 unless otherwise specified.

NOTE 8—If the purpose of testing cores is to evaluate the in-place conductivity, the specifier of tests may require that cores be tested in the "as received" condition.

10.2 Molded cylinders shall be in a saturated condition at the time of test by using one of the curing methods described in 9.1.

## 11. Procedure

11.1 Remove the specimen from water and blot off excess water from the side of the specimen.

11.1.1 Measure the length of the specimen to the nearest 0.1 mm along four lines spaced approximately 90° apart. If the range of lengths exceeds 5 mm, trim the end or ends of the specimen to achieve acceptance (See Note 9). Repeat the measurement of the length as stated above. If the ends of the molded specimens are convex or concave by more than 5 mm relative to the perimeter, trim the out-of plane end and measure the length as stated above. Calculate the average length to the nearest 0.1 mm.

NOTE 9—A large range of measured lengths indicates that one or both of the ends of the specimens are not perpendicular to the specimen axis. The end of the specimen that is not perpendicular to the axis should be trimmed.

11.2 Determine the diameter to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about midheight of the specimen. Alternatively, determine the average diameter to the nearest 0.1 mm using diameter tape placed around the specimen at its midheight.

11.3 Keep the specimen saturated between the end of conditioning and the time of testing. If there will be a delay between measurement of dimensions and measurement of conductivity, cover the specimen with a damp cloth or use other means to prevent drying.

11.4 Mount the specimen into the voltage cell in accordance with Test Method C1202, except that the side of the specimen does not need to be sealed. Prevent the side of specimen from drying until time of testing by covering with a damp cloth or other means.

11.5 Fill both cells with NaCl solution.

NOTE 10—In this test method both cells are filled with NaCl solution instead of using NaOH solution in one cell as in Test Method C1202. It is only necessary that the cells be filled with an electrically conductive solution.

11.6 Attach wiring to the cells and power supply in accordance with Test Method C1202.

11.7 Remove the damp cloth. If visible moisture is present on the sides of the specimen, wipe with a dry cloth or towel. As soon as the side of the specimen appears surface dry, turn on the power supply, set to 60.0 ± 0.1 V dc. Observe the initial current to verify that the apparatus is functioning correctly (See Note 11). During the measurement, the ambient temperature and the temperatures of the specimen and apparatus shall be in the range of 20 to 25 °C.

NOTE 11—For 100 mm diameter by 200 mm long specimens made from concretes with chloride ion penetrabilities in the range of 500 to 4000 C, measured in accordance with Test Method C1202, the current should be in the range of 6mA to 50 mA when a voltage of 60 V is applied across the ends of the specimens.

11.8 Read and record the current at 1 min ± 5 s from when the voltage was applied. Record the current to the nearest 0.1 mA.

11.9 Empty the cells and remove the specimen. Rinse the cells with tap water and remove residual sealant, if used.

## 12. Calculation

12.1 Calculate the bulk electrical conductivity to three significant digits using Eq 1:

$$\sigma = K \frac{I_1}{V} \frac{L}{D^2} \tag{1}$$

*where:*

$\sigma$ = bulk electrical conductivity, mS/m,
$I_1$ = current at 1 min, mA,
$V$ = applied voltage, V,
$L$ = average length of specimen, mm
$D$ = average diameter of specimen, mm, and
$K$ = conversion factor = 1273.2.

NOTE 12—The SI unit for electrical conductivity is siemens/meter, where a siemens has units of 1/ohm ($\Omega^{-1}$). To avoid reporting numbers that are less than 1, the electrical conductivity is reported in mS/m. The conversion factor $K$ in Eq 1 is used to make the necessary unit conversion. For concretes with coulomb values ranging from 500 to 4000 C measured in accordance with Test Method C1202, the values of bulk electrical conductivity should be in the range of 3mS/m to 20mS/m.

## 13. Report

13.1 For core specimens, report the following information, if known:

13.1.1 Identification number and the location in the structure where the core was obtained,

13.1.2 Date and time core was obtained,

13.1.3 Description of core, including presence and location of reinforcing steel, presence and thickness of overlay, presence of visible cracks, and presence and thickness of surface treatment,

13.1.4 Description of end preparation before testing,

13.1.5 Condition of core when tested if other than vacuum-saturated, and

13.1.6 Age of concrete at time of testing.

13.2 For molded cylinders, report the following information, if known:

13.2.1 Class of concrete, including binder type, and water-cementitious materials ratio,

13.2.2 Location where cylinder was molded,

13.2.3 Description of initial curing conditions,

13.2.4 Description of moist curing conditions after mold removal,

13.2.5 Description of end preparation, if required.

13.3 For each test specimen, report the following:

13.3.1 Average length of specimen, mm,

13.3.2 Average diameter of specimen, mm,

13.3.3 Applied voltage, V,

13.3.4 Current at 1 min, mA, and

13.3.5 Bulk electrical conductivity at 1 min to three significant digits and expressed in units of mS/m.

## 14. Precision and Bias

14.1 *Precision*

14.1.1 A preliminary interlaboratory study involving five laboratories and four concrete mixtures with average values of electrical conductivity measured at 1 min ranging from 3.2 to 16.4 mS/m resulted in an average single-operator coefficient of variation of 9.2 %.

NOTE 13—A complete interlaboratory study will be conducted and a complete precision statement is expected to be available within 5 years of the adoption of this test method.

14.2 *Bias*

14.2.1 Because there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

## 15. Keywords

15.1 chloride diffusion; chloride penetration resistance; conductivity; corrosion; resistivity

## REFERENCES


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