



# Standard Test Method for Determining the Penetration of Chloride Ion into Concrete by Ponding<sup>1</sup>

This standard is issued under the fixed designation C 1543; 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 determines the penetration of chloride ion into concrete from a sodium-chloride solution pond. This method is applicable to all types of concrete, as well as to concretes treated with systems such as sealants, penetrating sealers, or thin-bonded overlays.

1.2 The values stated in SI units are to be regarded as 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.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

C 125 Terminology Relating to Concrete and Concrete Aggregates<sup>2</sup>

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory<sup>2</sup>

C 672/C 672M Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals<sup>2</sup>

C 1152/C 1152M Test Method for Acid-Soluble Chloride in Mortar and Concrete<sup>2</sup>

C 1202 Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration<sup>2</sup>

### 2.2 AASHTO Standard:

T 259 Method of Test for Resistance of Concrete to Chloride Ion Penetration

## 3. Terminology

3.1 Terms used in this standard are defined in Terminology C 125.

## 4. Summary of Test Method

4.1 A sodium-chloride solution is ponded on the surface of concrete specimens. Samples from specified depths are peri-

odically extracted and chemically analyzed to determine the chloride content of the concrete at those depths. The curing and moisture conditioning to which a specimen is subjected prior to ponding affects the mechanisms involved in chloride-ion penetration. These factors must be considered carefully in interpreting the results. Information on the mechanisms of chloride penetration into concrete is given in the appendix.

## 5. Significance and Use

5.1 This test method is suitable for evaluation of materials and material proportions for construction purposes as well as for research and development.

5.2 This test method can be used to establish the correlation between indirect measures of the chloride-ion penetration of concrete (see Test Method C 1202) and the actual chloride-ion penetration under controlled conditions.

5.3 This test method is not intended to provide a measure of the length of service that may be expected from use of a specific concrete mixture or sealing material.

## 6. Apparatus

6.1 *Glass Plates or Polyethylene Sheets*, of sufficient size to cover the ponded surface of the specimen.

6.2 *Molds*, of the proper size for the test specimens to be used, and conforming to the applicable requirements of Practice C 192/C 192M.

## 7. Reagents

7.1 *Ponding Solution*—3 % reagent grade sodium chloride (NaCl) by mass in distilled water (see Note 1).

NOTE 1—Other chloride-bearing solutions or different sodium-chloride concentrations may be used when there is a need to evaluate their specific effects. The concentration of the solution can be checked using a hydrometer calibrated to indicate the mass fraction of sodium chloride.

## 8. Specimens

8.1 Use as ponding specimens in this test method slabs having a surface area of at least 0.030 m<sup>2</sup> and a thickness of 90 ± 15 mm. At least two replicate specimens shall be made for each combination of variables to be tested.

8.2 Fabricate and cure molded ponding specimens in accordance with applicable sections of Test Method C 672/C 672M, unless otherwise specified.

<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.

Current edition approved Aug. 10, 2002. Published October 2002.

<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.02.

8.3 Obtain a sample of concrete for use in determining the background chloride content. Cast a 100 by 200-mm cylinder from the concrete mixture for this purpose when fabricating ponding specimens.

8.4 Provide a dike approximately 20 mm high along the perimeter of the top surface of the specimen to retain the ponding solution. The dike shall be made of a material that adheres to the specimen or be integrally cast as a part of the specimen. It shall serve to keep the top of the specimen covered completely by ponding solution throughout the period of the ponding (see Note 2).

NOTE 2—Closed-cell polystyrene foam 12 to 25 mm thick and acrylic strips 6 mm thick, bonded to the specimen with an adhesive caulking compound or silicone sealant, have been used successfully.

8.5 Coat the sides of the specimens with a suitable material (see Note 3) to prevent lateral moisture migration. Do not coat the bottom of the specimen. Allow the coating to cure according to the manufacturer's instructions.

NOTE 3—A rapid setting epoxy sufficiently viscous to adhere to vertical surfaces without excessive running has been used successfully for this purpose.

## 9. Procedure

9.1 Following completion of curing, cover the surface of the specimen with the ponding solution to a depth of  $15 \pm 5$  mm.

9.2 Place a glass plate or polyethylene sheet over the ponded specimen to retard evaporation of water from the solution.

9.3 Store the ponded specimens at  $23.0 \pm 2^\circ\text{C}$  and  $50 \pm 5$  % relative humidity. Provide for air circulation around sides and bottom of specimens.

9.4 Periodically monitor the depth of solution on the surface of the specimen and maintain at the specified depth by adding additional fresh solution. At 2-month intervals during the ponding, remove the solution and replace with fresh solution.

9.5 Select the duration of the ponding period and the sampling intervals to be appropriate for the purposes for which the tests are being made (see Note 4).

NOTE 4—It is recommended that the initial sampling be performed after 3 months ponding. Subsequent sampling can be performed after 6 and 12 months of ponding and at 12-month intervals thereafter.

### 9.6 Sampling:

9.6.1 Prior to sampling, remove the ponded solution and allow the specimen surface to dry. After drying is completed, remove the salt crystals from the surface by brushing with a wire brush.

9.6.2 Sample the specimen by coring. The diameter of the core shall be at least three times the nominal maximum aggregate size.

9.6.3 Alternatively, obtain powdered sample by rotary-impact hammer as described in Test Method C 1152/C 1152M.

9.6.4 Space the sampling point at least 25 mm away from the inside edge of the dike or the edge of any previous sampling point. Samples shall be obtained from at least the following depths to provide a profile of the chloride penetration:

| Sampling Intervals, mm |
|------------------------|
| 10–20                  |
| 25–35                  |
| 40–50                  |
| 55–65                  |

9.6.5 If the purposes of the test require a precise profiling of the chloride penetration, the sampling shall be accomplished by removing a core from the specimen. The core shall be profiled by precision milling to obtain powdered concrete from horizons of the desired depth and thickness (see Note 5).

NOTE 5—Chloride penetration profiling on 1-mm thick horizons has been accomplished using this technique. An equation can then be fitted to the profile to calculate an effective diffusion coefficient using Fick's Second Law.<sup>3</sup> If a diffusion coefficient is to be calculated, at least 6 test points should be obtained.

9.6.6 If the specimen is to be re-ponded after sampling, patch the hole with a suitable low-permeability repair material (see Note 6). The location of the sampling point shall be clearly identifiable so it can be avoided during subsequent sampling.

NOTE 6—Epoxy mortar has been used successfully for this purpose.

9.7 Determine the chloride content of the sample from each depth of the ponded specimens and the background sample in accordance with Test Method C 1152/C 1152M. The background chloride content is subtracted from the value obtained for each depth of the ponded specimen to determine the penetrated chloride value.

## 10. Report

10.1 Report the following information:

10.1.1 Type and source of hydraulic cements,

10.1.2 Type and source of other cementitious materials,

10.1.3 Type and source of coarse and fine aggregates,

10.1.4 Type and source of chemical admixtures,

10.1.5 Concrete mixture proportions,

10.1.6 Type and manufacturer of any treatment system used,

10.1.7 Curing conditions and duration and other special specimen preparation procedures that were performed,

10.1.8 The moisture conditioning the specimen was subjected to prior to ponding,

10.1.9 The type and concentration of the ponding solution, if different from that specified in 7.1,

10.1.10 The chloride content of the specimen as a function of depth and the duration of ponding for each sample tested, and

10.1.11 The background chloride content of the concrete.

## 11. Precision and Bias

11.1 *Precision*—The precision of this test method has not been determined, but the subcommittee is planning to determine the precision in the future.

11.2 *Bias*—No information can be presented on the bias of the procedures in this test method because no material having an accepted reference value is available.

<sup>3</sup> Hearn, N., Hooton, R. D., and Mills, R. H., "Pore Structure and Permeability," STP 169C, *Significance of Tests and Properties of Concrete and Concrete Making Materials*, P. Klieger and J. F. Lamond, Eds., American Society for Testing and Materials, Philadelphia, PA, 1994, pp. 240–262.

## 12. Keywords

12.1 chloride; chloride content; concrete; penetration; permeability

## APPENDIX

### (Nonmandatory Information)

#### X1. MASS TRANSFER IN CONCRETE

X1.1 This test measures the chloride-ion content at selected depths within a concrete specimen on which a sodium-chloride solution has been maintained over an extended period of time. Differences in the chloride-ion content with depth and over time indicate the movement of chloride ions from the solution ponded on the concrete surface into the specimen being tested. Several different mechanisms are involved to greater or lesser degrees in this transport, depending on the pore structure, moisture condition, and surface treatment of the specimen.

X1.1.1 Permeability is the characteristic that describes the ease with which a fluid moves through concrete.<sup>4</sup> The primary controlling parameter in concrete permeability is the pore system of the paste fraction of the concrete, including the paste-aggregate interface.<sup>3</sup> The connectivity of the pore system depends on the amount of original mixing-water-filled space and the degree to which it has been filled with hydration products. Capillary pores are those voids remaining that were originally filled with mixing water; that is, pores with diameters in the range of 3.2 to 3,000 nm.<sup>5</sup> These capillary pores will cease to be connected at different times in the age of the concrete as a function of w/c and curing conditions.<sup>6</sup> If stored moist, these times are approximately:

|      |     |      |     |     |       |
|------|-----|------|-----|-----|-------|
| w/c  | 0.4 | 0.5  | 0.6 | 0.7 | >0.7  |
| Time | 3 d | 14 d | 6 m | 1 y | never |

X1.1.2 Concretes containing a pozzolan or ground granu-

lated blast-furnace slag show a continued decrease of pore size and continuity over a longer period of time than do portland-cement concretes not containing pozzolans or slag.

X1.1.3 Fluid movement in the capillary-pore system depends on the moisture condition of the pore system. When the concrete is at or near saturation, movement is due to laminar flow. The rate of flow depends on the pressure head causing the flow (in this case, gravity) and the tortuosity of the interconnected pore space. As the partial vapor pressure (relative humidity) falls below 1 to a value of about 0.45, vapor diffusion and capillary tension (absorption and wicking) dominate moisture movement. At partial vapor pressures below 0.45, movement is controlled by adsorption and surface diffusion.<sup>3</sup>

X1.1.4 In conditions of incomplete saturation where part of the capillary system is exposed to the atmosphere and the other to water, capillary tension is most important in the movement of water from the saturated zone into the unsaturated zone. In this test method, capillary tension plays an important role in initial chloride penetration if the specimen is subjected to drying prior to ponding. However, even if the specimen is saturated when subjected to ponding, exposure of the non-ponded bottom surface to the atmosphere will result in drying. As a consequence, moisture from the interior will be drawn by capillary tension toward the bottom surface, increasing the flow from the sodium-chloride solution pond.

X1.1.5 Ionic diffusion is the movement of ions through a solution. In this test method, the driving mechanism for chloride-ion diffusion is the concentration gradient between the sodium-chloride solution pond and the interior of the concrete. Most concrete structures have sufficient moisture in the pore system to allow for the diffusion of dissolved ions even though the internal relative humidity is less than 100 %.

<sup>4</sup> Young, J. F., "A Review of the Pore Structure of Cement Paste and Concrete and its Influence on Permeability," *SP-108, Proceedings, Permeability of Concrete*, D. Whiting, Ed., American Concrete Institute, Detroit, MI, 1988, pp. 1-18.

<sup>5</sup> Philleo, R. E., "Freezing and Thawing Resistance of High-Strength Concrete," *NCHRP Synthesis of Highway Practice 129*, Transportation Research Board, 1986, p. 31.

<sup>6</sup> Powers, T. C., Copeland, L. E., and Mann, H. M., "Capillary Continuity or Discontinuity in Cement Paste," *Journal of the PCA Research And Development Lab*, Vol 1, No. 2, 1959, pp. 38-48 (Reprinted as *PCA R&D Bulletin 110* 1988).

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