



Designation: C1876 – 23

# Standard Test Method for Bulk Electrical Resistivity or Bulk Conductivity of Concrete<sup>1</sup>

This standard is issued under the fixed designation C1876; 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 test method covers the determination of the bulk electrical resistivity or conductivity of molded specimens or cored sections of hardened concrete after immersion in water saturated with a simulated pore solution in order to provide a rapid indication of its resistance to the penetration of fluids and dissolved aggressive ions.

1.2 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard. If required results obtained from another standard are not reported in the same system of units as used by this standard, it is permitted to convert those results using the conversion factors found in the SI Quick Reference Guide.<sup>2</sup>

1.3 The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this standard.

1.4 *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.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.)<sup>3</sup> For specific warning statement see 8.1.2.

1.5 *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.*

<sup>1</sup> 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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<sup>2</sup> Annex A in Form and Style for ASTM Standards, www.astm.org/COMMIT/Blue\_Book.pdf.

<sup>3</sup> Section on Safety Precautions, Manual of Aggregate and Concrete Testing, Annual Book of ASTM Standards, Vol. 04.02.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>4</sup>

- C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
- C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
- 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
- C1202 Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
- C1556 Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion
- C1760 Test Method for Bulk Electrical Conductivity of Hardened Concrete (Withdrawn 2021)<sup>5</sup>

## 3. Terminology

### 3.1 Definitions:

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

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *bulk electrical resistivity, n*—material property that quantifies how strongly the material opposes the flow of electrical charge when an electric field is applied using electrodes placed on opposite faces of a test specimen; measured in units of ohm-meter.

3.2.2 *bulk electrical conductivity, n*—material property that quantifies how strongly the material permits the flow of electrical charge when an electric field is applied using electrodes placed on opposite faces of a test specimen; measured in units of milli-siemens per meter (mS/m).

3.2.2.1 *Discussion*—Bulk electrical conductivity is the reciprocal of bulk electrical resistivity.

<sup>4</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.

<sup>5</sup> The last approved version of this historical standard is referenced on www.astm.org.

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

#### 4. Summary of Test Method

4.1 The electrical resistance or conductance of a hardened concrete cylindrical specimen conditioned in accordance with this test method is determined on at least two specimens obtained from cores or cast in cylindrical molds, the ends are prepared, the dimensions measured, and then submerged in a simulated pore solution for at least 6 days, or from time of demolding in the case of molded cylinders. While the specimen is in the solution, the bulk resistivity or conductivity test device is verified over the expected range of resistivity or conductivity. Then the specimen is placed in the test device. In some testing apparatus, the voltage and current are measured such that the resistivity or conductivity can then be calculated. In other testing apparatus, the resistivity or conductivity is calculated directly once specimen dimensions are input.

#### 5. Significance and Use

5.1 The electrical resistivity of a concrete is the opposition to the movement of ions under an applied electric field. The electrical conductivity of a concrete is a measure of how readily the ions in the pore solution can be transported through the concrete under an applied electric field (the higher the conductivity, the greater the rate of transport). The electrical resistivity or conductivity is a material property that depends upon the pore volume, the pore structure (size and connectivity), the pore solution composition, the degree of saturation of the concrete specimen, and the specimen's temperature. Concrete mixture characteristics that are known to affect concrete electrical resistivity, as well as resistance to chloride ion penetration, include water-cementitious materials ratio, pozzolans, slag cement, the presence of polymeric admixtures, air-entrainment, aggregate type, aggregate volume fraction, degree of consolidation, curing method, and age.

5.2 The bulk electrical resistivity of concrete is the inverse of its bulk electrical conductivity. Bulk electrical conductivity can also be measured by Test Method **C1760**, which uses the apparatus described in Test Method **C1202**. This test method, however, uses apparatus specifically designed to measure bulk conductivity or bulk resistivity.

5.3 The purpose of conditioning in a simulated pore solution is to bring the specimen to a level of near complete saturation of the capillary and gel pores. When comparing two different concrete specimens, it is important to condition both specimens as close as possible to a comparable saturation state, using the same solution for conditioning, so that values can be compared in a meaningful way. This is particularly true for using the measured resistivity or conductivity, along with other information, to estimate the diffusivity.

5.4 The bulk electrical resistivity or conductivity of concrete can provide a rapid indication of its resistance to chloride ion penetration and resistance to penetration of other fluids. Resistivity or conductivity measurements have shown good correlations with other electrical indication tests including Test Method **C1202** (1, 2, 3).<sup>6</sup> Bulk electrical resistivity results have

shown good correlation with bulk diffusion determined using Test Method **C1556** on companion molded cylinders from the same concrete mixtures (4).

#### 6. Interferences

6.1 If this test method is used to compare different concrete mixtures, the results can be misleading if certain admixtures containing water-soluble ionic compounds, such as calcium nitrite and calcium nitrate, are present in one of the concrete mixtures. Chemical admixtures such as calcium nitrite can contribute to a lower electrical resistivity because they increase the conductivity of the pore solution (Note 1). This effect can be independent of the overall quality of the concrete because it has been shown in long-term bulk diffusion tests that concretes with calcium nitrite can perform as well as control mixtures without the admixture and lower conductivity.

NOTE 1—Similarly, other admixtures containing water-soluble ionic compounds might affect the results of this test method. Long-term chloride ion diffusion tests are recommended if an admixture effect is suspected. Alternately, this interference can be minimized by expressing results as a formation factor (see Appendix X1).

6.2 Because the test results are a function of the electrical resistance or conductance of the specimen, the presence of reinforcing steel, metal fibers, 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. The test is not applicable to specimens containing reinforcing steel positioned longitudinally that provide a continuous electrical path between the two ends of the specimen, and it is not applicable to specimens containing discrete metallic fibers.

6.3 Leaching of ions from the pore solution of concrete is known to affect measured resistivity or conductivity values. Even standard curing in water saturated with calcium hydroxide can influence the resistivity of the solution inside the pores of the concrete as potassium and sodium hydroxides are leached out. As such, concrete cylinders and cores are immersed in simulated pore solution for at least 6 days prior to testing.

6.4 The level of saturation of the concrete has a major impact on resistivity or conductivity because the electric current is mainly conducted through the liquid in the pores. Achieving full saturation is difficult, so while not perfect, the conditioning procedures used in this test method provide a methodology for achieving a high and reproducible level of saturation without allowing excessive leaching of alkalis.

6.5 Because concrete has a capacitive component, its electric response is characterized by a magnitude and a phase difference that is a function of the AC frequency. This may have an effect on the measured test result. The desired quantity is the magnitude of the impedance that is measured at the frequency that yields the minimum phase difference between the applied voltage and the measured current; that is, the system is behaving most like a resistor. A number of commercial devices operate at a single fixed frequency, typically

<sup>6</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

between 10 Hz and 1 kHz. The degree to which a limited frequency range impacts the result has been found to be no more than 5 % (5).

6.6 Electrical resistivity or conductivity is temperature dependent, so perform all tests on concrete specimens conditioned within  $\pm 2$  °C (5, 6).

6.7 The thin sponges, saturated with conductive fluid, that connect the test specimen to the plate electrodes, can provide a small amount of resistance (7). However, if both electrodes are clamped tightly to the test specimen, the resistance is minimal and can be neglected.

## 7. Apparatus

7.1 *Bulk Resistivity or Conductivity Test Device*, capable of supplying an ac voltage across the entire cross-section of the specimen, measuring the current passing through the specimen to three significant digits, and measuring the voltage drop across the ends of the specimen to three significant digits. The test device shall meet the verification requirements in Section 11.

NOTE 2—Several test devices are commercially available, but the voltage, frequency, and wave form used are different with each device. Some devices display resistivity or conductivity based directly on specimen geometry while others may display the electrical resistance of the specimen. In this test method, different devices may be used as long as they meet the verification requirements in Section 11.

7.2 *Stainless Steel Electrically Conductive Plate Electrodes*, made with at least the same nominal diameter (Note 3) as the ends of the specimens to be tested and between 6 mm and 8 mm thick. Plate electrodes shall be fitted with connectors that allow connection to the electrical cables. Plate electrodes are permitted to be larger than the specimen diameter or cross-section.

NOTE 3—Rectangular specimens, such as cubes or prisms, may also be measured using electrodes of at least the same size as the cross-section to be tested.

7.3 *Electrical Cables*, for connecting the plate electrodes to the test device. Two insulated cables or one insulated cable with two conductors made of 18 AWG stranded copper wire have been found to be satisfactory. The ends of the cables shall be suitable for connecting to the test device and the plate electrodes.

7.4 *Set of Verification Resistors*, including at least two precision resistors, with tolerances no greater than  $\pm 0.1$  % of their nominal value, that cover the potential range of resistivity values for the concrete mixtures to be tested. Use of a cylindrical verification cell containing multiple precision resistors, such as provided by some equipment suppliers, is also suitable for this purpose.

NOTE 4—It is recommended that the precision resistors cover the range from 100 ohm to 100 kohm.

7.5 *Sponges*, or other alkali-resistant absorbent material with at least the same dimensions as the cross-sections of the ends of the test specimen.

7.6 *Specimen Holder*, for tests to be conducted horizontally, sufficiently large enough to support the cylindrical specimen

during testing. The specimen holder shall be made of rigid plastic or other similar electrically non-conductive material.

NOTE 5—Two vertically oriented V-notch plates fixed to a base plate provides a suitable specimen holder.

7.7 *Non-Electrically Conductive Surface*, for tests to be conducted vertically, such as a rubber or plastic base or mat of at least 3 mm thickness and having a cross-sectional area larger than that of the plate electrodes. The test device is placed on top of this non-conductive mat or base.

7.8 *Ruler*, 300 mm to 380 mm in length divided into 1 mm graduations.

7.9 *Saw*, for trimming ends of cores. The saw shall have a diamond or silicon-carbide cutting edge and shall be capable of cutting cores without introducing cracks or dislodging aggregate particles.

## 8. Reagents and Materials

8.1 *Simulated Pore Solution Saturated with Calcium Hydroxide*—Add 7.6 g of dry NaOH, 10.64 g of dry KOH, and 2.0 g of dry  $\text{Ca}(\text{OH})_2$  to a 1 L container and add deionized water to the 1 L mark. Use reagent grade chemicals conforming to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.<sup>7</sup>

NOTE 6—Sufficient solution can be made in an 18 to 20 L bucket using 13 250 g deionized water, 102.6 g NaOH, 143.9 g KOH, and 27 g  $\text{Ca}(\text{OH})_2$ . No correction for purity of reagents is made.

NOTE 7—This simulated pore solution has been found to minimize the potential for leaching of alkalis and calcium hydroxide from the test specimens and minimize changes to the electrical conductivity of the pore solution. The conductivity and resistivity of this pore solution has been found to be 7874 mS/m and 0.127 ohm-m, respectively. Compositions and conductivities of pore solutions in different concretes and at different ages will vary but it is not practical to match pore solution compositions to those of each concrete being tested.

8.1.1 Bring the simulated pore solution to room temperature prior to use.

8.1.2 **Warning**—Before using NaOH and KOH, review the following: (1) the safety precautions for using NaOH and KOH; (2) first aid for burns; and (3) the emergency response to spills, as described in the manufacturer's Material Safety Data Sheets or other reliable safety literature. NaOH and KOH as well as solutions made with them can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used when making the solution and when placing and removing specimens from the pore solution. These should include full-face shields, rubber aprons, and gloves impervious to NaOH and KOH. Gloves should be checked periodically for pin holes.

8.2 *Conductive Fluid*—An electrically conductive liquid is applied to sponges and each electrode to ensure electrical

<sup>7</sup> Reagent Chemicals, American Chemical Society Specifications, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.