HMEC

Highway Materials Engineering Course

PARTICIPANT WORKBOOK

LABORATORY MANUAL

Testing Hardened Concrete

MODULE

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U.S.Department of Transportation
Federal Highway Administration

Contents

Laboratory Safety

Personal Protective Equipment

All participants in the laboratory experience must wear the following safety equipment at all times:

- Safety glasses
- Safety shoes or shoe covers
- Gloves
- Other safety equipment may be necessary for certain tests

Hazard Exposures

Fresh hydraulic cementitious mixtures are caustic and may cause skin irritation, severe chemical burns, or eye damage.

Ensuring Your Safety

For your safety, please follow all instructions provided by the laboratory experience instructors. Do not touch or handle equipment unless you have been given permission to do so.

Guidance on Precision Estimates

Each of the test methods described herein provide single-operator (repeatability) and multilaboratory (reproducibility) precision estimates. The single-operator precision provides an estimate of the expected variation of tests performed on the same material, by the same operator, using the same equipment, in the same laboratory. The multilaboratory precision provides an estimate of the expected variation of two tests performed on the same material, by different operators, using different equipment, in different laboratories. If the differences between properly performed tests exceeds these values, the testing practices and equipment should be investigated to determine the cause of the variation.

Laboratory Procedures and Time Needed to Complete

Standard Designation	Test Name	Prep Time	Total Time
AASHTO T 22/ ASTM C39	Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens	10 minutes	30 minutes
ASTM C42	Standard Method of Test for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete	Varies	0–7 days
AASHTO T 177/ ASTM C293	Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)	7 minutes	20 minutes
AASHTO T 97/ ASTM C78	Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)	7 minutes	20 minutes
ASTM C457	Standard Method of Test for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete	1 hour	2.5 hours
AASHTO T 161	Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing	14 days	64 days
ASTM C672	Standard Method of Test for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals	30 days	80 days
ASTM C469	Standard Method of Test for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression	30 minutes	2 hours
ASTM C418	Standard Test Method for the Abrasion Resistance of Concrete by Sandblasting	24 hours	25 hours
ASTM C779/C779M	Standard Method of Test for Abrasion Resistance of Horizontal Concrete Surfaces	15 minutes	2.5–4 hours
ASTM C944	Standard Method of Test for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating Cutter Method	1 hour	1.5 hours
ASTM C512/C512M	Standard Method of Test for Creep of Concrete Compression	28 days	1 year, 28 days
ASTM E660	Standard Method of Test for Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel, Circular Track Polishing Machine	30 days	31 days

Standard Designation	**Test Name**	**Prep Time**	**Total Time**
AASHTO T 277/ ASTM C1202	Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration	25 hours	31 hours
AASHTO T 259	Standard Method of Test for Resistance of Concrete to Chloride Ion	42 days	145 days
ASTM C157	Standard Method of Test for Length Change of Hardened Hydraulic-Cement Mortar and Concrete	15 minutes	28 days
ASTM C805	Standard Method of Test for Standard Method for Rebound Number of Hardened Concrete	10 minutes	35 minutes
ASTM C803	Standard Method of Test for Penetration Resistance of Hardened Concrete	5 minutes	25 minutes
ASTM C597	Standard Method of Test for Pulse Velocity Through Concrete	5 minutes	10 minutes
ASTM C900	Standard Method of Test for Pullout Strength of Hardened Concrete	Varies	Varies
AASHTO T 325	Estimating the Strength of Concrete in Transportation Construction by Maturity Tests	n/a	n/a
AASHTO TP 95	Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration	28 days	29 days

AASHTO T 22/ASTM C39, Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens

Background Information

This standard test method is limited to concrete having a density in excess of 800 kg/m3 (50 lb./ft3).

Significance and Use

The test method covers determination of compressive strength of cylindrical concrete specimens. Care must be taken in the interpretation of the significance of compressive strength determinations by this test method. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

Related Tests and Specifications

- AASHTO T 23/ASTM C31, Practice for Making and Curing Concrete Test Specimens in the Field
- AASHTO R 39/ASTM C192, Practice for Making and Curing Concrete Test Specimens in the Laboratory
- AASHTO T231/ASTM C617, Practice for Capping Cylindrical Concrete Specimens
- ASTM C1231/C1231M, Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

Timeline for Completion

Preparation Time: 10 minutes

Measurements of the test specimens must be taken. The ends of the test specimen must be made to conform to the planeness requirements by sawing, grinding, or a capping method.

Test Time: 10 minutes

The first half of the anticipated load can be performed at a higher rate of loading, while the second half is completed at a rate of loading of 0.25± 0.05 MPa/s [35 ± 7 psi/s]. Loading is concluded when the load indicator shows that the load is decreasing steadily and the specimen shows a well-defined fracture pattern.

Calculations: 10 minutes

The surface area of the specimen is determined based on the average diameter. The total load is divided by the area to determine compressive strength.

TOTAL TEST TIME: 30 minutes

Note: If specimen requires bonded cap, preparation requires sufficient time for cap to develop the required strength.

Apparatus

Testing Machine – Shall have sufficient capacity and capable of providing the rates of loading necessary. It shall meet all of the criteria specified in AASHTO T 22 and ASTM C39.

Sample Preparation

Specimen diameters are to be determined by averaging two diameters measured at right angles at about mid-height. No individual diameter of a cylinder should differ by more than 2% of any other diameter of the same cylinder. If all cylinders are known to have been made from a single lot of reusable or single-use molds, which consistently produce specimens with average diameters within a range of 0.5 mm (0.02 in.), then diameter determinations can be reduced to the greater of one in 10, or three specimens per day.

The ends of the test specimen shall also be checked for perpendicularity and planeness prior to testing. No specimen shall depart from perpendicularity to the axis by more than 0.5 degrees. The ends of the compression test specimens that are not plane within 0.050 mm [0.002 in.] should be sawed or ground to meet that tolerance, or capped in accordance with either ASTMC617 or, when permitted, ASTM C1231.

While the use of bonded caps is not as popular as it has been in previous decades, it is the primary end treatment in approximately 25% of the laboratories in the US. Care needs to be taken to assure that the caps are done correctly. Voids in the caps caused by water vaporizing and forming air pockets are a common problem. Improper use of alignment devices on the capping stand will cause the cylinder to experience an eccentric load. Caps should be as thin as possible to allow the best possible testing of the cylinder. Attention is invited to AASHTO T 231 and ASTM C617.

Procedure

Step 1

All test specimens for a given age shall be broken within the time tolerances permitted in Table 1.

Table 1: Permissible Time Tolerance

Test Age	Permissible Tolerance
1 day	± 0.5 hours or 2.1%
3 days	2 hours or 2.8%
7 days	6 hours or 3.6%
28 days	20 hours or 3.0%
90 days	2 days or 2.2%

Step 2

Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen and place the specimen on the lower bearing block. Align the axis of the specimen with the center of thrust of the spherically seated block.

Step 3

Verify the load indicator is set to zero after placing the specimen in the machine, but prior to applying the load on the specimen. Tilt the movable portion of the spherically seated block by hand so that the bearing faces appears to be parallel to the top of the test specimen.

Step 4

During the first half of the loading phase of the anticipated load, a higher rate of loading is permitted. The designated rate of movement of 0.25± 0.05 MPa/s [35 ± 7 psi/s] shall be maintained during the latter half of the anticipated loading phase.

Step 5

No adjustments are to be made as the ultimate load is being approached. Continue to apply the load until the load indicator shows that the load is decreasing steadily and the specimen displays a well-defined fracture pattern.

Note: When testing with unbonded caps, a corner fracture similar to a Type 5 or 6 pattern may occur before the ultimate capacity of the specimen has been attained!

Step 6

Record maximum load carried by the specimen and note the type of fracture pattern.

Calculations

Calculate the compressive strength of the specimen.

Divide the maximum load carried by the specimen during the test by the average cross-sectional area determined during preparation.

If the specimen length to diameter ratio is 1.75 or less, correct the result obtained by multiplying by the appropriate correction factor in Table. Use interpolation to determine correction factors between those given in the table.

Table 2: Correction Factors

L/D	1.75	1.5	1.25	1.00
Factor	0.98	0.96	0.93	0.87

$$Compressive\ Strength = \frac{Maximum\ Load\ Carried}{Average\ Cross\ Sectional\ Area}$$

Example Calculations

Diameters Measurement #1: 4.02 in.

Diameters Measurement #2: 4.00 in.

Average Diameter: 4.01 in.

Length: 7.95 in.

Length to Diameter ratio: 1.98 (No correction required)

Specimen Area (πr^2): 12.62 in^2

Total Load: 41,160 pounds force

Compressive Strength: 3,260 psi

$$3260\ \text{psi} = \frac{41{,}160\ \text{pounds force}}{12.62\ \text{in}^2}$$

Reporting the Test Results

- Information to be reported:
- Identification number
- Average measured diameter (millimeters or in.)

- Cross-sectional area (square millimeters or square in.)
- Maximum Load (kilonewtons or pounds-force)
- Compressive Strength (MPa or psi)
- Type of fracture (See Figure 1)
- Defects in either specimen or caps
- Age of specimen

Compressive strength is reported to the nearest 0.1 MPa (10 psi).

Specimen ID	**Age (days)**	**Average Diameter (in)**	**Specimen Area (in2)**	**Total Load (pounds)**	**Compressive Strength (psi)**	**Type of Fracture**	**Defects**
XXX-1	28	4.01	12.62	41,160	3,260	2	None

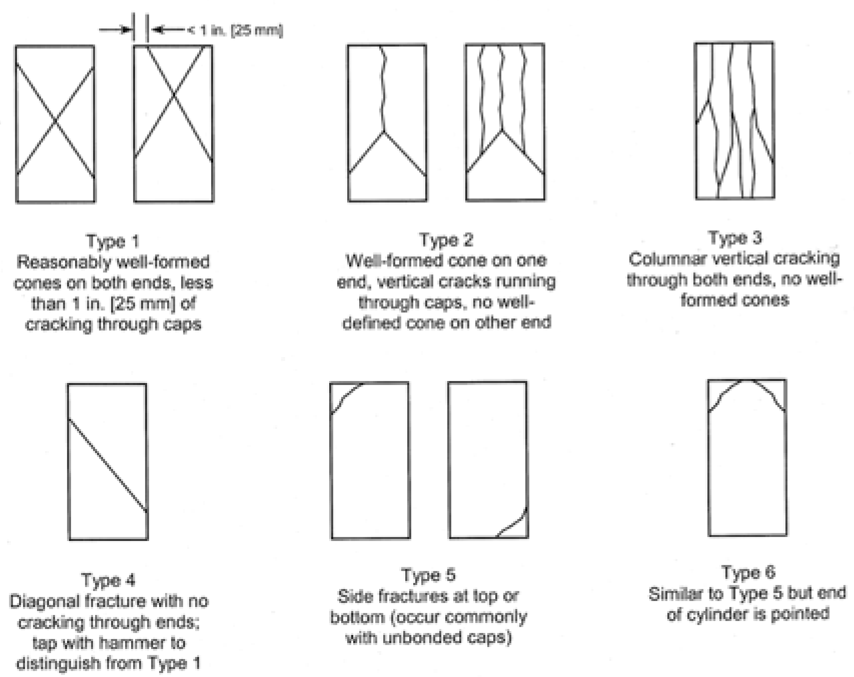


Figure 1: Types of Fracture

Reprinted, with permission, from ASTM C39 Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.

Common Errors

- Ends of specimens not checked for perpendicularity and planeness.
- Diameter measured at the ends of specimen rather than mid-height.
- Correct number of specimens measured per day.
- Rate of load continually adjusted until fracture occurs.

Data Sheets

Specimen ID	Age (days)	Average Diameter (in)	Specimen Area (in^2)	Total Load (pounds)	Compressive Strength (psi)	Type of Fracture	Defects

ASTM C42, Standard Method of Test for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

Background Information

Determines the in place strength of hardened concrete.

Significance and Use

This test is typically run when the strength of hardened concrete is in question. An actual sample of the hardened concrete is drilled in place and tested to confirm its strength.

Related Tests and Specifications

- AASHTO T 22/ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
- AASHTO T 231/ASTM C617, Standard Practice for Capping Cylindrical Concrete Specimens.
- ASTM C1231, Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders.
- AASHTO T 148/ASTM C174, Standard Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores
- ASTM C1542, Standard Test Method for Measuring Length of Concrete Cores

Timeline for Completion

Preparation Time: Varies

Concrete is drilled out of a hardened slab.

Test Time: 0–7 days

The core must be checked, measured, and tested (broken) within seven days of drilling.

Calculations: 15 minutes

Determination of strength.

TOTAL TEST TIME: 0–7 days

Apparatus

Core Drill – Used to obtain a core sample. Machine will have a series of drill bits with different diameters. The drill bits must be diamond impregnated and bit must be able to make a core at least 94 mm [3.70 in.] in diameter.

Balance – Must be accurate to the nearest 5g.

Saw – Used to cut/trim ends of specimens.

Measuring Equipment ¬– Used to determine the length of the specimen. Can use either a jig, as described in C174, calipers, or a ruler as described in C1542.

End Treatment Equipment – One of three options are available to treat the ends of the cores.

- Grinder – capable of creating a surface plane to 0.050 mm [0.002 in.]
- Capping material as described in C617.
- Unbonded caps as described in C1231.

Sample Preparation

Cores must be taken from hardened concrete that has been cured long enough so that drilling will not affect the bond between the mortar and coarse aggregate.

The core must be drilled perpendicular to the surface. It must also be at least six in. away from formed joints or edges.

Any core that has been damaged during removal, or shows abnormal defects, shall not be used.

Procedure

Step 1
As described in C39, take 2 diameters of the cylinder, in the middle, at 90 degree angles to each other.

Step 2
Determine the uncapped length of the core, using the method described in C174 or C1542.

Step 3
Weigh the core, and using measured dimensions determine the density

Step 4
Treat the ends by capping (C617), use of unbounded caps (C1231), or by grinding ends of cores plane to 0.050 mm [0.002 in.]

Step 5
If capping was used (C617), determine the length of core again (capped length)

Step 6
Break specimen according to C39

Step 7
Determine if length to diameter ratio warrants a correction factor for strength. If capping (C617) was used, use the capped length in L/D ratio.

L/D Ratio	1.75	1.50	1.25	1.00
Strength Correction Factor	0.98	0.96	0.93	0.87

Calculations

Step 1
Calculate average measured diameter and use as ‘D’.

Step 2
Average the length measurements to determine ‘L’

Step 3
Using ‘L’ and ‘D’, determine the density of the core

Step 4
If capping was used calculate a new ‘L’ after capping’

Step 5
Compute an L/D ratio. If ratio does not align with correct correction factor, use linear interpolation between points.

Step 6
Multiply recorded strength by correction factor

Example Calculations

Diameters: 3.78 in., 3.80 in.

$$D = \frac{3.78 + 3.80}{2} = 3.79\ in$$

Length, per C1542: 6.15 in., 6.13 in., 6.15 in., 6.17 in., 6.14 in.

$$L = \frac{6.15 + 6.13 + 6.15 + 6.17 + 6.14}{5} = 6.148 = 6.15\ in$$

Weight of Core: 4.67 lbs., *Volume of Core* = π x $(3.79 / 2)^2$ x 6.15 = 69.381 in^3

Density of Core = (4.67 lbs / 69.381 in^3) (1 in^3 / 0.000578704ft^3) = 116.37 lbs/ft^3 = 116 lbs/ft^3

Length after capping: 6.25 in, 6.26 in, 6.23 in

$$L = \frac{6.25+6.26+6.25+6.26+6.23}{5} = 6.25\ in$$

$$\frac{L}{D} = \frac{6.25}{3.79} = 1.65$$

L/D Ratio	1.75	1.50	1.25	1.00
Strength Correction Factor	0.98	0.96	0.93	0.87

Linear interpolation dictates correction factor should be 0.97

Max load = 50,770 lbf

$$Strength = \frac{50{,}770\ lbf}{11.28\ in^2} = 4{,}500\ psi \times 0.97 = 4{,}366\ psi = 4370\ psi$$

Reporting the Test Results

- Density should be calculated to the nearest 1 lb./ft^3
- Strength is to be reported to the nearest 10 psi

Common Errors

- Length not measured correctly.
- Incorrect rate of loading.
- Rate of load continually adjusted until fracture occurs.

Data Sheets

Diameters: ________, ________ Average Diameter _________

Average Length _________

L/D = __________

L/D Ratio	1.75	1.50	1.25	1.00
Strength Correction Factor	0.98	0.96	0.93	0.87

Max Load = ___________

Strength = ____________

Corrected Strength = ____________

Weight of Core = __________

Volume of Core = __________

AASHTO T 177/ASTM C293, Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)

Background Information

This test method covers the determination of the flexural strength of concrete by the use of a simple beam with center-point loading.

Significance and Use

Flexural strength of specimens is determined for those specimens prepared and cured in accordance with Test Method T 24/C42 or Practices T 23/C31 or R 39/C192. Results are calculated and reports as the modulus of rupture.

Related Tests and Specifications

- AASHTO T 23/ASTM C31/C31M, Practice for Making and Curing Concrete Test Specimens in the Field
- AASHTO T 24/ASTM C42/C42M, Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- AASHTO R 39/ASTM C192/C192M, Practice for Making and Curing Concrete Test Specimens in the Laboratory
- AASHTO T 231/ASTM C617, Practice for Capping Cylindrical Concrete Specimens

Timeline for Completion

Preparation Time: 7 minutes

Mark guidance lines on specimen to aid in alignment in machine.

Test Time: 8 minutes

Specimen placed in machine and small load applied. Gaps checked and mitigated. Specimen loaded until failure.

Calculations: 5 minutes

Specimen is measured and calculations performed.

TOTAL TEST TIME: 20 minutes

Apparatus

Testing Machine – Shall have sufficient capacity and capable of providing the rates of loading in one continuous stroke to complete a test without requiring replenishment.

Loading Apparatus – The center point loading method shall be used employing bearing blocks that will ensure that forces applied to the beam will be perpendicular to the face of the specimen and applied without eccentricity.

Sample Preparation

The specimen shall conform to all requirements of Test Method T 24/C42 or Practices T 23/C31 or R 39/C192 applicable to beam specimens, and shall have a test span within 2% of being three times its depth as tested. The sides of the specimen shall be at right angles with the top and bottom. Alignment marks can be drawn on the specimen to aid in proper placement of the specimen in the machine.

Procedure

Step 1
Tests of moist-cured specimens shall be made as soon as practical after removal from moist storage.

Step 2
The test specimen shall be tested on its side in respect to its position when molded. Center the specimen on the bearing blocks.

Step 3
Load 3 to 6% of the anticipated ultimate load to bear on the test specimen.

Step 4
Using 0.10-mm and 0.40-mm [0.004 in. and 0.015 in.] feeler gauges, determine whether any gap is greater than or less than each of the gauges and eliminate the gaps by grinding, capping, or using leather shims.

Step 5
Continue loading specimen at a rate of 0.9 to 1.2 MPa/min [125 to 175 psi/min] until failure.

Step 6
Measure the specimen's cross-sectional area.

Note: This measurement is to be done as tested and not as fabricated.

Calculations

The modulus of rupture is calculated as follows:

$$Modulus\ of\ Rupture = \frac{3 \times Load \times Span\ Length}{2 \times Width \times Depth^2}$$

Example Calculations

The specimen fractured in the middle third of the span and the following items were measured during the test:

Average Width of Specimen = 153 mm

Average Depth of Specimen = 150 mm

Span Length = 460mm

Maximum Load = 12,700 N

Calculations:

Modulus of Rupture = (3 X 12,700 X 460)/(2 X 153 X 150^2)=**2.55 MPa**

Reporting the Test Results

The modulus of rupture should be reported to the nearest 0.05 MPa [5 psi]. Average width, depth, and lengths are to be reported to the nearest 1 mm [0.05 in.]. Maximum load is to be reported in N. Identification numbers, curing history, age of specimen, gap mitigation, and any defects in the specimen are also to be reported.

Common Errors

- Not checking the gaps with feeler gauges with a load on the specimen.
- Leather shims used when either not needed or when grinding and/or capping is required.
- Incorrect load rate is used.

Data Sheet

Identification Number = ______________

Average Width of Specimen = ______________

Average Depth of Specimen = ______________

Span Length = ______________

Maximum Load = ______________

Modulus of Rupture = ______________

Age of Specimen = ______________

Gap mitigation (capped, ground, leather shims, none) = ______________

Specimen fabrication (sawed, molded) = ______________

Span Length = ______________

Curing history and apparent moisture condition:

____

Defects or other notes:

____

AASHTO T 97/ASTM C78, Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

Background Information

This test method covers the determination of the flexural strength of concrete by the use of a simple beam with third-point loading.

Significance and Use

Flexural strength of specimens is determined for those specimens prepared and cured in accordance with Test Method T 24/C42 or Practices T 23/C31 or R 39/C192. Results are calculated and reports as the modulus of rupture.

Related Tests and Specifications

- AASHTO T 23/ASTM C31/C31M, Practice for Making and Curing Concrete Test Specimens in the Field
- AASHTO T 24/ASTM C42/C42M, Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- AASHTO R 39/ASTM C192/C192M, Practice for Making and Curing Concrete Test Specimens in the Laboratory
- AASHTO T 231/ASTM C617, Practice for Capping Cylindrical Concrete Specimens

Timeline for Completion

Preparation Time: 7 minutes

Mark guidance lines on specimen to aid in alignment in machine.

Test Time: 8 minutes

Specimen placed in machine and small load applied. Gaps checked and mitigated. Specimen loaded until failure.

Calculations: 5 minutes

Specimen is measured and calculations are performed.

TOTAL TEST TIME: 20 minutes

Apparatus

Testing Machine – Shall have sufficient capacity and capable of providing the rates of loading in one continuous stroke to complete a test without requiring replenishment.

Loading Apparatus – The third point loading method shall be used employing bearing blocks that will ensure that forces applied to the beam will be perpendicular to the face of the specimen and applied without eccentricity.

Sample Preparation

The specimen shall conform to all requirements of Test Method T 24/C42 or Practices T 23/C31 or R 39/C192 applicable to beam specimens and shall have a test span within 2% of being three times its depth as tested. The sides of the specimen shall be at right angles with the top and bottom. Alignment marks can be drawn on the specimen to aid in proper placement of the specimen in the machine.

Procedure

Step 1
Tests of moist-cured specimens shall be made as soon as practical after removal from moist storage.

Step 2
The test specimen shall be tested on its side in respect to its position when molded. Center the specimen on the bearing blocks.

Step 3
Load 3 to 6% of the anticipated ultimate load to bear on the test specimen.

Step 4
Using 0.10-mm and 0.40-mm [0.004 in. and 0.015 in.] feeler gauges, determine whether any gap is greater than or less than each of the gauges and eliminate the gaps by grinding, capping, or using leather shims.

Step 5
Continue loading specimen at a rate of 0.9 to 1.2 MPa/min [125 to 175 psi/min] until failure.

Step 6
Measure the specimen's cross-sectional area.

Note: This measurement is to be done as tested and not as fabricated.

Calculations

Step 1
If the fracture is within the middle third of the span length.

$$Modulus\ of\ Rupture = \frac{Load \times Span\ Length}{Width \times Depth^2}$$

Step 2
If the fracture is outside the middle third of the span length by no more than 5%.

$$Modulus\ of\ Rupture = \frac{3 \times Load \times Distance\ From\ Fracture\ to\ Nearest\ Support}{Width \times Depth^2}$$

Step 3
If the fracture is outside the middle third of the span length by more than 5%, discard the results of the test.

Example Calculation

The specimen fractured in the middle third of the span and the following items were measured during the test:

Average Width of Specimen = 152 mm

Average Depth of Specimen = 150 mm

Span Length = 460mm

Maximum Load = 21,200 N

Calculations:

Modulus of Rupture = (21,200 X 460)/(152 X 150^2)=**2.85 MPa**

Reporting the Test Results

The modulus of rupture should be reported to the nearest 0.05 MPa [5 psi]. Average width, depth, and lengths are to be reported to the nearest 1 mm [0.05 in.]. Maximum load is to be reported in N. Identification numbers, curing history, age of specimen, gap mitigation, and any defects in the specimen are also to be reported.

Common Errors

- Not checking the gaps with feeler gauges with a load on the specimen.
- Leather shims used when either not needed or when grinding and/or capping is required.
- Incorrect load rate is used.

Data Sheet

Identification Number = ______________

Average Width of Specimen = ______________

Average Depth of Specimen = ______________

Span Length = ______________

Maximum Load = ______________

Modulus of Rupture = ______________

Age of Specimen = ______________

Gap mitigation (capped, ground, leather shims, none) = ______________

Specimen fabrication (sawed, molded) = ______________

Span Length = ______________

Curing history and apparent moisture condition:

____

Defects or other notes:

____

ASTM C457, Standard Method of Test for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

Background Information

The microscopic air content of hardened concrete is determined by either the Linear-Traverse Method (Procedure A) or by the Modified Point-Count Method (Procedure B).The void frequency, specific surface, spacing factor, and paste-air ratio may also be determined. Procedure A consists of measuring the length of air voids across a series of regularly spaced lines along the specimen, and Procedure B consists of counting the frequency in which the air voids occur over a section of the specimen.

Significance and Use

The determinations made relate 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 in the development of products or procedures intended to enhance the resistance of concrete to cyclic freezing and thawing.

Related Tests and Specifications

- ASTM C42/C42M, Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- ASTM C125, Terminology Relating to Concrete and Concrete Aggregates
- ASTM C138/C138M, Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- ASTM C173/C173M, Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
- ASTM C231, Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
- ASTM C666/C666M, Test Method for Resistance of Concrete to Rapid Freezing and Thawing
- ASTM C670, Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- ASTM C672/C672M, Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
- ASTM C823, Practice for Examination and Sampling of Hardened Concrete in Constructions

- ASTM C856, Practice for Petrographic Examination of Hardened Concrete
- ASTM D92, Test Method for Flash and Fire Points by Cleveland Open Cup Tester
- ACI 201.2R, Guide to Durable Concrete
- ACI 211.1, Recommended Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

Timeline for Completion

Preparation Time: 1 hour

The sample must be sawed to testing size and, if needed, lapped smooth.

Test Time: 1 hour

Using magnification, either the lengths of air voids are measured or the number of air voids are determined for a section of the sample.

Calculations: 30 minutes

Calculate the air content and, if measured, void frequency, specific surface, spacing factor, and air-paste ratio.

TOTAL TEST TIME: 2.5 hours

Apparatus

Means of Preparing the Surface of the Sample – Apparatus as described ASTM C856 or any suitable apparatus for preparing the surface of the sample.

Microscope Lamp – To provide sufficient illumination of the sample.

Spirit level – For leveling the prepared sample.

Leveling Device – Used with the spirit level in leveling the prepared sample.

Microscope – A stereoscopic microscope and support for magnifying the sample is recommended; however, other suitable means may be used.

Apparatus for Procedure A

Linear-Traverse Device – For moving and measuring the sample, linear-traverse device is recommended; however, other suitable means may be used.

Apparatus for Procedure B

Point-Count Device – For moving and measuring the sample, a point-count device is recommended; however, other suitable means may be used.

Sample Preparation

Samples of concrete should be obtained from specimens cast in the field, from specimens cast in the laboratory, or from specimens removed from the structure being tested. The sampling procedures should generally be in accordance with ASTM C42 and/or ASTM C823.A sample may be composed of any number of specimens, but the minimum sample area given in Table 3 must be provided. The sections of the sample used in testing should be sawed to a size as large as can be examined by the available equipment. The sections should be sawed perpendicular to the layers in which the concrete was placed or perpendicular to the finished surface. If gross irregularities are present after sawing, the sections should be lapped smooth.

Table 3: Minimum Area

Nominal or Observed Maximum Size of Aggregate in the Concrete mm (in.)	**Total Area to be Traversed, Based on Direct Measurement of Total Air-Void Content $cm^2(in.^2)$**	**Total Area to be Traversed, Based on Direct Measurement of Paste Air Ratio $cm^2(in.^2)$**
150 (6)	1,613 (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 (#4)	45 (7)	45 (7)

Procedure A

Step 1

Place the specimen in the device, and level the surface. Adjust the lamp to evenly illuminate the field of view, and angle the lamp so the air voids are demarked by a shadow.

Step 2
Using a constant magnification of at least 50x, adjust the microscope so that its index point is at the top and end of the specimen, just short of the edges. Set all counters to zero.

Step 3
Use the main lead screw to move the specimen in the east-west direction until the index point reaches the start of an air-void. Actuate the tally counter once, and continue moving the specimen in an east-west direction but this time using the upper lead screw. Continue until the index point reaches the end of the air void. Resume using the main lead screw until the next air void is encountered.

Step 4
Continue along the specimen in this manner, using the main lead screw between air voids and the upper lead screw when traversing air voids, until the index point is just short of the edge of the specimen. Be sure to actuate the tally counter once for each air void encountered. The distances are recorded automatically by the rotation counter.

Using the north-south lead screw, shift the specimen to the next traverse line and repeat the procedure for measuring air voids. Repeat until the total length traversed meets the minimum requirement of Table.

Table 4: Minimum Length of Traverse for the Linear Traverse Method

Nominal or Observed Maximum Size of Aggregate in the Concrete mm (in.)	**Minimum Length of Traverse Needed for Determinations mm (in.)**
150 (6)	4,064 (160)
75 (3)	3,048 (120)
37.5 (1½)	2,540 (100)
25.0 (1)	2,413 (95)
19.0 (¾)	2,286 (90)
12.5 (½)	2,032 (80)
9.5 (⅜)	1,905 (75)
4.75 (#4)	1,397 (55)

Step 5
If the paste content is being determined, carry out the above procedure, except use a second east-west upper lead screw with rotation counter while traversing the paste regions of the specimen.

Procedure B

Step 1
Place the specimen in the device, and level the surface. Adjust the lamp to evenly illuminate the field of view, and angle the lamp so the air voids are demarked by a shadow.

Step 2
Using a constant magnification of at least 50x, adjust the microscope so that its index point is at the top and end of the specimen, just short of the edges. Position the stopping device at a stop or click position. Zero all counters.

Step 3
Use the east-west lead screw to move the specimen while simultaneously scrutinizing the surface. At each stop, record on the counters the material that the index point is over, either air void, paste, or other.

Step 4
Continue along the specimen in this manner until the final stop is reached just short of the edge of the specimen. Be sure to actuate the correct counter at each stop. Turn off the totaling counter. Using the east-west lead screw reverse directions back along the same line, recording every air void encountered on a separate counter whether or not a stop occurred.

Step 5
Using the north-south lead screw, shift the specimen to the next traverse line and repeat the procedure. Repeat until the total length traversed and the total points determined meet the minimum requirements of Table.

Table 5: Minimum Area

Nominal or Observed Maximum Size of Aggregate in the Concrete	Minimum Length of Traverse Needed for Determinations	Minimum Number of Points Needed for Determinations (mm)
150 (6)	4,064 (160)	2,400
75 (3)	3,048 (120)	1,800
37.5 (1½)	2,540 (100)	1,500
25.0 (1)	2,413 (95)	1,425
19.0 (¾)	2,286 (90)	1,350
12.5 (½)	2,032 (80)	1,200
9.5 (⅜)	1,905 (75)	1,125
4.75 (No. 4)	1,397 (55)	1,000

Calculations for Procedure A

Step 1
The data determined from this test will consist of:

N = total number of air voids intersected

R_i = number of rotations of the respective lead screws

P_i = pitch of the corresponding lead screws

Step 2
Calculate the total length of traverse (T_t), the traverse length through air (T_a), and the traverse length through paste (T_p):

$$T_t = \sum P_i \times R_i$$

$$T_a = P_a \times R_a$$

$$T_p = P_p \times R_p$$

Step 3
Calculate the air content (A) in %:

$$A = \frac{T_a \times 100}{T_t}$$

Step 4
Calculate the void frequency (n):

$$n = \frac{N}{T_t}$$

Step 5
Calculate the specific surface (α):

$$\alpha = \frac{4N}{T_a}$$

Step 6
Calculate the paste air ratio (p/A):

$$\frac{p}{A} = \frac{T_p}{T_a}$$

Step 7
Calculate the spacing factor (L).

When p/A is less than or equal to 4.342:

$$L = \frac{T_p}{4N}$$

When p/A is greater than 4.342:

$$L = \frac{3}{\alpha}\left[1.4 \times \left(1 + \frac{p}{A}\right)^{\frac{1}{3}} - 1\right]$$

Calculations for Procedure B

Step 1
The data determined from this test will consist of:

N = total number of air voids intersected

S_t = total number of stops

S_a = number of stops in air voids

S_p = number of stops in paste

l = east-west translation distance between stops

Step 2
Calculate the total length of traverse (Tt):

$$T_t = S_t \times l$$

Step 3
Calculate the air content (A) in %:

$$A = \frac{S_a \times 100}{S_t}$$

Step 4
Calculate the void frequency (n):

$$n = \frac{N}{T_t}$$

Step 5
Calculate the specific surface (α):

$$\alpha = \frac{400n}{A}$$

Step 6
Calculate the paste air ratio (p/A):

$$\frac{p}{A} = \frac{S_p}{S_a}$$

Step 7
Calculate the spacing factor (L).

When p/A is less than or equal to 4.342:

$$L = \frac{S_p \times 100}{S_t \times 400n}$$

When p/A is greater than 4.342:

$$L = \frac{3}{\alpha}\left[1.4 \times \left(1 + \frac{p}{A}\right)^{\frac{1}{3}} - 1\right]$$

Reporting the Test Results

Report the air content and, if measured, void frequency, specific surface, spacing factor, and air-paste ratio.

Interpreting and Utilizing the Test Results

For air-entrained concrete, the paste-air ratio (p/A) is usually in the range of 4 to 10, the specific surface (α) is usually in the range of 25 to 45 mm− 1 (600 to 1,100 in.−1), and the spacing factor (L) is usually in the range of 0.1 to 0.2 mm (0.004 to 0.008 in.).

The question of whether or not the determined parameters are acceptable to provide protection in water-saturated cyclic freezing and thaw conditions shall be made by the specifier, or be determined from actual freeze-thaw testing of the concrete.

The spacing factor (L) is generally regarded as the most significant indicator of the durability of the cement paste to freezing and thawing exposure of the concrete. The maximum value of the spacing factor for moderate exposure of the concrete is usually taken to be 0.20 mm (0.008 in.). Somewhat larger values may be adequate for mild exposure, and smaller ones may be required for severe exposure.

Satisfactory values of specific surface (α) and spacing factor (L) require that the void frequency (n) be larger than about 300/m (8/in.).

Data Sheet for Procedure A

N = total number of air voids intersected = ______________

R_i = number of rotations of the respective lead screws = ______________

P_i = pitch of the corresponding lead screws = ______________

Data Sheet for Procedure B

N = total number of air voids intersected = ______________

S_t = total number of stops = ______________

S_a = number of stops in air voids = ______________

S_p = number of stops in paste = ______________

l = east-west translation distance between stops = ______________

AASHTO T 161, Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing

Background Information

A temperature chamber is used to rapidly subject concrete to repeated cycles of freezing and thawing.

Significance and Use

Evaluation of resistance to rapid freezing and thawing allows testers to determine how concrete may react over time when used in environments where freezing and thawing is common.

Related Tests and Specifications

- AASHTO M 194, Chemical Admixtures for Concrete
- AASHTO M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- AASHTO R 39, Making and Curing Concrete Test Specimens in the Laboratory
- AASHTO T157, Air-Entraining Admixtures for Concrete
- AASHTO T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete
- ASTM C215, Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens
- ASTM C295, Guide for Petrographic Examination of Aggregates for Concrete
- ASTM C341, Practice for Length Change of Cast, Drilled, or Sawed Specimens of Hydraulic-Cement Mortar and Concrete
- ASTM C666, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
- ASTM C670, Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- ASTM C823, Practice for Examination and Sampling of Hardened Concrete in Constructions

Timeline for Completion

Preparation Time: 14 days

Specimens are cured for 14 days before being tested.

Test Time: 50 days

The specimens are subjected to 300 cycles of freezing and thawing with measurements being made every 36 cycles.

Calculations: 1 hour

TOTAL TEST TIME: 64 days

Apparatus

Chamber – In which specimens may be subjected to the freezing and thawing cycles.

Thermometers – Needed to measure the temperature at various points within the chamber and at the center of the control specimens.

Length Comparator – Capable of measuring the length change of the specimens.

Scale – Capacity approximately 50% greater than the weight of the specimens and accurate to at least 5 grams.

Temperature Tank – Capable of maintaining the specimens within -1°C and +2 °C (-2 °F and +4°F) of the target thaw temperature.

Sample Preparation

If made in the laboratory, the specimens shall be sampled by using the applicable standard methods. If cut from hardened concrete, the specimens are to be obtained in accordance with ASTM C823.The specimens shall be either prisms or cylinders, shall be 75-125 mm (3–5 in.) in width, depth, and diameter, and shall be 275-405 mm (11–16 in.) in length. Store specimens in saturated lime water until time of testing.

Procedure

Step 1

Immediately after the curing period, bring the specimen to a temperature within -1 °C and +2 °C (-2 °F and +4 °F) of the target thaw temperature that will be used in the freeze-thaw cycle and test for fundamental transverse frequency. Determine the mass and average length and cross-section dimensions of the concrete specimen within the tolerance required in ASTMC215.Determine the initial length comparator reading for the specimen with the length change comparator.

Step 2

Start freezing-and-thawing tests by placing the specimens in the thawing water at the beginning of the thawing phase of the cycle. Remove the specimens from the apparatus at intervals that are not to exceed 36 cycles. Make sure the specimens are completely thawed and at the specified temperature and place those in the tempering tank.

Step 3

In a thawed condition, test for fundamental transverse frequency, measure length, determine the mass of each specimen, and return them to the apparatus. Return the specimens either to random positions in the apparatus or to positions according to some predetermined rotation scheme.

Step 4

Continue with each specimen until it has been subjected to 300 cycles or until its relative dynamic modulus of elasticity reaches 60% of the initial modulus, whichever occurs first. Whenever a specimen is removed because of failure, replace it with a dummy specimen for the remainder of the test.

Calculations

Calculate the Relative Dynamic Modulus of Elasticity

$$P_c = \left(\frac{{n_1}^2}{n^2}\right) \times 100$$

Where:

$P_c = relative\ dynamic\ modulus\ of\ elasticity, after\ c\ cycles$

$n = fundamental\ transverse\ frequency\ at\ 0\ cycles$

$n_1 = fundamental\ transverse\ frequency\ after\ c\ cycles$

Calculate the Durability Factor

$$DF = \frac{P \times N}{M}$$

Where:

$DF = durability\ factor$

$P = relative\ dynamic\ modulus\ of\ elasticity\ at\ N\ cycles$

N= $number\ of\ cycles\ at\ which\ P\ reaches\ the\ minimum\ required$

M= $specified\ number\ of\ cycles\ at\ which\ exposure\ is\ terminated$

Calculate the Length Change

$$L_c = \frac{(L_2 - L_1)}{L_s} \times 100$$

Where:

$L_c = length\ change\ after\ c\ cycles$

$L_1 = length\ comparator\ reading\ at\ 0\ cycles$

$L_2 = length\ comparator\ reading\ at\ c\ cycles$

$L_s = effective\ gauge\ length$

Reporting and Interpreting the Test Results

The durability factor should be reported to the nearest whole number. The properties of the concrete along with the mass and dimensions of the specimen must be reported. It is recommended that modulus of elasticity or percent length change be plotted as curves against time expressed in cycles.

Common Errors

- Leaving the specimen in the wrong state when the test is interrupted.
- Not measuring the transverse frequency.

Data Sheets

Specimen ID:			
Length:			
Cross-Section:			
Nominal Gauge Length:			
Number of Cycles	**Mass**	**Fundamental Traverse Frequency**	**Length Comparator Reading**
0			

ASTM C672, Standard Method of Test for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

Background Information

This test method is used in determining the resistance to scaling of a concrete surface exposed to freezing-and-thawing cycles in the presence of deicing chemicals by visual examination.

Significance and Use

This test is used to evaluate the effect of mixture proportioning, surface treatment, curing, and other variables on resistance to scaling.

Related Tests and Specifications

- ASTM C143, Slump of Hydraulic-Cement Concrete
- ASTM C173, Air Content by the Volumetric Method
- ASTM C192, Practice for Making and Curing Concrete Test Specimens in the Laboratory
- ASTM C231, Air Content by the Pressure Method
- ASTM C511, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks

Timeline for Completion

Preparation Time: 28 days

The specimen is molded and then placed in moist storage for 14 days and air storage for 14 days before the test is started.

Test Time: 50 days

The specimen is placed in a freezing environment for 16 to 18 hours and placed in air for 6 to 8 hours. This cycle is repeated five times and the deicing solution flushed and replaced. The test is continued for approximately 50 cycles, until the surface area can be sufficiently evaluated.

TOTAL TEST TIME: 80 days

Apparatus

Freezing Equipment – Of sufficient size and capable of lowering the temperature of specimens to -18 ± 3°C [0 ± 5 °F] within 16 to 18 hours.

Molds – Conforming to ASTM C192, and having a surface area of at least 0.045 m2 [72 in2] and at least 3 in. in depth.

Tamping Rod – Conforming to ASTM C143.

Small Tools – Wood strike off board, steel trowel, and moderately stiff bristle brush.

Slump Cone – Conforming to ASTM C143.

Air Meter – Conforming to ASTM C173 or ASTM C231.

Scales – Conforming to ASTM C192.

Concrete Mixer – Conforming to ASTM C192.

Calcium Chloride – Or other suitable chemical deicers can be used.

Sample Preparation

Step 1
Mix the concrete in accordance with ASTM C192.Or if desired, test specimens may be cut from hardened concrete.

Step 2
Coat the inside surface of the mold with a light coat of mineral oil, or other release agent.

Step 3
Fill the mold in one layer and rod one time for each 1400 mm2 [2 in2] of surface. Tap the mold, spade around the outsides of the mold with a trowel, and level the surface with the wood strike-off board.

Step 4
After concrete has stopped bleeding, finish surface with three sawing motion passes of the wood strike-off board and use the brush on the surface.

Step 5
Place a dike (about 25 mm wide and 20 mm high [1-in. wide and ¾-in. high]) along the perimeter of the top surface of the specimens.

Step 6
Cover specimens with a polyethylene sheet after finishing. Remove the specimens from molds between 20 and 24 hours and place in moist storage meeting ASTM C511. Remove specimens from the moist room after 14 days (or until desired strength level has been obtained) and then

store specimens in air at 23.0 ± 2.0 °C [73.5 ± 3.5 °F] and 45 to 55% relative humidity for 14 days.

Note: Concrete with the following characteristics has been found useful for this test:

- **Non-air entrained**
- **Cement content of 565 ± 10 lb./yd^3**
- **Slump of 3 ± 0.5 in.**
- **Durable aggregate of 1 in. maximum size**

Procedure

Step 1
Cover the finished specimen surface with 6 mm [¼in.] of deicing solution (calcium chloride and water; 100 mL of solution contains 4 g calcium chloride).

Step 2
Place specimens in freezing environment for 16 to 18 hours.

Step 3
Remove specimens and place in air at 23.0 ± 2.0 °C [73.5 ± 3.5 °F] and 45 to 55% relative humidity for 6 to 8 hours.

Step 4
Add water between each cycle as necessary to maintain depth of solution.

Step 5
Repeat the cycle daily.

Step 6
Flush surface thoroughly at the end of each of the five cycles. Make a visual examination and replace the solution before continuing the test. Maintain specimens in a damp condition after removal of solution and flushing surfaces.

Step 7
Continue testing until a sufficient evaluation of the surface treatment can be made. This generally takes about 50 cycles or more.

Reporting the Test Results

Report the cement content, water-cement ratio, any admixture, slump, and air content of mixture; or report the size, shape, and orientation if specimens are cut from hardened concrete. Also include the type of surface treatment and deicer used and the time and rate of these applications. The visual rating of the surface is then reported after every 5, 10, 15, 25, and every 25 cycles thereafter using the numbered scale in the text, and photographs are to be included where possible.

Data Sheets

Mixing

Cement Content	
Water-Cement Ratio	
Admixture	
Slump	
Air content	

Sample Preparation

	Type (description)	**Time of Application**	**Rate of Application**
Surface Treatment			
Deicer			

Visual Rating of surface

# of Cycles	**Visual Rating of Surface (0–5 scale)**
5	
10	
15	
25	
50	
75	
100	

ASTM C469, Standard Method of Test for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

Background Information

This test is used to determine Young's chord modulus of elasticity and Poisson's ratio for cylinders and cores by applying a compressive load to the specimen. The specimen is fitted with a compressometer and/or an extensometer and loaded in the testing machine. The change in height, change in diameter, and load are then recorded.

Significance and Use

The results from this test method are used in sizing of reinforced and non-reinforced structural members, establishing the quantity of reinforcement, and computing stress for observed strains. The test provides a stress to strain ratio value and a ratio of lateral to longitudinal strain for hardened concrete.

Related Tests and Specifications

- ASTM C31, Making and Curing Concrete Test Specimens in the Field
- ASTM C39, Compressive Strength of Cylindrical Concrete Specimens
- ASTM C42, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- ASTM C174, Measuring Thickness of Concrete Elements Using Drilled Concrete Cores
- ASTM C617, Capping Cylindrical Concrete Specimens
- ASTM E4, Force Verification of Testing Machine

Timeline for Completion

Preparation Time: 30 minutes

Measure the specimen and cap or grind it to planeness.

Test Time: 60 minutes

Load approximately three specimens while recording stress and strain values at different test points.

Calculations: 30 minutes

Chord modulus of elasticity and Poisson's ratio are calculated from the values recorded.

TOTAL TEST TIME: 2 hours

Apparatus

Testing Machine – Shall conform to ASTM E4 and have bearing blocks conforming to ASTM C39.

Compressometer – To be used in determining the modulus of elasticity. The system can be bonded or unbonded, and must be capable of measuring to the nearest 5 millionths the average deformation of two diametrically opposite gauge lines that are parallel to the axis at about mid-height of the specimen. See Section 4.2 of ASTM C469 for more detail. The deformation shall be read by either a dial gauge, a wire strain gauge, or by a linear variable differential transformer.

Extensometer – To be used if determining Poisson's ratio. The transverse strain shall be determined by an unbonded extensometer, such as a dial gauge, capable of measuring the change in diameter at the mid-height of the specimento the nearest 0.5 µm; or by two bonded strain gauges. A convenient unbonded method is to use a combined compressometer and extensometer.

Sample Preparation

The test cylinders should be molded in accordance with ASTM C192 or ASTM C31, and cores obtained in accordance with ASTM C42, except that cores must have a length-to-diameter ratio greater than 1.50.Specimens are tested within 1 hour after removal from the curing environment. The ends of the specimen are capped in accordance with ASTM C617, ground, or lapped to meet the planeness requirement. The diameter is determined to the nearest 0.2 mm (0.01 in.) by averaging two diameters taken at right angles at the mid-height of the specimen. The length of the specimen, including caps, is measured to the nearest 2 mm (0.1 in.); cores must be measured in accordance with ASTM C174.

Procedure

Step 1
Use a companion specimen to establish the compressive strength in accordance with ASTM C39.

Step 2
Place specimen in compression machine with the strain-measuring equipment attached.

Step 3
Align specimen in machine with the upper bearing block and rotate the spherical block as it is brought to bear on the specimen. Take note of the reading on the strain indicators.

Step 4

Load the specimen at least twice (at a constant rate of 35 ± 7 psi/s).The first loading is used for seating gauges. Base calculations on the average of the results of the subsequent loadings (it is recommended to take at least two subsequent loadings to establish repeatability in the test).

Step 5

The applied load and longitudinal strain (total longitudinal deformation divided by the effective gauge length) are recorded at two points, without interruption of loading:

a) When the longitudinal strain, is at 50 millionths; and

b) When the applied load is equal to 40% of the ultimate load.

Step 6

If determining Poisson's ratio, record the transverse strain at the same points.

Step 7

Upon reaching the maximum load (except on the final loading), reduce the load to zero at the same rate at which it was applied.

Calculations

Determine the modulus of elasticity to the nearest 200 MPa (50,000 psi):

$$E = \frac{(S_2 - S_1)}{(\varepsilon_2 - 0.000050)}$$

Where:

E = chord modulus of elasticity, MPa (psi)

S_2= stress corresponding to 40% of the ultimate load

S_1= stress corresponding to a longitudinal strain, ε_1, of 50 millionths, MPa (psi)

ε_2= longitudinal strain produced by S_2

Determine Poisson's ratio, the nearest 0.01:

$$\mu = \frac{(\varepsilon_{t2} - \varepsilon_{t1})}{(\varepsilon_2 - 0.000050)}$$

Where:

μ = Poisson's ratio

εt_2= transverse strain at mid-height of the specimen produced by stress S_2

εt_1= transverse strain at mid-height of the specimen produced by stress S_1

Reporting the Test Results

Report the specimen identification number, dimensions of the specimen, curing and environmental histories of the specimen, age of the specimen, and chord modulus of elasticity. If determined, also report the strength of the concrete, unit weight of the concrete, stress-stain curves, and Poisson's ratio.

Common Errors

- Not securing the compressometer or extensometer correctly.
- Incorrect load rate.

Data Sheets

Specimen ID	
Diameter (D)	
Length (L)	
Cross Sectional Area (A) = ¼ π D^2	
Age when tested	
Ultimate Load	

After measuring the specimen and testing the companion cylinder, determine where the two test points will be taken. Determine the longitudinal deformation that will be read on the gauge when the longitudinal strain is at 50 millionths for test point 1.Determine the load at 40% of the ultimate load for test point 2.

Data Sheet During Loading of Specimen

	Load (lb.)	Stress (S) = Load/Area	Longitudinal deformation	Longitudinal Strain (ε)	Transverse strain (ε_t)
At 50 millionths (1)					
At 40% of Ultimate Load (2)					

ASTM C418, Standard Test Method for the Abrasion Resistance of Concrete by Sandblasting

Background Information

Determination of the abrasion resistance characteristics of concrete subject the concrete under study to the impingement of air-driven silica sand.

Significance and Use

This test method covers the laboratory evaluation of the relative resistance of concrete surfaces to abrasion. This procedure simulates the action of waterborne abrasives and abrasives under traffic on concrete surfaces. A cutting action is performed that tends to abrade more severely on the less resistant components of the concrete.

Related Tests and Specifications

- ASTM C127, Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
- ASTM C778, Specification for Sand
- ASTM C779/C779M, Test Method for Abrasion Resistance of Horizontal Concrete Surfaces
- ASTM C994, Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method
- ASTM C1138, Test Method for Abrasion Resistance of Concrete (Underwater Method)

Timeline for Completion

Preparation Time: 24 hours

Soak sample in water then surface dry.

Test Time: 30 minutes

Blast sample with sand; fill cavities with clay; weigh.

Calculations: 5 minutes

Calculate mass of clay on sample, then its specific gravity.

TOTAL TEST TIME: 25 hours

Apparatus

Scales – The scale shall have a capacity of 5,000 g or more. The permissible variation at a load of 5,000 g (11 lbs.) shall be ± 0.5 g (0.2 oz.).

Weights – The permissible variations on weights used in weighing shall be as prescribed in Table. The permissible variations on new weights shall be one half of the values given in Table.

Table 6: Permissible Variations on Weights

Weight, g	**Permissible Variations on Weights in Use, g**
1,000	±0.50
500	±0.35
300	±0.30
250	±0.25
200	±0.20

Sand Blast Apparatus – The sand blast apparatus shall consist of an injector-type gun. The gun shall have a high-velocity air jet fed by a suitably controlled rate of flow for the abrasive material. Provision shall be made to collect the spent abrasive and dust. Suitable jigs and clamps shall be provided to hold the test specimen in a fixed position with relation to the discharge end of the nozzle. The nozzle shall conform to the specifications in the standard.

Shield – The shield is square or circular, made from zinc-coated steel sheet or equivalent. It is 150 mm (6 in.) on a side or diameter and has a thickness in the range of 0.90 to 1.90 mm (0.035 to 0.075 in.). The shield has an opening 28.70 ± 0.25 mm (1.13 ± 0.01 in.) in diameter in the center.

Abrasive – The abrasive shall be 20–30 sand conforming to Specification C778 [predominantly graded to pass an 850-µm (#20) sieve and be retained on a 600-µm (#30) sieve].

Sample Preparation

Immerse the specimens in water for 24 hours and then surface dry with a damp cloth.

Procedure

Step 1

Calibrate the apparatus by adjusting the air pressure to 410 ± 1 kPa (59.5 ± 1 psi) and collect the abrasive for a period of 1 minute. Adjust the rate of flow of abrasive to 600 ± 25 g/min.

Step 2
Place the specimen at a distance of 75 ± 2.5 mm (3.0 ± 0.1 in.) from the end with the surface to be tested normal to the nozzle axis. Clamp the specimen firmly in place with shield attached. Expose the surface to the blast for a period of 1 minute.

Step 3
Repeat this on eight different spots.

Step 4
Weigh the clay.

Step 5
Press clay into the cavities with your fingers and weigh.

Step 6
Repeat the clay filling operation to ensure repeatable results.

Calculations

Calculate the volume of clay (V) used and the area of abraded surface to then compute the abrasion coefficient (A_c).

$$V = \frac{W_i - W_f}{B(B-C)^{-1}}$$

If the specific gravity of the clay is known, this can be reduced to:

$$V = \frac{W_i - W_f}{D}$$

Where:

W_i = initial mass of clay supply

W_f = final mass of clay supply

B = mass of a clay sample in air

C = mass of the same clay sample in water

D = specific gravity of the clay

$$A_c = V/A$$

Where:

A = area of the abraded surface

Example Calculations

$$V = \frac{200 - 100}{50(50 - 40)^{-1}}$$

$$V = \frac{100}{5} = 20$$

$$A_c = \frac{20}{80} = 0.25cm^3/cm^2$$

Reporting the Test Results

Report results to the nearest 0.01 cm^3/cm^2.Also report the location of the concrete that supplied the specimen and any other relevant characteristics.

Interpreting and Utilizing the Test Results

Higher coefficient values correspond to a more brittle concrete caused by segregation, excessive plasticizers, or other indeterminate effects.

Common Errors

- Improper equipment.
- Clay not finished flush with the surface.
- Failing to verify values with repeat operations.

Data Sheet

	Value
Weight of Clay (g)	
Weight of Clay in Water (g)	
Mass of Abraded Sample (g)	
Mass of Abraded Sample with Clay (g)	
Area of Abraded Surface (cm^2)	
Volume of Clay (cm^3)	
Coefficient of Abrasion (cm^3/cm^2)	

ASTM C779/C779M, Standard Method of Test for Abrasion Resistance of Horizontal Concrete Surfaces

Background Information

This method is not intended to provide a quantitative measurement of the length of service that may be expected from a specific surface.

Significance and Use

The three test methods provide simulated abrasion conditions, which can be used to evaluate the effects on abrasion resistance of concrete, concrete materials, and curing or finishing procedures. They may also be used for quality acceptance of products and surface exposed to wear.

Related Tests and Specifications

- ASTM C418, Test Method for Abrasion Resistance of Concrete by Sandblasting
- ASTM C944, Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method

Timeline for Completion

Preparation Time: 15 minutes

Attach the apparatus to the sample and prep it.

Test Time: 100–200 minutes

Initial measurements, grinding, final measurements.

Calculations: 15 minutes

Graphing results.

TOTAL TEST TIME: 2.5–4 hours

Apparatus

Revolving Disks Abrasion Test Machine (Procedure A) – The revolving-disk machine (Figure 2) operates by sliding and scuffing of steel disks in conjunction with abrasive grit. The machine must come equipped with a micrometer bridge for measuring the degree of abrasion.

Dressing Wheel Abrasion Test Machine (Procedure B) – The dressing-wheel machine (Figure 3) operates by impact and sliding friction of steel dressing wheels. The measuring instrument shall be a dial micrometer. A jig located on the underside of the spider holds the micrometer magnetically in the approximate center of the path of the dressing wheels.

Ball Bearing Abrasion Test Machine (Procedure C) – The ball-bearing machine (Figure 4) operates by high-contact stresses, impact, and sliding friction from steel balls. It shall be equipped with a dial indicator.

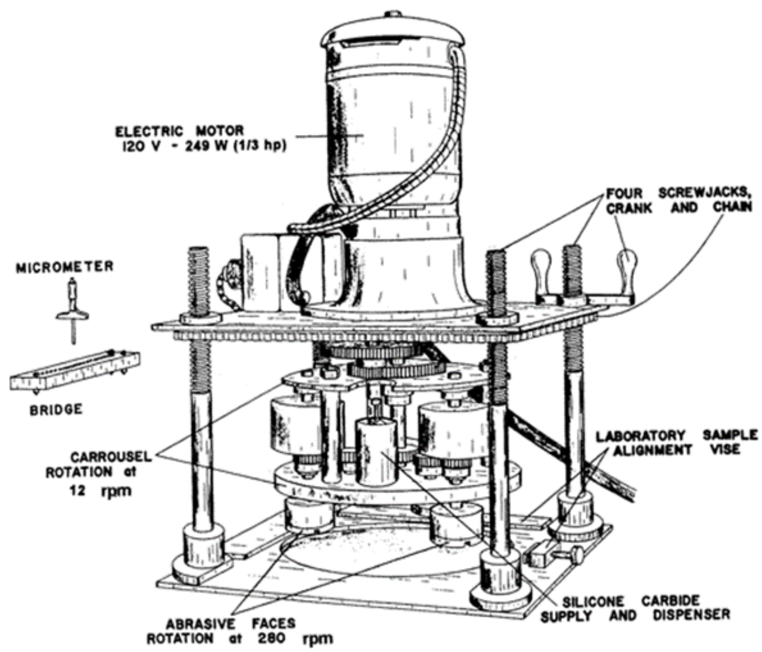


Figure 2: Revolving Disks Abrasion Test Machine

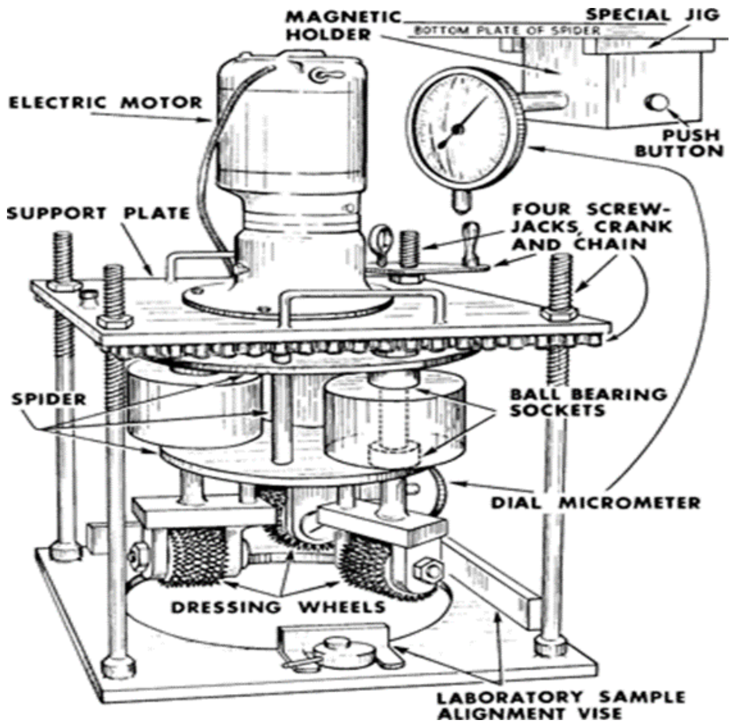


Figure 3: Dressing Wheel Abrasion Test Machine

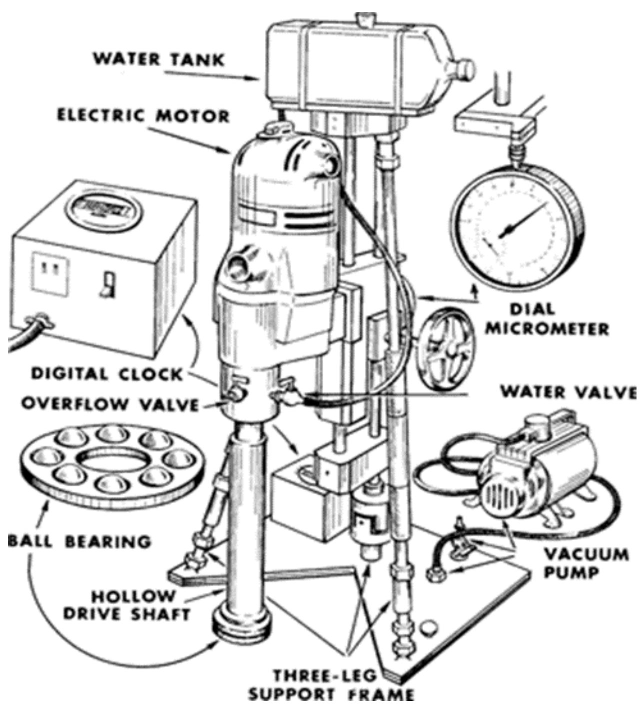


Figure 4: Ball Bearing Abrasion Test Machine

Figures 2, 3, and 4 are reprinted, with permission, from ASTM C779/ C779M Standard Method of Test for Abrasion Resistance of Horizontal Concrete Surfaces, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org.

Sample Preparation

Procedure A: The machine is designed to accommodate approximately 300 by 300-mm (12 by 12 in.) test specimens. Precondition the sample to remove curing compound and surface irregularities by running the abrasion machine for 5 minutes.

Procedure B: Place a sample approximately 300 by 300 by 100-mm (12 by 12 by 4 in.) thick into the machine and lock it in place with vises provided. Do not remove the sample until the test is completed.

Procedure C: Use test samples 300 by 300 by 100-mm (12 by 12 by 4 in.) thick.

Procedure A

Step 1
Obtain initial measurements to an accuracy of 0.025 mm (0.001 in.) of the test area by taking two series of 20 measurements at right angles to each other using the micrometer bridge. Make sure the test area is level.

Step 2
Abrade using the specified apparatus for 30–60 minutes.

Step 3
Clean the test area and repeat the measurements on the exact same spots as before.

Step 4
Make three tests on the surface of the sample. Replace disks with depth slots less than 1.5 mm (1/16 in.). Break in new disk faces for 15 minutes before testing.

Procedure B

Step 1
Position the apparatus on the surface to be tested, allowing a space of 15 mm (0.5 in.) for vertical travel of the wheels.

Step 2
Obtain initial measurements to the nearest 0.025 mm (0.001 in.) on the test area with the dial micrometer while revolving the spider two revolutions by hand.

Step 3
Abrade using the specified apparatus for 30–60 minutes.

Step 4
Clean the test area and repeat the measurements on the exact same spots as before. Conduct the measurements every 15 minutes if total abrasion time is 60 minutes to produce a time versus wear curve.

Step 5
Make three tests on the surface of the sample. Replace the dressing wheels after every third test.

Procedure C

Step 1
Place a sheet of paper between the test surface and the ball bearings under the load of the motor. Revolve the drive shaft several times by hand. A complete circular mark should form on the paper. This indicates the drive shaft is normal to the surface.

Step 2
Open the two valves at the base of the drive motor. One will allow water to fill the hollow drive shaft and the other will determine that the hollow shaft is filled. Close the overflow valve. Fill the water tank to the prescribed mark to ensure a standard initial head.

Step 3
Bring the dial gauge clamped to the supporting shaft to bear on the sliding bracket of the motor and drive shaft. Reset the digital clock to zero.

Step 4
Take the reference dial micrometer reading immediately following the slight jump of the dial, just after the motor is started.

Step 5
Take dial micrometer readings to an accuracy of at least 0.025 mm (0.001 in.) of the depth of abrasion at least every 50 seconds for a total period of 1,200 seconds, or until a maximum depth of 3.0 mm (0.1225 in.) is reached. Take an average reading of the pulsating micrometer dial.

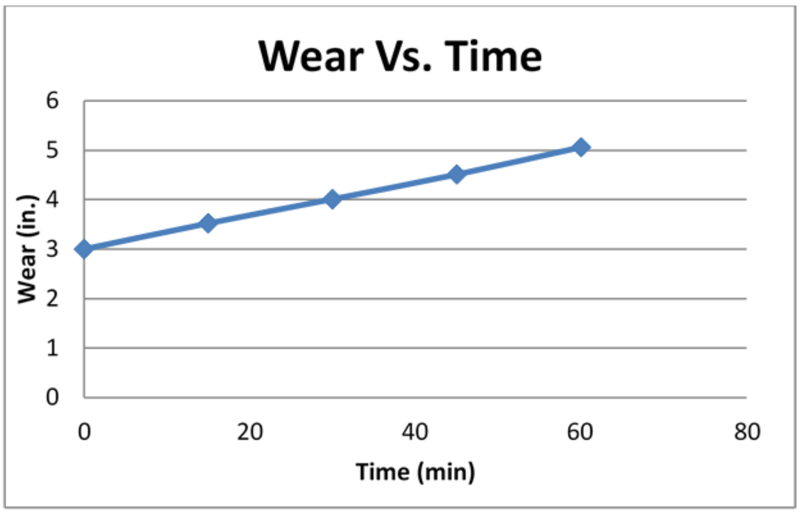
Step 6
Perform three tests on the surface of the sample.

Calculations

The difference between the initial and final measurements is the value of the wear. Plot wear versus time to see the effects of abrasion over the desired length of time.

Reporting the Test Results

Make a graph to chart the abrasive characteristics of the concrete over time.



Interpreting and Utilizing the Test Results

Determine the depth of wear for each interval of the test. The comparison of curves showing a plot of depth of wear versus time for each series of concrete surfaces tested will indicate the relative abrasion resistance of these surfaces. A material that is uniform in abrasion resistance will have a curve approximating a half-parabola inclined toward the time axis. A comparison of curves will indicate whether the resistance to abrasion is primarily at the surface or at greater depth.

Common Errors

- Failing to make identical measurements at chosen locations.
- Failing to reinforce the abrasion apparatus to prevent it from moving.
- Failing to replace dressings or disk faces.

Data Sheet

Site 1			Site 2			Site 3		
Initial	Final	Diff	Initial	Final	Diff	Initial	Final	Diff

ASTM C944, Standard Method of Test for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating Cutter Method

Background Information

This test method covers a procedure for determining the resistance of concrete or mortar to abrasion.

Significance and Use

This test method gives an indication of the relative wear resistance of mortar and concrete based on testing cored or fabricated specimens.

Related Tests and Specifications

- AASHTO T 24/ASTM C42, Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- ASTM C125, Standard Terminology Relating to Concrete and Concrete Aggregates
- ASTM C418, Standard Test Method for Abrasion Resistance of Concrete by Sandblasting
- ASTM C779, Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces

Timeline for Completion

Preparation Time: 1 hour

A sample core must be obtained for testing and weighed prior to being loaded in to the apparatus. Once this is completed, the cutting head must be installed and aligned to be parallel with the surface of the specimen.

Test Time: 15 minutes

Allow cutter head to rotate in contact with the specimen for two minutes. Remove specimen, clean and weigh. Repeat this process at least three times in three separate areas of representative surfaces of the material.

Calculations: 15 minutes

Report the weight of sample lost during testing.

TOTAL TEST TIME: 1.5 hours

Apparatus

Abrasion Device – A drill press or similar device capable of holding the cutting head and applying a load of 98 ± 1 N (22 ± 0.2 lbf) or a double load of 197 ± 2 N (44 ± 0.4 lbf) on the test specimen surface. A weight system may be placed on the spindle of the drill press to maintain consistent pressure. The device must also be capable of maintaining a speed of 200 r/min. The device shall be equipped with a leveling device to aid in making the cylinder parallel to the cutting head.

Rotating Cutter – The cutter is comprised of 37.5 mm (1.5-in.) diameter dressing wheels attached to a shaft and spaced evenly with washers in between. The dressing wheels are to be mounted perpendicular to the drive shaft and so as to allow individual wheels to rotate independently of one another. The overall diameter of the cutter is to be 82.5 mm (3.25 in.).

Balance – A balance having a capacity of at least 4 kg and accurate to at least 0.1 g.

Leveling Plate – A plate capable of rotating on the horizontal plane created by the drill press table is to be used to allow the specimen to make maximum contact with the specimen.

Sample Preparation

Sample core specimens in accordance with AASHTO T 24/ASTM C42.Weigh each core prior to testing and remove loose debris. Specimens for this test may be any size and shape so long as there is a flat surface capable of being positioned parallel to the cutting head.

Procedure

Step 1
Clean and then weigh the specimen. Report to 0.1 grams.

Step 2
Mount the specimen in the abrasion device and position the surface to be tested.

Step 3
Install rotating cutter head into the abrasion device and check to make sure cutter head and testing surface are parallel.

Step 4
Start the abrasion device and make contact with the cutter head and the specimen.

Step 5
Continue abrasion with a normal or double load (98 ± 1 N [22 ± 0.2 lbf] or 197 ± 2 N [44 ± 0.4 lbf]) on the specimen for 2 minutes.

Step 6
Remove the cutter head from the specimen and remove the specimen from the holder.

Step 7
Clean and weigh the specimen.

Step 8
Repeat Steps 3–7, three times.

Step 9
Repeat Steps 3–8 on three separate areas of representative surfaces.

Run Time: The run time for this procedure may be increased if the material being tested is found to be especially abrasion resistant.

Calculations

Report the material lost by subtracting the weight of the specimen before abrasion from the weight after abrasion to 0.1 grams.

Reporting the Test Results

Include the following:

- Description of the surface
- Size of the specimen
- Type of finish
- Concrete compaction, age, and strength
- Applied surface treatment
- Time of abrasion and load used
- Average loss in grams or depth of wear in millimeters
- Loss in mass and time abraded

Data Sheet

Run #1	Area 1 Before	Area 1 After	Area 2 Before	Area 2 After	Area 3 Before	Area 3 After
Description of surface						
Size of specimen						
Finish type						
Compaction						
Age						
Strength						
Surface Treatment						
Time of Abrasion						
Load Used						
Weight of Specimen						
Loss in grams						
Average Loss in grams						

Run #2	Area 1 Before	Area 1 After	Area 2 Before	Area 2 After	Area 3 Before	Area 3 After
Description of surface						
Size of specimen						
Finish type						
Compaction						
Age						
Strength						
Surface Treatment						
Time of Abrasion						
Load Used						
Weight of Specimen						
Loss in grams						
Average Loss in grams						

Run #3	Area 1 Before	Area 1 After	Area 2 Before	Area 2 After	Area 3 Before	Area 3 After
Description of surface						
Size of specimen						
Finish type						
Compaction						
Age						
Strength						
Surface Treatment						
Time of Abrasion						
Load Used						
Weight of Specimen						
Loss in grams						
Average Loss in grams						

ASTM C512/C512M, Standard Method of Test for Creep of Concrete Compression

Significance and Use

This test is used to determine the creep of molded concrete cylinders subjected to sustained longitudinal loads.

Related Tests and Specifications

- ACI SP-9, Symposium on Creep of Concrete

Timeline for Completion

Preparation Time: 28 days

After molding, the specimen is cured until the age of 28 days.

Test Time: 1 year

At 28 days, the specimens are loaded in to the loading frame. Measurements are taken at 2, 7, 28, 90, and 365 days.

Calculations: 15 minutes

The total load-induced strain per unit stress will be calculated at each measurement.

TOTAL TEST TIME: 1 year, 28 days

Apparatus

Cylinder Molds – For molding the cylinders as per C470 (150 mm [6-in.] specimens only).

Loading Frame – Must be capable of applying a constant load on the specimen despite any change in dimension. Bearing plates must be plane to 0.025 mm [0.001 in.]. The load must be capable of being read to the nearest 2% of the total applied load.

Strain-Measuring Device – Must be readable to the nearest 10 millionth, capable of measuring strains for a year minimum without changing calibration, and have a minimum effective gauge length of three times the maximum aggregate size. Can be either:

- Portable – Gauge points must be attached in positive manner;

- Embedded – Must be such that strain movement is along the longitudinal axis of the specimen; or
- Attached – Cannot rely on friction contact.

Sample Preparation

Prepare a minimum of six 150 mm [6-in.] cylinders (as specified in C192) with a coarse aggregate no larger than 2 in. The specimens are to be de-molded between 20–48 hours after molding and stored in a moist condition until an age of 7 days (as per C511). From 7 days until the completion of the test, the specimens shall be stored at 23.0±1.0 °C [73.5±1.5 °F] and a relative humidity of 50±4%. Specimens may be placed and sealed in moisture-proof enclosures at the time they are stripped from their molds. Other curing conditions are permitted as long as the method is carefully detailed on the final report.

Procedure

Step 1
If comparing creep potential of different concretes, specimens are to be placed in loading apparatus at an age of 28 days.

Step 2
If complete creep behavior of concrete is required, specimens are to be placed in loading apparatus at age of 2, 7, 28, and 90 days, and 1 year.

Step 3
If cylinders are to be stacked in the load frame, ends should be lapped, capped, grinded, or bearing plates fitted (planeness of 0.002 in. per 6 in. is required).

Step 4
Immediately prior to loading, determine the compressive strength of a specimen as per C39.

Step 5
Load specimens at no more than 40% intensity of the compressive strength and immediately take strain readings pre and post loading.

Step 6
Take additional strain readings at2–6 hours, daily for 1 week, weekly for 1 month, and monthly for 1 year.

Step 7
Measure the load before each strain reading. If it varies by more than 2% from the correct value (40% of compressive load), you must adjust it.

Step 8
Take strain readings on the same time frame as loaded specimens.

Calculations

Calculate the total load-induced strain per unit stress.

$$\varepsilon = \left(\frac{1}{E}\right) + F(K)\ln(t + 1)$$

Where:

ε = total strain per unit stress (MPa^{-1} or psi^{-1})

E = instantaneous elastic modulus (MPa or psi)

F(K) = creep rate: calculated as the slope of a straight line representing the creepcurve on the semi log plot

t = time after loading (days)

Reporting the Test Results

Reports must include:

- Cement content
- Water-cement ratio
- Maximum aggregate size
- Slump
- Air content
- Type and source of: cement, aggregate, admixture, and mixing water
- Position of cylinder when cast
- Storage conditions before and after loading
- Age at time of loading
- Compressive strength at loading age
- Type of strain measuring device
- Magnitude of any preload

- Intensity of applied load
- Initial elastic strain
- Creep strain per unit stress at designated ages up to one year
- Creep rate, F(K), if determined

Common Errors

- Use of 4-in. specimens is prohibited for use in this test.

Data Sheet

Cement	
Source	
Type	
Content	
Water-Cement Ratio	

Concrete Mix, Field (C31/C192)		
Agg. Source		
Agg. Type		
Max Agg. Size		
Admixture (type/source)		
Mixing Water (if other than fresh)		
Slump (C143)		
Air Content (C173/C231)		
Date/Time Cast		
Casting Position		
Technician		

Lab	
Compressive Strength (C39, C617/1231)	
Preload	
Applied Load	
Initial Strain	
Type of Strain Measuring Device	
Creep Rate (F(K))	
Technician	

$$\varepsilon = \left(\frac{1}{E}\right) + F(K)\ln(t+1)$$

ε = total strain per unit stress (MPa^{-1} or psi^{-1})
E = instantaneous elastic modulus (MPa or psi)
F(K) = creep rate: calculated as the slope of a straight line representing the creepcurve on the semi log plot
t = time after loading (days)

Creep			
Age	Date	Measured Strain (psi)	Creep Strain per unit Stress (ε)
Prior to Load			
Immediately After Load			
2–6 Hours			
1 Day			
2 Day			
3 Day			
4 Day			
5 Day			
6 Day			
7 Day			
Week 2			
Week 3			
Week 4			
Month 2			
Month 3			
Month 4			
Month 5			
Month 6			
Month 7			
Month 8			
Month 9			
Month 10			
Month 11			
Month 12			
Year 2			

ASTM E660, Standard Method of Test for Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel, Circular Track Polishing Machine

Background Information

This test is also known as the skid resistance test.

Significance and Use

Used to obtain the polishing curves and speed gradients of aggregate combinations and pavement mixtures in the laboratory. This can be characteristic of road behavior when implemented in the field.

Related Tests and Specifications

- ASTM C192, Making and Curing Concrete Test Specimens in the Laboratory

Timeline for Completion

Preparation Time: 30 days

The specimen is molded, cut, and cured.

Test Time: 8+ hours

Test time varies with a minimum runtime of 8 hours. This is dependent on the type of material and specifications of the client.

TOTAL TEST TIME: 31 days

Apparatus

Small-Wheel Circular Track – This device is equipped with four power-driven wheels that are equally spaced, independently suspended, and must be outfitted with four smooth treaded pneumatic tires.

Electrical System – Used to power a motor, which must be equipped with a revolution counter and safety guards.

Studded Steel Abrasion Wheel – Used on trapezoidal specimens when no holder plate is required. A fiber bristle brush shall be mounted behind one wheel to sweep the track during abrasion.

Friction-Measuring Device – Any device that would measure friction and fit within the center of the circular track

Molds – Molds for concrete, exposed aggregate, and bituminous specimens should be available, based on testing scope. The lab should be equipped to saw the specimens into trapezoidal shaped testing blocks.

Sample Preparation

Mold specimens in accordance with C192, with the exception of finishing. A texture is imprinted on the specimen when it is stiff enough to retain the texture. The desired texture may change from job to job. After 24 to 48 hours, the specimen is to be demolded and cut into trapezoidal blocks using a diamond-saw. The curing is continued until 28 days in accordance with C192.

Standardization and Calibration: Include at least two specimens, made from standard lab aggregates, in every fourth 12-specimen run of the circular track. This is used for comparison to a master curve that should have been previously created for the standard aggregate or aggregate gradient. Compare the terminal hour exposure friction value for the average of the two specimens from every fourth run to establish the master curve. If the difference is greater than ± 3 whole numbers, the data is suspect.

Procedure

Step 1
Mount the specimens, randomly, in the 12-specimen track.

Step 2
Epoxy or clamp specimens to mounting plates, and adjust them to be level and flush with the surface of the track.

Step 3
Use a 50-lb. weight on each wheel apron when testing hardened cement bound specimens.

Step 4
Measure initial friction of mounted specimens.

Step 5
Lower the wheel to the track and adjust the tire pressure to 20 psi.

Step 6
Record temperature near surface of track.

Step 7
Set the revolution counter to the desired revolutions.

Step 8
Set the wheel assembly in motion at a rate of 30 r/min.

Step 9
Stop the assembly for friction measurements at 1 and 2 hours and then every 2 hours after.

At each interval, monitor the tire pressure, temperature near track, adjustment of specimens, and condition of individual specimens.

Step 10
If a specimen becomes too worn, replace it with a dummy plate and cease measurements for that specimen for the remainder of the test.

Step 11
If the polishing curve for texture-less, exposed, coarse aggregate concrete is desired, remove the texture using studded wheel-abrading wheels and a bristle brush.

Reporting the Test Results

The report must include the following:

- Full identification of specimens, aggregate source, gradation, and mix design
- Friction values at from start of test through each interval for each specimen and control specimen
- Average friction values for each set and control specimen
- Correction factors for friction values for average of the control versus the master control curve
- Corrected average friction values for each set
- Remarks about wear of specimens
- Test temperatures
- Date of testing

AASHTO T 277/ASTM C1202, Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

Background Information

Originally developed for evaluating alternative materials but has evolved into quality control and acceptance testing.

Significance and Use

Used to determine the electrical conduction of concrete, providing rapid indication of its resistance to chloride ion penetration.

Related Tests and Specifications

- AASHTO T 23, Practice for Making and Curing Concrete Test Specimens in the Field
- AASHTO R 39, Practice for Making and Curing Concrete Test Specimens in the Laboratory

Timeline for Completion

Preparation Time: 25 hours

Coating, applying a vacuum, and soaking in de-aerated water.

Test Time: 6 hours

Test the specimen in the applied voltage cell.

Calculations: 10 minutes

TOTAL TEST TIME: 31 hours

Apparatus

Vacuum Saturation Apparatus – Must be able to maintain a pressure of 55 mm Hg in a desiccator and have a gauge with a range of 0–100 mm Hg accurate to ±5 mm Hai separator funnel and beaker must also be equipped.

Applied Voltage Cell – Two symmetric chambers containing electrically conductive mesh and external connectors.

Voltage Application and Data Readout Apparatus – Must be able to maintain a 60±0.1 V dc across the cell over the range of currents and display accurately to ±0.1 V and ±1 mA.

Sample Preparation

Once cast, concrete cylinder shall be cured as for 56 days or as specified by the client. Cut a 50±3 mm slice from the top of the cylinder and sand to remove any burrs or rough surfaces. Let the sample dry for 1 hour then apply the rapid setting coating on the sides. Fill any holes that are not completely covered, if necessary. After the coating dries (no longer sticky to the touch) place the sample directly in the vacuum desiccator, or first in a beaker then in the desiccator. Seal the desiccator and set the vacuum to less than 50 mm Hg and maintain the pressure for 3 hours. Add de-aerated water (boiled previously) in the separator funnel to the desiccator while the vacuum is running until the sample is covered. Continue the vacuum for 1 hour. Remove the vacuum and let the sample remain soaking for 18±2 hours.

Procedure

Step 1
Remove sample from water and blot to remove excess water.

Step 2
Place into a sealed container.

Step 3
Seal specimen into an applied voltage cell.

Step 4
Fill side of cell containing the top of the sample with 3.0% NaCl solution.

This is the side that will be connected to the negative terminal.

Step 5
Fill the other side with 0.3 normal NaOH solution.

This is the side that will be connected to the positive terminal.

Step 6
Set power supply to 60.0±0.1V and turn on.

Step 7
Take initial current reading.

Step 8
Record current at least every 30 minutes.

Step 9
Test is complete after 6 hours.

Note: Maintain an air temperature around the cells of 20–25 ˚C and also make sure chemicals in cells are full to eliminate any outside variables. Damage to cells can occur if solutions are allowed to exceed 90 ˚C.

Calculations

The total charge passed is a measure of the electrical conductance through the time of the test.

$$Q = 900(I_0 + 2I_{30} + 2I_{60} \ldots + 2I_{300} + 2I_{330} + I_{360})$$

Where:

Q = charge passed (Coulombs)

I_0 = current (amperes) immediately after voltage is applied

I_t = current (amperes) at t minutes after voltage is applied

If a specimen is used with a diameter other that 95 mm (3.75 in.), an adjustment must be made using the following ratio

$$Q_s = Q_x \times (\frac{95}{x})^2$$

Where:

Q_s = charge passed (Coulombs) through 95 mm diameter specimen

Q_x = charged passed (Coulombs) through x (mm) diameter specimen

x = diameter (mm) of nonstandard sample

Reporting the Test Results

The results should be plotted in current (amperes) versus time (seconds), with a smooth curve drawn through the data. This will be reported, along with the total charge passed (corrected for diameter if necessary).

Interpreting and Utilizing the Test Results

Using AASHTO T277 Table 1, determine your chloride ion penetrability. This will show you whether your penetrability is negligible, low, medium, or high. Several factors known to the permeability include: water-cement ratio, polymeric admixtures, age, air void system, type of aggregate, degree of consolidation, and type of curing.

Common Errors

- Absolute vacuum gauges shall not be used for this test.
- The presence of calcium nitrite in admixtures can produce misleading results showing lower resistance to chloride ion penetration.

Data Sheet

Date	
Technician	
Identification Number	
Source of Cylinder/Core	
Mix Information	
Location of Specimen in Cylinder/Core	
Cure Type	
Diameter	
Additional Remarks	

Time (min)	Current (amperes)
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	

AASHTO T 259, Standard Method of Test for Resistance of Concrete to Chloride Ion

Background Information

This is a long-term test to measure the penetration of chloride into concrete and is commonly known as the “salt ponding test.” Reinforced concrete is subject to chloride penetration during its service life. Steel exposed to chloride ions corrodes, and in turn, the strength, purpose, and aesthetics of the reinforced concrete are compromised. Therefore, the ability of chloride to penetrate concrete is important to consider for design. This test method assists in determining how variations of concrete mixes can affect the resistance of the concrete to chloride ion penetration. Concrete mix variations can include water-cement ratio, aggregate type and proportions, admixtures, changes to the cement type and content, treatments, curing, and consolidations.

Significance and Use

The results of this test method allow for observation of how various concrete mix types used for reinforced concrete may resist chloride ion penetration.

Related Tests and Specifications

- AASHTOR 39, Making and Curing Concrete Test Specimens in the Laboratory
- AASHTOT 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete
- AASHTOT 260, Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials
- AASHTOT 277/ASTM C1202, Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration

Timeline for Completion

Preparation Time: 42 days

Samples are moist cured for 14 days then stored in a drying room for 28 days.

Test Time: 103 days

Samples are abraded and dammed, except the control sample, and are returned to drying room storage for 13 days. The samples with dams are then exposed to a sodium chloride solution for 90 days in the drying room. The chloride content is then calculated on sub-samples taken at two different depth ranges.

Calculations: 30 minutes

The baseline chloride ion content from the control sample slab and absorbed chloride ion values are calculated.

TOTAL TEST TIME: 145 days

Apparatus

Moist Room – Conforming to AASHTO R 39.

Drying Room – Conforming to AASHTO T 260.

Sample Preparation

The sample specimens are concrete slabs and shall be fabricated and cured in accordance with AASHTO R 39.At least four specimens are required. All concrete slabs are to be fabricated from concrete having a cement factor of 390 kg/m3 (658 lb./yd3), a water-cement ratio mass of 0.5, and an air content of 6 ± 1%.

The minimum thickness for the sample slab is 75 mm (3 in.) and the minimum surface area is 17,500 mm2 (28 in2).If a sample is to be tested with a special overlay material, then the concrete slab shall be made 50 mm (2 in.) thick and the special overlay material cast 25 mm (1 in.) thick, unless otherwise specified by the manufacturer.

Samples are to be moist cured for 14 days (unless earlier removal is recommended by the manufacturer).Samples are then to be stored for 28 days in a drying room that is in accordance with AASHTO T 160.

If a sample is to be tested with a concrete treatment, the treatment is to be applied at 21 days of age and in accordance with the manufacturer's recommendations.

Procedure

Step 1

The slabs are to be removed from the drying room on the 29th day of age. If the concrete slabs are not to be subject to vehicular wear, proceed to Step 2.If the concrete slabs are to be subject to vehicular wear, the following must be completed: abrade a 3.2 1.6 mm (0.125 0.062 in.) area of the slab. Techniques permitted are grinding or sandblasting, but no water is to be used in this process.

Step 2
The sides of all of the slabs, except one, are to be sealed with dams that are 19mm (0.75 in.) high and 13 mm (0.5 in.) wide. The top and bottom of the slabs are to be left exposed. One slab is to be left undammed to be used as the control in the test.

Step 3
Return all slabs to the drying room for 13 days.

Drying Time: Chloride ingress in concrete is significantly influenced by the saturation state of the concrete. In general, the more saturated concrete is, the less chloride it will absorb. In order to reduce saturation and maintain consistency in preparation for chloride exposure, it is important to follow the drying times set forth in the standard.

Step 4
The slabs are to be removed from the drying room on the 43rd day of age.Apply3% sodium chloride solution at a depth of approximately 13 mm (0.5 in.) to the slabs with dams. These slabs will be subject to continuous ponding with chloride solution for 90 days. Add additional solution in order to maintain the 13 mm (0.5 in.) depth. A glass plate is to be placed over the ponded solution to slow evaporation but it is important to ensure the top is not sealed off from the surrounding atmosphere.

Step 5
Return all slabs to the drying room for 90 days.

Step 6
Remove slabs from the drying room, remove the solution from the top of the slab, and permit the slabs to air dry. Then, remove all salt crystal buildup from the surface with a wire brush.

Step 7
Sample the slabs in accordance with AASHTO T 260 to prepare for chloride ion analysis. Obtain the samples from two depth spans (unless otherwise directed by the specifying agency): 1.6 mm (0.065 in.) to 13 mm (0.5 in.) and 13 mm (0.5 in.) to 25 mm (1.0 in.).

Step 8
Determine the total chloride ion content as specified in AASHTO T 260 of each sample depth of each slab.

Rotary Hammer of AASHTO T 260: If the starter bit is longer than the pulverizing bit, the end of the starter bit is to be cut so that the sample depth is not compromised. Cut the starter bit to that its overall length does not exceed the length of the pulverizing bit by more than 1.6 mm (1/16 in.).

Calculations

Step 1
Determine the baseline chloride ion content by averaging the chloride ion content of each depth of control slab that was not exposed to the chloride solution.

Step 2
Determine the absorbed ion content of each sample depth of each concrete slab by taking the difference between the baseline and the total chloride ion content of that sample depth.

Step 3
Determine the average chloride ion absorbed between all of the slabs at both sampling depths.

Reporting the Test Results

For each sample set, report the average and maximum baseline chloride ion. For each concrete slab sample, report the total chloride ion value and absorbed ion value for each depth. For the entire sample set, report the average and maximum absorbed chloride ion values for each depth. If the results of the absorbed ion value are less than zero, report the result as zero.

The report shall also include a statement that discloses if the abrasion process in Step 1 of the procedure was performed or not.

Limitations

The results of this test only determine the average chloride concentration over the sample depth taken from the slab, the actual chloride profile, or variations across the sample depth is not detected. The implication is that with reinforcing concrete, it is important to know where the chloride permeates in order to predict the vulnerability of the rebar.

For higher quality concrete, the 90-day period is not of sufficient time to allow the chloride significantly permeate the concrete. A longer exposure should be considered in these cases.

Common Errors

- In Step 4 of the procedure, sealing off the surface of the slab from the surrounding atmosphere.
- The salt crystal buildup is not completely removed.

Data Sheet

Determination of the baseline from the control concrete slab:

Total Chloride Ion Content from Depth 1 = _________

Total Chloride Ion Content from Depth 2 = _________

Baseline Average of Depth 1 and Depth 2 (**B**) = _________

Determination of the absorbed chloride ion content at each depth of each slab:

		Total Chloride Ion Content (**T**)	Absorbed Chloride Ion Content (**T-B**)
Concrete Slab 1	Depth 1		
	Depth 2		
Concrete Slab 2	Depth 1		
	Depth 2		
Concrete Slab 3	Depth 1		
	Depth 2		

Determination of the average chloride ion absorbed at each depth from all slabs:

Depth 1 Average = _________

Depth 2 Average = _________

ASTM C157, Standard Method of Test for Length Change of Hardened Hydraulic-Cement Mortar and Concrete

Background Information

This test provides useful information for products that require testing under nonstandard conditions.

Significance and Use

Determines the changes in length from factors other than applied forces and temperature changes for hardened cement mortar and hardened concrete.

Related Tests and Specifications

- ASTM C192, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- ASTM C490, Standard Practices for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete

Timeline for Completion

Sample Time: 15 minutes

Concrete or mortar should be sampled in accordance with practice C192.

Test Time: 28 days

Mold specimens, cure, and measure at intervals.

Calculations: 10 minutes

Compare measurement to reference bar, calculate difference as described in C490.

TOTAL TEST TIME: 28 days

Apparatus

Molds – Must have one or two compartments and conform to the requirements prescribed in Section 5.2 of C490.

Length Comparator – Used for determining the length change of the specimen must conform to the requirements prescribed in Section 5.3 of C490.

Tamper (mortar only) – Made from a nonabsorptive and nonabrasive material and has a tamping face with cross sectional area of 13 by 25 mm (0.5 by 1.0 in.). Tamper should be approximately 150 mm (6 in.) in length.

Tamping Rod (concrete only) – A straight steel rod with a diameter of 10 mm (3/8 in.) with either one end or both ends of the rod rounded to the same diameter as the rod. The overall length of the rod shall be at least 250 mm (10 in.).

Drying Room and Controls – Situated with racks that allows for adequate circulation around the specimen. The air in the room must be maintained at 23 ± 2 °C (73 ± 3 °F) with a relative humidity of 50 ±4%. The air movement must be adequate to maintain an evaporation rate of77 ±30 mL per day when using an atmometer or 13 ±5 mL per day when using a low form beaker.

Atmometer – If used, must be set up as shown in Figure 1 and Figure 2 of ASTM C157.

Filter Paper – Used in conjunction with the atmometer. Paper shall be smooth, white, have a diameter of 150 mm (6 in.), and a thickness of 1.27 ± 0.08 mm (0.050 ±0.003 in.) The cotton fiber content should be at least 75% by weight. The density of the paper shall be between 0.400 and 0.425 g/cm3. Also, the paper must have a minimum Mullen bursting strength of 345 kPa (50 psi).

Sample Preparation

If concrete specimens are to be used, specimens must be prepared in accordance to C192.

If mortar is used, mortar must be mixed in accordance to the procedures outlined in C305.

Procedure

Step 1

Molding of Specimens (mortar) – Place the mortar in the mold in two equal layers. Make sure the mortar is worked into the corners of the mold, around the gauge studs. Consolidate the material using a tamper until material is evenly distributed. After the second layer is finished, strike off the mold, using a trowel, to remove excess material and smooth the surface.

Step 2

Molding of Specimens (concrete) –Fill the mold in two equal layers. Make sure the concrete is worked into the corners of the mold, around the gauge studs. Consolidate the material using a tamping rod. After completion of the second layer, strike off and finish to a smooth surface, using a straightedge.

Step 3
After molding, loosen the screws holding the gauge studs to prevent any possible restraint.

Step 4
Immediately after, place the mold into moist storage for 23½ ± ½ hours.

Step 5
Remove the hardened specimens from the mold and mark the specimen to help ensure the same orientation when measuring.

Step 6
Place specimen in water for at least 15 minutes (25 mm/1-in. specimens) or 30 minutes (75 or 100 mm/3 or 4-in. specimens).

Step 7
Remove specimens from water and obtain initial reading on the length comparator.

Step 8
Return specimen to water storage or place in drying room between comparator readings.

Step 9
Repeat Steps 7 and 8 for desired readings.

Note: Slightly overfill the bar mold to allow for strike off. Doing so assists in making a flat, even surface

Calculations

$$\Delta L_x = \frac{CRD - Initial\ CRD}{G} \times 100$$

Where:

ΔL_x = percent change in length of the specimen

CRD: comparator reading at time ‘x’ [in]

Initial CRD: first comparator measurement

G: gauge length

Example Calculations

CRD = 0.1103 in

Initial CRD = 0.1260 in

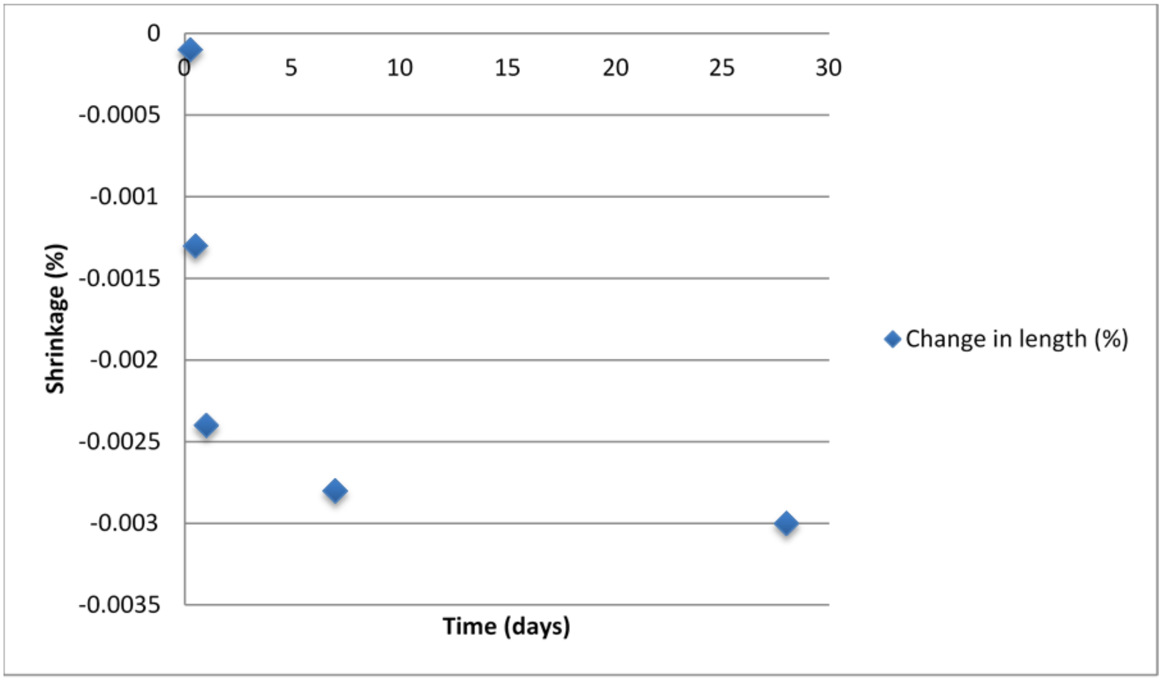
G = 10 in

$$\Delta L_x = \frac{0.1103 - 0.1260}{10} \times 100 = -0.157\%$$

Reporting the Test Results

The following items must be included in the report:

- Identification of specimen including quantity, size, and date molded
- Source and identification of each material used
- Description of the aggregate used
- Flow or slump and temperature of mixture at time of mixing
- Consolidation method
- Description of storage conditions
- Storage time and age of specimen
- Length change reported to nearest 0.001%



Common Errors

- Incorrect drying room humidity
- Incorrect drying room temperature
- Not rotating the bar
- Wear on reference bar from excessive use

Data Sheet

Sample ID	Date	Curing Method	Length Reading

ASTM C805, Standard Method of Test for Standard Method for Rebound Number of Hardened Concrete

Background Information

Also known as Schmidt hammer or Swiss hammer test.

Significance and Use

The rebound number of hardened concrete is obtained and used to determine uniformity of concrete along a given surface. The rebound number can also be used to estimate the in-place strength of concrete.

Related Tests and Specifications

- ASTM C42, Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

Timeline for Completion

Preparation Time: 10 minutes

Appropriate test site is selected and prepared.

Test Time: 10 minutes

Hammer is impacted in prescribed spots, readings recorded, and impressions visually examined.

Calculations: 15 minutes

Interpret readings and determine appropriate average number.

TOTAL TEST TIME: 35 minutes

Apparatus

Rebound Hammer – Spring-loaded steel hammer that contacts a concrete surface when released. Force and velocity of releases must be consistent and repeatable. The hammer should have manufacturer produced correction factors that account for different orientations of the hammer.

Abrasive stone – Used to grind a surface if necessary must be of medium-grain texture.

Verification Anvil – Used to verify adequacy of the rebound hammer. Must be made of steel capable of producing a rebound number of at least 75 using the rebound hammer.

Sample Preparation

Test area should be at least 100 mm [4-in.] thick and free of honeycombing, scaling, and high porosity. The area should be at least 150 mm [6 in.] in diameter. Textured, soft, or loose mortar containing surfaces should be ground with the abrasive stone. Also, free surface water should be removed. If rebar is present and is covered by less than 20 mm [0.75 in.] of concrete, select a different test site.

Procedure

Step 1
Align the hammer so that plunger is perpendicular to the tested surface. If readings are taken at an angle, take note of the angle compared to the horizontal and round to the nearest 45-degree mark.

Step 2
Slowly push the hammer into the test surface until the hammer impacts the surface.

Step 3
Read and record the number. Readings should be rounded to the nearest whole number.

Step 4
Obtain a total of 10 readings. Be sure that each impact point is at least 25 mm [1 in.] away from each other and at least 50 mm [2 in.] away from any edges of the concrete member.

Step 5
Be sure to examine each impression made by the hammer. If the hammer causes crushing or a break in the concrete, due to a nearby air void, disregard that reading and take another one.

Calculations

Step 1
Average all 10 readings.

Step 2
If any of the individual readings depart from the average calculated in the first step by more than six units, discard that test point and re-calculate a new average.

Step 3
If more than two of the original 10 readings have to be discarded, the test is considered invalid and 10 new readings must be taken.

Step 4
Apply correction factors, if necessary, so that the readings are corrected to the hammer being in the horizontal position.

Example Calculations

Test Point	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Reading	75	78	69	73	91	74	77	70	70	66

$$Average = \frac{75+78+69+73+91+74+77+70+70+66}{10} = 74.30$$

Readings (5) and (10) depart by more than 6 units, discard said readings and recalculate.

$$New\ Average = \frac{75+78+69+73+74+77+70+70}{8} = 73.25$$

Reporting the Test Results

Report individual readings to the nearest whole number.

Interpreting and Utilizing the Test Results

Add additional information on how the results of the test are used. Refer back to the HMEC Design Guides to ensure continuity of the information being shared.

Common Errors

- Not recording the proper angle orientation.

Data Sheet

Test Point	1	2	3	4	5	6	7	8	9	10
Reading										
Angle (to horizontal)										
Correction Factor (if applicable)										
Corrected Reading										

ASTM C803, Standard Method of Test for Penetration Resistance of Hardened Concrete

Background Information

This test method covers the penetration resistance of hardened concreted by using either a pin or steel probe.

Significance and Use

This test is used to determine the uniformity of concrete, such as a poured slab foundation. It can also be used to delineate zones of deteriorated concrete in structures or poor quality.

Related Tests and Specifications

- ANSI A10.3, Safety Requirements for Powder Actuated Fastening Systems

Timeline for Completion

Preparation Time: 5 minutes

Smooth the surface of the concrete larger than the area to be tested.

Test Time: 15 minutes

Using a driver unit, a pin or probe is inserted into the concrete and measurements are taken.

Calculations: 5 minutes

Only measurements are recorded and reported. There are no calculations for this test.

TOTAL TEST TIME: 25 minutes

Apparatus

Resistance Testing with Probes
Driver Unit – Must be able to drive the probe into the concrete with enough energy so the probe remains firmly embedded in the concrete.

Probe – The probe will have one threaded end and one blunt end, which is driven into the concrete.

Measuring Equipment – Such as a depth gauge, caliper, or other measuring device capable of measuring exposed length of the probe to the nearest 0.5 mm or 0.025 in. This equipment also needs a reference base plate that is supported on the surface of the concrete at three equally spaced points.

Positioning Device – A device used to position and guide the driver unit during firing.

Resistance Testing with Pins

Driver Unit – A spring-actuated driver capable of driving a pin into the concrete as to create a hole so the depth can be measured.

Pin – A single-use pin that has one blunt end and one sharpened end.

Measuring Equipment – A depth gauge including a reference plate capable of measuring the depth of penetration to the nearest 0.025 mm or 0.001 in.

Air Blower – Used to clean the penetration hole prior to measuring.

Sample Preparation

Both methods require that the concrete be sufficiently cured and smooth prior to performing the test. When testing using a probe, any concrete that is coarser than burlap must be ground smooth to an area larger than the reference base plate. When using a pin to test the resistance, the area to be tested will need to be ground smooth if it is heavily textured, consists of loose mortar, or is soft. The area to be ground will be at least as large as the bearing area of the driver unit.

Procedure for Testing the Resistance Using Probes

Step 1

If needed, smooth the concrete prior to testing.

Step 2

Place the positioning device on the area to be tested.

Step 3

Load the driver unit with the appropriate pin and place it on the positioning device.

Step 4

Fire the probe into the concrete, remove the positioning device, and tap the probe to ensure that it is firmly embedded in the concrete.

Step 5
Place the reference plate over the probe to determine the next two areas to be tested.

Step 6
Determine the average exposed probe length.

Procedure for Testing the Resistance Using Pins

Step 1
If needed, smooth the concrete prior to testing taking care to ensure that the area to be tested is relatively flat.

Step 2
Using a new pin for each test, load the pin into the driver.

Step 3
Place the driver against the surface to be tested and pull the trigger to drive the pin into the concrete.

Step 4
Remove the driver and the pin. Using the blower tool clean the resulting pin hole.

Step 5
Using the depth gauge, measure the depth of the pin hole.

Reporting the Test Results

For the probe procedure measure the exposed length of the probe and the average length in each test area. When using the pin procedure measure the penetration depth of the pins and the average penetration depth in each test area.

Data Sheet

Resistance of Concrete Using Probes	
Measurement 1	
Measurement 2	
Measurement 3	
Average	

Resistance of Concrete Using Pins	
Measurement 1	
Measurement 2	
Measurement 3	
Measurement 4	
Measurement 5	
Measurement 6	
Average	

ASTM C597, Standard Method of Test for Pulse Velocity Through Concrete

Significance and Use

This test method is used as a nondestructive way to assess the uniformity and the quality of concrete. The results of the test method provide estimation the severity of deterioration or cracking of existing structures and can be used to monitor the condition of concrete over a desired period of time. This test method is applicable for both field and laboratory settings.

Related Tests and Specifications

- ASTM C125, Terminology Relating to Concrete and Concrete Aggregates
- ASTM C215, Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens
- ASTM C823, Practice for Examination and Sampling of Hardened Concrete in Constructions
- ASTM E1316, Terminology for Nondestructive Examinations

Timeline for Completion

Test Time: 5 minutes

Transmitting and receiving transducers are attached to surface and the transit time is measured.

Calculations: 5 minutes

The transit time and distance are used to determine the pulse velocity.

TOTAL TEST TIME: 10 minutes

Apparatus

Pulse Velocity Apparatus – A system that consists of a pulse generator, a transmitting and receiving transducer, an amplifier, a time measuring circuit, a time display unit, and connecting cables.

Pulse Generator – Circuitry for generating pulses of voltage. Known effective range 500 to 1,000 V.

Transmitting Transducer – Transforms electronic pluses into waves of mechanical energy in a range from 20 to 100 kHz.

Receiving Transducer – Transforms received waves of mechanical energy into electronic pluses.

Amplifier – Ability to amplify pulses from the receiving transducer.

Time Measuring Circuit – Timer is triggered by the voltage from the pulse generator and ends when a received pulse is detected.

Display Unit – Capable to indicate the pulse transit time to the nearest 0.1 μs.

Coupling Agent – Used to eliminate air between the contact surfaces of the transducer and specimen. A suitable material such as grease, oil, petroleum jelly, or water soluble jelly. Additionally, water can function as a coupling agent if surface is ponded or if testing is underwater.

Reference Bar – (Used only with manual zero-time adjustment units.) Bar of metal or durable material in which transit time of longitudinal waves is known. Transit time is marked on the bar.

Procedure

Step 1
Verify proper operation of equipment by performing a zero-time adjustment.

Unit with Automatic Zero-Time Adjustment – Apply coupling agent to contact surfaces of transducers and place surfaces together.

Unit with Manual Zero-Time Adjustment – Apply coupling agent to the ends of the reference bar and place surfaces of transducers against the ends. Adjust zero reference on display until it agrees with transit time of value of reference bar. Check the zero adjustment hourly.

Step 2
Apply coupling agent to either the transducer surfaces or the concrete test specimen surfaces.

Step 3
Place transducer surfaces against the surfaces of the concrete specimen. Ensuring that good contact is achieved between the contact points. The location of the transducers should be directly opposite of each other.

Calculations

Step 1
Measure the distance between the centers of the transducer faces to a precision of at least 0.5% of the distance.

Step 2
Record the transit time from the pulse velocity apparatus to at least 0.1 µs.

Step 3
Use the following equation to calculate the pulse velocity to nearest 10m/s.

$$Pulse\ Velocity\ (\frac{m}{sec}) = \frac{Distance\ Between\ Centers\ of\ Transducer\ Faces\ (m)}{Transit\ Time\ (\text{sec})}$$

Example Calculation

If the distance between the transducers is 6 meters and the transit time displayed on the pulse velocity apparatus is 1,414.5 µs, the pulse velocity in the concrete specimen would be 4,241.5 m/sec as shown in the calculation below.

$$4{,}240\ (\frac{m}{sec}) = \frac{6.0\ m}{0.0014145\ sec}$$

Reporting the Test Results

The report for ASTM C597 should contain the location of the test, location of the transducers, and distance between centers of the transducer faces (precise within 0.5% of distance), the transit time (nearest 0.1 µs) and the pulse velocity (nearest 10 m/s).

Data Sheet

ASTM C597 - Pulse Velocity Through Concrete

Location of Test: ____________________

Location of Transducers: ____________________

Distance between Transducers (m): ____________
Transit Time (µs): ____________
Pulse Velocity (m/s): ____________

ASTM C900, Standard Method of Test for Pullout Strength of Hardened Concrete

Background Information

ASTM C900 determines the pullout strength of concrete by embedding a metal insert into concrete and measuring the force required to fracture the concrete.

Significance and Use

The pullout strength determined from ASTM C900 can be related to compressive strength. ASTM C900 test results can be used to determine if concrete has reached a specific level to proceed with construction processes.

Related Tests and Specifications

- ASTM C670, Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- ASTM E4, Practices for Force Verification of Testing Machines
- ASTM E74, Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines

Timeline for Completion

Preparation Time (Procedure A): Varies

Sample cast in place and tested at a user specified time.

Preparation Time (Procedure B): 30 minutes to 4 hours

Concrete is drilled, area is ground into the concrete, and insert placed into concrete.

Test Time: 5 minutes

Force applied to an insert until a specified force is reached or until failure.

TOTAL TEST TIME: Varies upon preparation methods

Apparatus

Pullout Insert – The insert must be made of metal or a material nonreactive with cement. It shall be cylindrical in shape and consist of a shaft that is firmly attached to the head of the insert. The diameter of the head of the insert must be equal to the length of the insert.

Loading System – Shall contain a bearing ring, tensile loading apparatus, and a load measuring device that can be attached to the pullout insert. The bearing ring inside diameter shall be 2 to 2.4 times the insert head diameter. While the outside diameter of the bearing ring shall be at least 1.25 times the inside diameter. The thickness of the bearing ring shall be at least 0.4 times the diameter of the head. The loading system shall include a centering feature for the bearing ring and must load axially to the pullout shaft at a uniform rate. The applied load shall be uniformly loaded onto the bearing ring.

Load Measuring System – Shall be either an analog gauge (readable to 0.5kN), or a digital gauge (readable to 0.1 kN).The gauge shall retain the maximum value of load from the test.

Sample Preparation

Ensure that the test locations for each pullout test are separated by at least 7 times the diameter of the pullout head as well as 3.5 times the diameter of the pullout head away from the edge. The depth must be equal to the diameter of the insert head. Ensure that the rebar is located outside the expected failure area by at least a diameter of a bar or maximum aggregate size. Complete at least five pullout tests for every 115 m3 of the volume of concrete or every 470 m2of the surface of concrete.

Cast-in-Place Insert – Attach inserts to forms, secure inserts and ensure they are perpendicular to the surface of form surface before pouring concrete. Also ensure the insert is set at a correct depth.

Post-Installed Insert – Drill a core hole perpendicular to the surface. Cut a groove in the core hole with a grinding tool to act as a bearing surface for the expandable insert. Place expansion tool and expandable insert into the core hole, with the expandable insert bearing against the groove surface.

Procedure

Step 1
Place bearing ring around pullout; insert shaft and attach shaft to the hydraulic ram; tighten until snug.

Step 2
Apply load at a rate of 70 ± 30 kPa/s until failure and record gauge reading. If test is used to verify minimum strength, apply specified load for at least 10 seconds.

Reporting the Test Results

The report for ASTM C900 shall contain the following information: dimensions of the pullout insert and bearing ring, location of the pullout test, date, and time test is performed. If a concrete is tested to failure, include the maximum pullout load of each test, the average, and standard deviation (kN).If concrete is tested to specified load, record pullout load applied to each test (kN).Also record any abnormalities in a ruptured specimen, curing method of concrete, moisture condition at time of testing, and any other unusual job conditions that may have affected the test results.

Interpreting and Utilizing the Test Results

Reject test results if:

1. The large end of the conical failure is not the same diameter as the inside of the bearing ring.
2. Distance from surface of concrete to top of insert head is not equal to the diameter of insert head.
3. Groove diameter or expanded insert diameter does not equal manufacture requirements.
4. Rebar is visible in failure zone.

Data Sheet

Date: ______________________________

Time: ______________________________

Dimensions: ______________________________

Diameter of Insert Shaft: ______________________________

Diameter of Insert Head: ______________________________

Inside Diameter of Bearing Ring: ______________________________

Outside Diameter of Bearing Ring: ______________________________

Location of Test:

____

____

Abnormalities in Ruptured Specimen:

____

____

Curing Method:

____

Moisture Condition of Concrete:

____

Additional Information:

____

____

AASHTO T 325, Estimating the Strength of Concrete in Transportation Construction by Maturity Tests

Background Information

This standard provides a way to estimate concrete strength in roads, bridges, and other transportation structures through the use of maturity index. It is also used to determine the strength-maturity relationship of a job mix in the laboratory and determination of the temperature history subsequent to placement in the field.

Significance and Use

Estimate the strength placed in pavements and structures. These results can be used to make decisions concerning opening to traffic, form removal, post tensioning, termination of curing procedures, and initiation of strength tests on the concrete, such as coring and pullout tests.

Related Tests and Specifications

- AASHTO R 9, Acceptance Sampling Plans for Highway Construction
- AASHTO T 276, Measuring Early-Age Compression Strength and Projecting Later-Age Strength
- ASTM C1074, Standard Practice for Estimating Concrete Strength by the Maturity Method
- ASTM D3665, Standard Practice for Random Sampling of Construction Materials
- ASTM E105, Standard Practice for Probability Sampling of Materials
- ASTM E122, Standard Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
- ASTM E141, Standard Practice for Acceptance of Evidence Based on the Results of Probability Sampling

Apparatus

Laboratory Requirements:
Temperature Sensors – Suitable for embedment in the center of cylindrical concrete test specimens and a device suitable for monitoring and recording the temperature.

Computer Terminal – For input of laboratory test data or a supply of concrete test reports.

Field Requirements:
Temperature Probes/Sensors – Suitable for embedment in the concrete placement.

Monitoring System – A device suitable for monitoring and recording the temperature of the concrete. The device may be any of the following:

- A system with a computer remote from the job site that reads and logs the probes/sensors through a remote connection for necessary calculations;
- A system with a computer at the job site that automatically reads, logs, and makes the necessary calculations; or
- A system with a device that automatically reads the probe/sensor signals, calculates the maturity index, and digitally displays the data on demand.

Field Sampling

Select the temperature sampling sites for installing probes/sensors by determining the quantity of concrete that is to be evaluated and dividing the concrete placement into lots that approximate the quantities indicated in Table.

Table 7: Minimum Number of Probes/Sensors Required to Be Placed in Each Concrete Lot

Structure Component	Quantity of Concrete in Lot	Number of Probes/Sensors
Slabs, beams, and abutment walls	100 m^3	5
Columns	2–10 m^3	1
Columns	More than 10 m^3	2
Pavement, pavement overlays	1,000 m^2	2
Pavement repairs	Per repair or per 750 m^2, whichever is smaller	2

Select temperature sampling alternates in the following manner.

When the maturity of all lots is to be determined, use a stratified random selection procedure in determining where to place the temperature probes/sensors in each concrete lot to be evaluated, as indicated in:

Structure Component	Quantity of Concrete in Lot	Number of Probes/Sensors
Slabs, beams, and abutment walls	100 m^3	5
Columns	2–10 m^3	1
Columns	More than 10 m^3	2
Pavement, pavement overlays	1,000 m^2	2
Pavement repairs	Per repair or per 750 m^2, whichever is smaller	2

When the maturity of only a fraction of the total lots is to be measured, determine the number of lots in accordance with Equation 1:

$$L_1 = F * T - L_L$$

Where:

L_1 = lots to be randomly chosen (rounded to the nearest whole number)

F = fraction of lots to be sampled for maturity testing,

T = total number of lots

L_L= last lot placed

Sample Preparation

Laboratory Operations

Check to ensure that an adequate supply of temperature sensors is available for the scheduled work and prepare the concrete temperature monitoring and recording device for attachment to the temperature sensors immediately after they are embedded in the concrete cylinders.

Field Operations

Select which sampling alternate is to be used and check to ensure that an adequate supply of temperature probes/sensors is available for the scheduled concrete placement, and then determine the locations at which the temperature probes/sensors will be installed. Finally prepare the concrete temperature monitoring and recording system for attachment.

Procedure

Step 1
Develop the strength-maturity relationship for the approved concrete job mix using the Strength Maturity Relationship section of ASTM C1074.

Step 2
Determine the temperature history of concrete after placement in the field as follows:

1. Insert the active end of the temperature probe/sensor in the fresh concrete at the predetermined location(s).
2. Probes/sensors should be placed 50 to 100 mm from any surface of the concrete placement.
3. Protect wires connecting the probes/sensors to the meter. Duplicate probes/sensors with separated wiring runs may need to be used in critical locations.
4. Immediately after concrete placement, make final maturity system connections with the probes/sensors and activate the system.

Step 3
After placement of the concrete in the field, determine the maturity index at each probe/sensor location by reading the appropriate channel(s) of the maturity monitoring system.

Step 4
Use the strength-maturity relationship and the maturity index to estimate the in-place strength of concrete in the field.

Step 5
Compare the maturity index determined in Step 4 to the strength-maturity relationship determined in Step 1. The concrete strength value of the strength-maturity relationship corresponding to the measured maturity index from a particular probe/sensor location is the estimated concrete strength for that location.

Calculation

Determine the estimated strength of a concrete lot using Equation 2:

$$S_{L(est)} = \frac{\sum_{i=1}^{i=n} X_i}{n}$$

Where:

$S_{L(est)}$ = estimated strength of the concrete lot

X_i = estimated strength of the concrete at a specific probe/sensor location

i = individual probe/sensor

n = number of probes/sensors in the concrete lot

Reporting the Test Results

Step 1
Identification of the laboratory, date of testing, and concrete job mix used for laboratory tests

Step 2
Strength of each test specimen and the average strength of test specimens at each test age

Step 3
Maturity index for each instrumented test specimen and the average maturity index for the instrumented specimens at each test age

Step 4
A graph of the average compressive strength versus the average value of the maturity index as described in the Strength-Maturity Relationship section of ASTM C1074

Step 5
Project and route number

Step 6
A list for each concrete lot evaluated, identifying the concrete job mix used and showing the station numbers, offset, item number, quantity of concrete, location and count of each probe/sensor installed, maturity index determined for each probe/sensor location, estimated strength determined for each probe/sensor location, and estimated average strength for each concrete lot

Common Errors

- Improper placement of probes.

AASHTO TP 95, Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration

Background Information

The test evaluates the surface resistivity of water-saturated concrete and provides a rapid indication of water-saturated concretes resistance to the penetration of chloride ions. There is a proven correlation between this test and other electrical indication tests and chloride exposure tests. Thus, this method is considered a less variable and expedient alternative to those tests.

Chloride ion penetration is important to evaluate because the service of the concrete is compromised if the steel in reinforced concrete is exposed to chloride ions. Different mixture types, such as the water-cement ratio, pozzolan, admixtures, air-void system, aggregate type, and degree of consolidation, will affect chloride ion penetration and should be taken into consideration.

Significance and Use

The results from this test indirectly indicate the permeability of chloride ions in concrete mixtures. The results can be used to evaluate concrete mix proportions used in design and/or research purposes for corrosion risk.

All details of the test method should be used and followed unless otherwise noted by the specifying agency.

Related Tests and Specifications

- AASHTO R 39, Making and Curing Test Specimens in the Laboratory
- AASHTO T 23, Making and Curing Concrete Test Specimens in the Field
- AASHTO T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- AASHTO T 277, Electrical Indication of Concrete's Ability to Resist Chloride Penetration
- ASTM C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- ASTM C1202, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
- ASTM C1556, Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion

Timeline for Completion

Preparation Time: 28 days

Specimens obtained or casted and then moist-cured for 28 days.

Test Time: 30 minutes

Take a total of eight readings per specimen with the Wenner probe array.

Calculations: 30 minutes

Calculate averages of the readings and determine the chloride penetration resistance.

TOTAL TEST TIME: 29 days

Apparatus

Surface Resistivity Apparatus – A device that supplies a flat-topped trapezoidal wave at a frequency of about 13 Hz and a pk-pk level with a nominal voltage limit of 25V pk-pk.

Wenner Probe Array – An attachment to the surface resistivity apparatus that has four pins. The probe should be capable of an adjustment to the probe tip spacing to 38.1 mm (1.5 in.).

Specimen Holder – A device to hold the specimen during the test so that the specimen will not rotate.

Sample Preparation

A set of a minimum of three test samples are required. Specimens are to be prepared and selected one of the following ways:

- Cores from structures or larger diameter cast cylinders as per AASHTO T 24M/T 24
- 4 in. (100 mm) diameter by 8 in. (200 mm) cast cylinders as per AASHTO R 39 or AASHTO T 23
- 6 in. (150 mm) diameter by 12 in. (300 mm) cast cylinders as per AASHTO R 39 or AASHTO T 23

After casting or obtaining the sample, they are to be moist cured for 28 days.

Accelerated Moist Cure: This curing method can provide an earlier indication of potential property development with slower hydrating supplementary cementitious materials. The samples are cured for 7 days in accordance with AASHTO R 39 or T 23, depending on the method used for sample preparation. The samples are then cured for 21 days in a lime-saturated tank.

Sample Curing Conditions: The advised method is moist-cure in a 100% relative humidity moist room. Curing specimens in a lime-saturated tank is known to produce lower results by 10%. The samples must remain in a moist condition at all times prior to testing in order to minimize any effects on electrical resistivity.

Transport the samples to the laboratory in a moist condition. The transportation container should be sealed and watertight, as well as protect the sample from freezing or damage.

Remove the sample from its mold and make four permanent marks and labels on the sample at 0, 90, 180, 270-degree points of the circumference. The marks are to be on the top, finished circular face of the specimen and extend onto the longitudinal faces (sides) of the specimens. Next, make a permanent center line mark on the longitudinal face extending all the way around the specimen.

Procedure

Step 1
Ensure air temperature of the test location is stable and maintained from 20 to 25 °C (68 to 77 °F).

Step 2
Remove the sample from the moist condition and blot off excess water. Transfer the specimen to the sample holder; place the specimen on its side with the 0° mark on the top. Do not let the sample stand in the holder for longer than 5 minutes to ensure moist conditions for the test.

Step 3
Arrange the Wenner array probe on the longitudinal side of the sample. Ensure that the center line is in the center of the two inner probe pins and that two outer pins are aligned with the 0° line marks.

Step 4
Allow the reading to stabilize and then record the measurement from the display unit.

Step 5
Repeat Steps 3 and 4 at each degree marking until 4 readings are obtained.

Step 6
Rotate until the 0° mark is on the top and follow Steps 3 and 4 to record a second reading at each degree resulting in a total of 8 readings.

Step 7
Repeat Steps 2 through 6 for the remaining samples in the set.

Calculations

Step 1
Calculate the average resistivity for each sample.

Step 2
Calculate the average resistivity of the set.

Step 3
Multiply each set of samples by a curing condition correction:

Lime-water tank = 1.1

100% relative humidity room = 1.0

Step 4
Refer to Table 8and evaluate the chloride penetration resistance based on the average set resistivity and appropriate sample size.

Table 8: Qualitative Determination of the Surface Resistivity Test

Chloride Ion Penetration Resistance Type	**Surface Resistivity for 100 mm x 200 mm [4-in. x 8-in.] Specimen (kΩ-cm)**	**Surface Resistivity for 150 mm x 300 mm [6-in. x 12-in.] Specimen (kΩ-cm)**
High	< 12	< 9.5
Moderate	12-21	9.5 – 16.5
Low	21 – 37	16.5 – 29
Very Low	37 – 254	29 – 199
Negligible	>254	>199

Reporting the Test Results

Report the following information:

- Source of core or cylinder
- Specimen identification number
- Description of the type of concrete (binder type, water/cement ratio, etc.)

- Description of the specimen
- Curing history of specimen
- Surface resistivity measured
- Qualitative chloride ion penetrability

Limitations

Samples containing calcium nitrate or other admixtures have been documented to produce misleading results. In most cases, admixtures lower the resistance to chloride ion penetration. Long-term diffusion tests are recommended as the alternative.

The sample age may also produce significant effects on the test results. In most cases, concretes become significantly less permeable with time.

Tests are not valid with samples containing reinforcement.

Common Errors

- Not ensuring consistent moist conditions during the indicated points of the test.

Data Sheet

Determination of Test Results:

Surface Resistivity Readings (kΩ-cm) Set 1									
Sample ID	0°	90°	180°	270°	0°	90°	180°	270°	Average Reading
A									
B									
C									
D									
								Set Average	
								Average Adjusted with Curing Condition Correction	
								Penetration Resistance Type	

Determination of Associated Data:

Type of Concrete Tested: ______________________________

____

____

Air Temperature of Testing Room = ________

Moist Condition Temperature = ________

Curing History Description: ______________________________

____

____

Appendix A: Lab Materials – Station 1

AASHTO T 22/ASTM C39, Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens

Reporting the Test Results

- Information to be reported:
- Identification number
- Average measured diameter (millimeters or in.)
- Cross-sectional area (square millimeters or square in.)
- Maximum Load (kilonewtons or pounds-force)
- Compressive Strength (MPa or psi)
- Type of fracture (See Figure 1)
- Defects in either specimen or caps
- Age of specimen

Compressive strength is reported to the nearest 0.1 MPa (10 psi).

Specimen ID	Age (days)	Average Diameter (in)	Specimen Area (in^2)	Total Load (pounds)	Compressive Strength (psi)	Type of Fracture	Defects
XXX-1	28	4.01	12.62	41,160	3,260	2	None

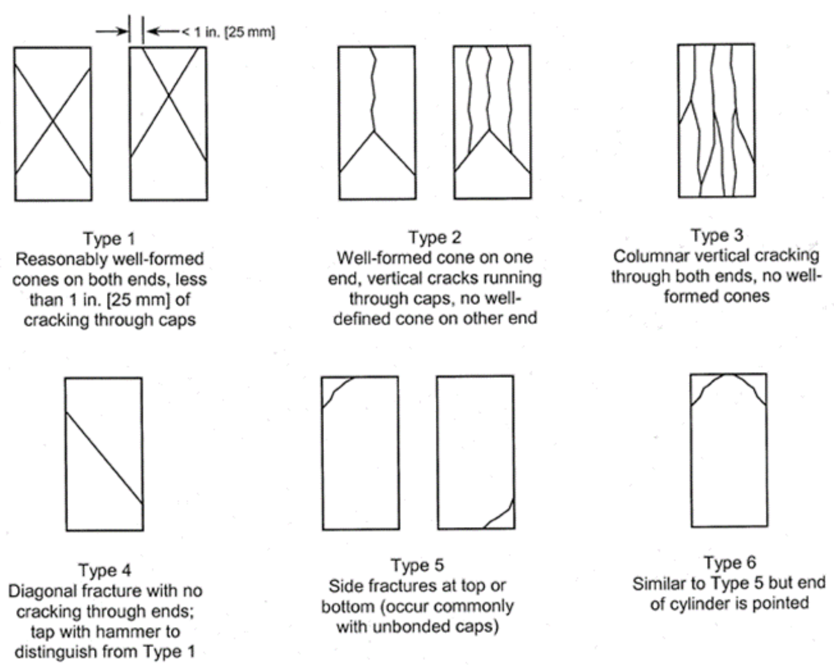


Figure 5: Types of Fracture

Common Errors

- Ends of specimens not checked for perpendicularity and planeness.
- Diameter measured at the ends of specimen rather than mid-height.
- Correct number of specimens measured per day.
- Rate of load continually adjusted until fracture occurs.

Data Sheet

Specimen ID	Age (days)	Average Diameter (in)	Specimen Area (in^2)	Total Load (pounds)	Compressive Strength (psi)	Type of Fracture	Defects

Station 2 – ASTM C42, Standard Method of Test for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

Reporting the Test Results

- Density should be calculated to the nearest 1 lb./ft^3
- Strength is to be reported to the nearest 10 psi

Common Errors

- Length not measured correctly.
- Incorrect rate of loading.
- Rate of load continually adjusted until fracture occurs.

Data Sheet

Diameters: ________, ________ Average Diameter _________

Average Length _________

L/D = __________

L/D Ratio	1.75	1.50	1.25	1.00
Strength Correction Factor	0.98	0.96	0.93	0.87

Max Load = ___________

Strength = ____________

Corrected Strength = ____________

Weight of Core = __________

Volume of Core = __________

Station 3 – AASHTO T 177/ASTM C293, Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)

Reporting the Test Results

The modulus of rupture should be reported to the nearest 0.05 MPa [5 psi]. Average width, depth, and lengths are to be reported to the nearest 1 mm [0.05 in.]. Maximum load is to be reported in N. Identification numbers, curing history, age of specimen, gap mitigation, and any defects in the specimen are also to be reported.

Common Errors

- Not checking the gaps with feeler gauges with a load on the specimen.
- Leather shims used when either not needed or when grinding and/or capping is required.
- Incorrect load rate is used.

Data Sheet

Identification Number = ______________

Average Width of Specimen = ______________

Average Depth of Specimen = ______________

Span Length = ______________

Maximum Load = ______________

Modulus of Rupture = ______________

Age of Specimen = ______________

Gap mitigation (capped, ground, leather shims, none) = ______________

Specimen fabrication (sawed, molded) = ______________

Span Length = ______________

Curing history and apparent moisture condition:

____

Defects or other notes:

____

AASHTO T 97/ASTM C78, Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

Reporting the Test Results

The modulus of rupture should be reported to the nearest 0.05 MPa [5 psi]. Average width, depth, and lengths are to be reported to the nearest 1 mm [0.05 in.]. Maximum load is to be reported in N. Identification numbers, curing history, age of specimen, gap mitigation, and any defects in the specimen are also to be reported.

Common Errors

- Not checking the gaps with feeler gauges with a load on the specimen.
- Leather shims used when either not needed or when grinding and/or capping is required.
- Incorrect load rate is used.

Data Sheet

Identification Number = ______________

Average Width of Specimen = ______________

Average Depth of Specimen = ______________

Span Length = ______________

Maximum Load = ______________

Modulus of Rupture = ______________

Age of Specimen = ______________

Gap mitigation (capped, ground, leather shims, none) = ______________

Specimen fabrication (sawed, molded) = ______________

Span Length = ______________

Curing history and apparent moisture condition:

____

Defects or other notes:

____

Station 4 – AASHTO T 259, Standard Method of Test for Resistance of Concrete to Chloride Ion

Reporting the Test Results

For each sample set, report the average and maximum baseline chloride ion. For each concrete slab sample, report the total chloride ion value and absorbed ion value for each depth. For the entire sample set, report the average and maximum absorbed chloride ion values for each depth. If the results of the absorbed ion value are less than zero, report the result as zero.

The report shall also include a statement that discloses if the abrasion process in Step 1 of the procedure was performed or not.

Limitations

The results of this test only determine the average chloride concentration over the sample depth taken from the slab, the actual chloride profile, or variations across the sample depth is not detected. The implication is that with reinforcing concrete, it is important to know where the chloride permeates in order to predict the vulnerability of the rebar.

For higher quality concrete, the 90-day period is not of sufficient time to allow the chloride significantly permeate the concrete. A longer exposure should be considered in these cases.

Common Errors

- In Step 4 of the procedure, sealing off the surface of the slab from the surrounding atmosphere.
- The salt crystal buildup is not completely removed.

Data Sheet

Determination of the baseline from the control concrete slab:

Total Chloride Ion Content from Depth 1 = _________

Total Chloride Ion Content from Depth 2 = _________

Baseline Average of Depth 1 and Depth 2 (**B**) = _________

Determination of the absorbed chloride ion content at each depth of each slab:

		Total Chloride Ion Content (**T**)	Absorbed Chloride Ion Content (**T-B**)
Concrete Slab 1	Depth 1		
	Depth 2		
Concrete Slab 2	Depth 1		
	Depth 2		
Concrete Slab 3	Depth 1		
	Depth 2		

Determination of the average chloride ion absorbed at each depth from all slabs:

Depth 1 Average = _________

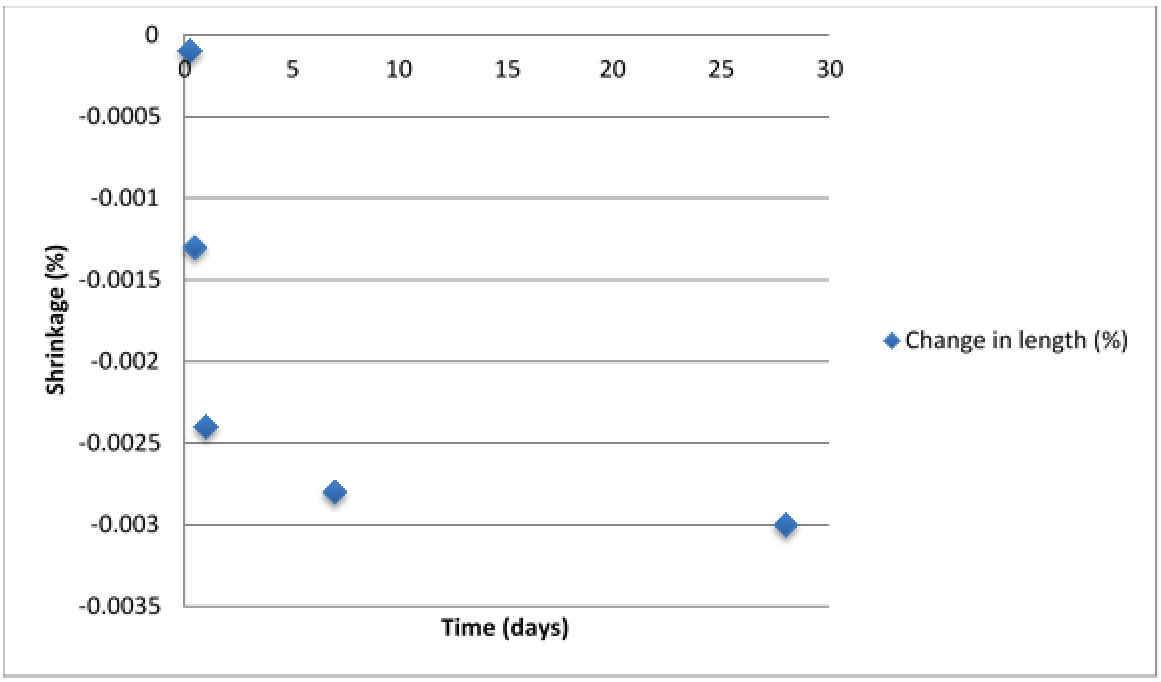
Depth 2 Average = _________

ASTM C157, Standard Method of Test for Length Change of Hardened Hydraulic-Cement Mortar and Concrete

Reporting the Test Results

The following items must be included in the report:

- Identification of specimen including quantity, size, and date molded
- Source and identification of each material used
- Description of the aggregate used
- Flow or slump and temperature of mixture at time of mixing
- Consolidation method
- Description of storage conditions
- Storage time and age of specimen
- Length change reported to nearest 0.001%



Common Errors

- Incorrect drying room humidity
- Incorrect drying room temperature
- Not rotating the bar
- Wear on reference bar from excessive use

Data Sheet

Sample ID	Date	Curing Method	Length Reading

Station 5 – AASHTO T 277/ASTM C1202, Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

Reporting the Test Results

The results should be plotted in current (amperes) versus time (seconds), with a smooth curve drawn through the data. This will be reported, along with the total charge passed (corrected for diameter if necessary).

Interpreting and Utilizing the Test Results

Using AASHTO T277 Table 1, determine your chloride ion penetrability. This will show you whether your penetrability is negligible, low, medium, or high. Several factors known to the permeability include: water-cement ratio, polymeric admixtures, age, air void system, type of aggregate, degree of consolidation, and type of curing.

Common Errors

- Absolute vacuum gauges shall not be used for this test.
- The presence of calcium nitrite in admixtures can produce misleading results showing lower resistance to chloride ion penetration.

Data Sheet

Date	
Technician	
Identification Number	
Source of Cylinder/Core	
Mix Information	
Location of Specimen in Cylinder/Core	
Cure Type	
Diameter	
Additional Remarks	

Time (min)	**Current (amperes)**
0	
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	

ASTM C469, Standard Method of Test for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

Reporting the Test Results

Report the specimen identification number, dimensions of the specimen, curing and environmental histories of the specimen, age of the specimen, and chord modulus of elasticity. If determined, also report the strength of the concrete, unit weight of the concrete, stress-stain curves, and Poisson's ratio.

Common Errors

- Not securing the compressometer or extensometer correctly.
- Incorrect load rate.

Data Sheets

Specimen ID	
Diameter (D)	
Length (L)	
Cross Sectional Area (A) = ¼ π D^2	
Age when tested	
Ultimate Load	

After measuring the specimen and testing the companion cylinder, determine where the two test points will be taken. Determine the longitudinal deformation that will be read on the gauge when the longitudinal strain is at 50 millionths for test point 1. Determine the load at 40% of the ultimate load for test point 2.

Data Sheet During Loading of Specimen

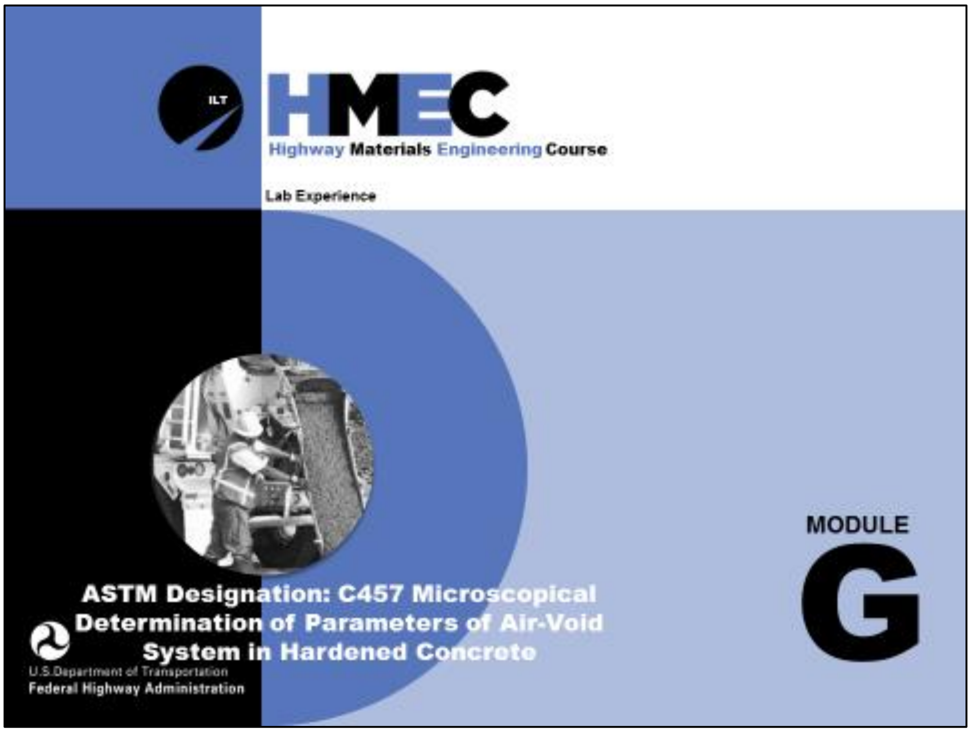
	Load (lb.)	**Stress (S) = Load/Area**	**Longitudinal deformation**	**Longitudinal Strain (ε)**	**Transverse strain (ε_t)**
At 50 millionths (1)					
At 40% of Ultimate Load (2)					

Appendix B: Presentations

ASTM Designation: C457

Microscopical Determination of Parameters of Air-Void System in Hardened Concrete

Slide 1



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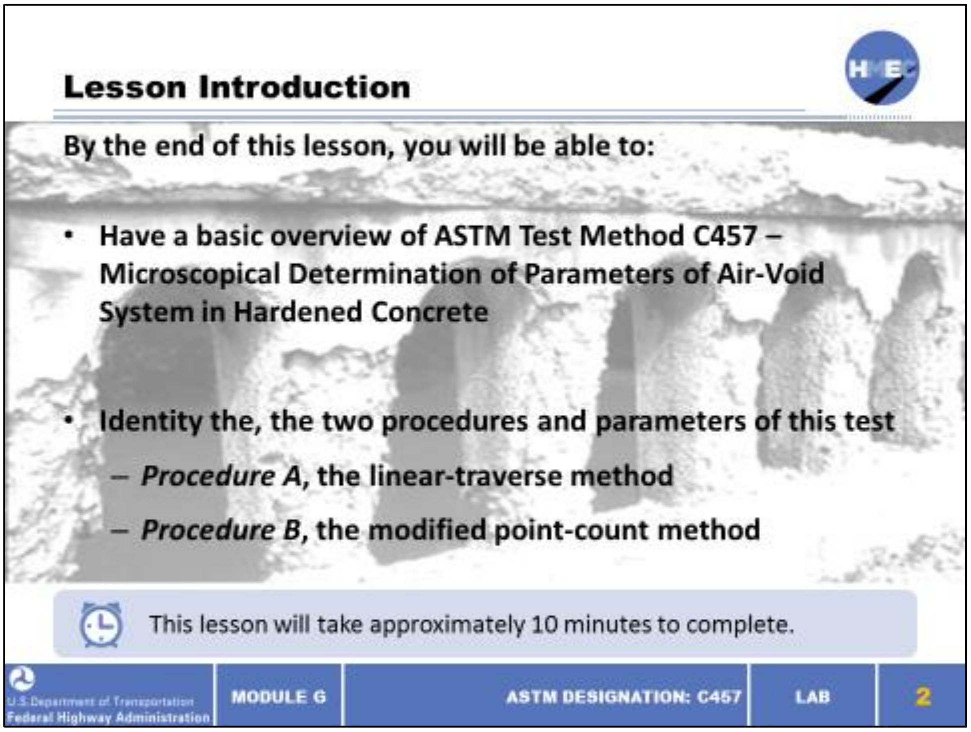
Slide 2


Lesson Introduction
By the end of this lesson, you will be able to:
• Have a basic overview of ASTM Test Method C457 – Microscopical Determination of Parameters of Air-Void System in Hardened Concrete
• Identity the, the two procedures and parameters of this test
– Procedure A, the linear-traverse method
– Procedure B, the modified point-count method
This lesson will take approximately 10 minutes to complete.
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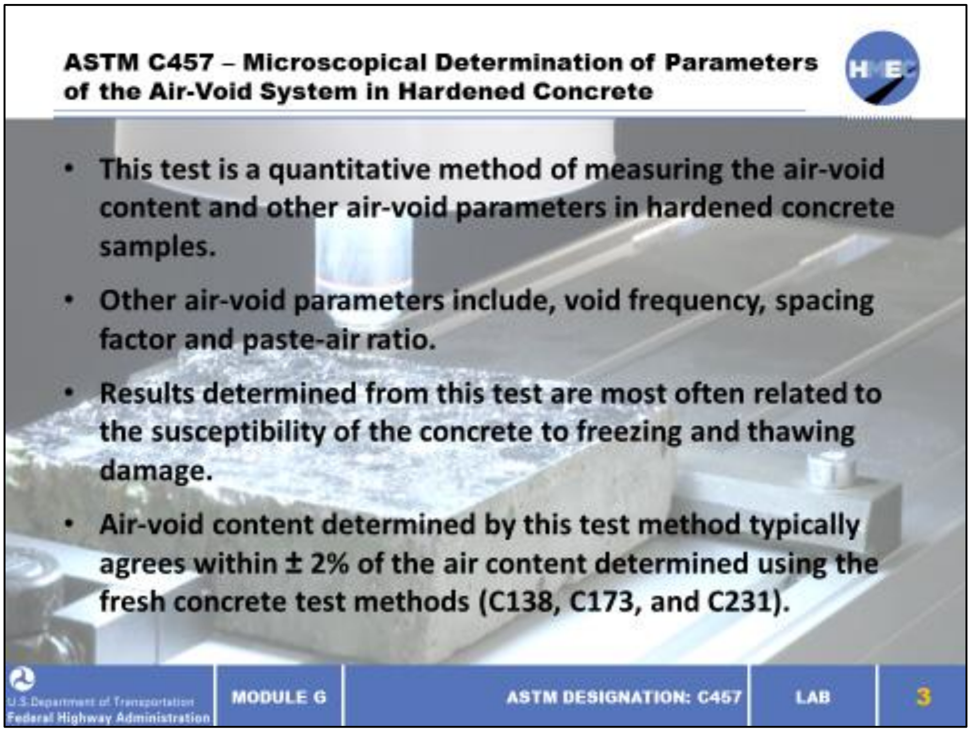
Slide 3


ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete
• This test is a quantitative method of measuring the air-void content and other air-void parameters in hardened concrete samples.
• Other air-void parameters include, void frequency, spacing factor and paste-air ratio.
• Results determined from this test are most often related to the susceptibility of the concrete to freezing and thawing damage.
• Air-void content determined by this test method typically agrees within ± 2% of the air content determined using the fresh concrete test methods (C138, C173, and C231).
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Slide 4

ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C457 Equipment

- ***Procedures A*** **and** ***B*** **use the following equipment:**

A – Lower stage assembly

B – Lower East/West screw

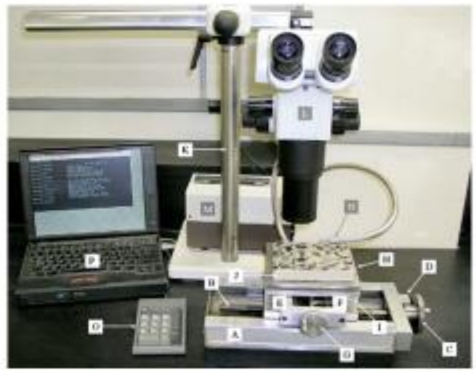
C – Crank for turning E/W screw

D – Stopping device for point count positions on the line of traverse

E –Upper stage assembly

F – Cross feed screw for North/South upper stage

G – Crank for turning N/S screw



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Slide 5

ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C457 Equipment (continued)

H – Plate supporting the concrete specimen (the stage) (must be level)

J – Concrete specimen

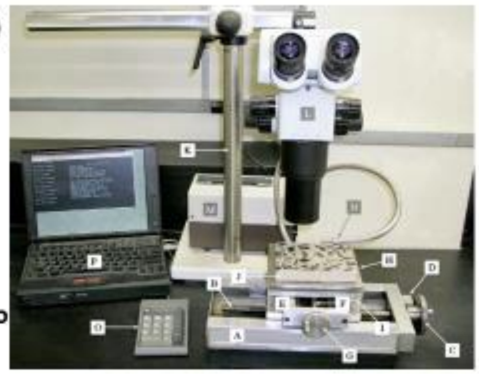
K – Support

L – Stereoscopic Microscope

M & N – Adjustable light source

O & P – Data collection devices

Procedure B **also requires the screws to be fitted with stopping devices (a click), operator will know when a stop position has been reached**



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Slide 6

ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C457 Samples

- Concrete specimens for this test can be either cast or cored samples.
- Samples may be composed of any number of specimens.
- For referee or compliance purposes, samples shall be obtained from at least three randomly selected locations in the area being tested.
- The area tested should be parallel to the finished concrete surface or to the layers in which the concrete was placed.
- Samples are saw cut to an appropriate size that will fit on the testing equipment.

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Slide 7

ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C457 Samples (continued)

- Test samples need to have a finished area conforming to Table 1 in C457 which is determined by the Nominal Maximum Aggregate size in the concrete sample.
- The surface to be measured for air-voids will need to be lapped (grinding on a flat surface).
- Surfaces need to be cleaned prior to measurements

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

Nominal or Observed Maximum Size of Aggregate in the Concrete, mm [in.]	Total Area to be Traversed for Determination of A, α or $\bar{L}^{B}$, min. cm² [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]

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Slide 8

ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C457 Samples (continued)

- The edges of air-voids should have sharp surfaces
- Damaged portions of the surface can not be analyzed.
- Additional preparations may be needed for weak cement-paste matrixes.

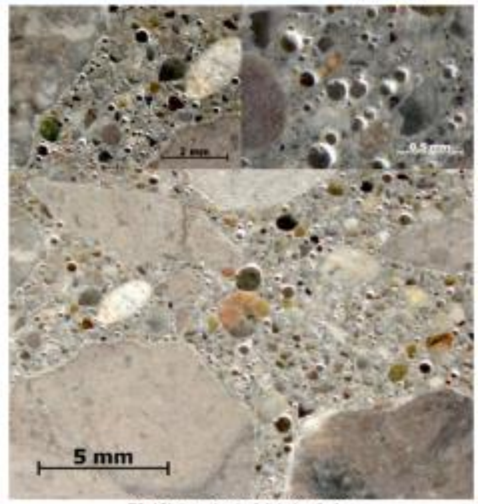

FIG. 1 Photographs of a Satisfactory Surface

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Slide 9

ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

C457 Calculations – *Procedure A*

- Air Content – $A = \frac{T_a \cdot 100}{T_t}$
- Paste Content – $p = \frac{T_p \cdot 100}{T_t}$
- Void Frequency – $n = \frac{N}{T_t}$
- Paste Air Ratio – $r = \frac{T_p}{T_a}$
- Average Chord Length – $\bar{l} = \frac{T_a}{N}$
- Spacing Factor – $4.342\ \bar{L} = \frac{T_p}{4N}$
- Specific Surface – $\alpha = \frac{4}{\bar{l}}$
- Percent Air – $A = \frac{100}{r(1+M)+1}$

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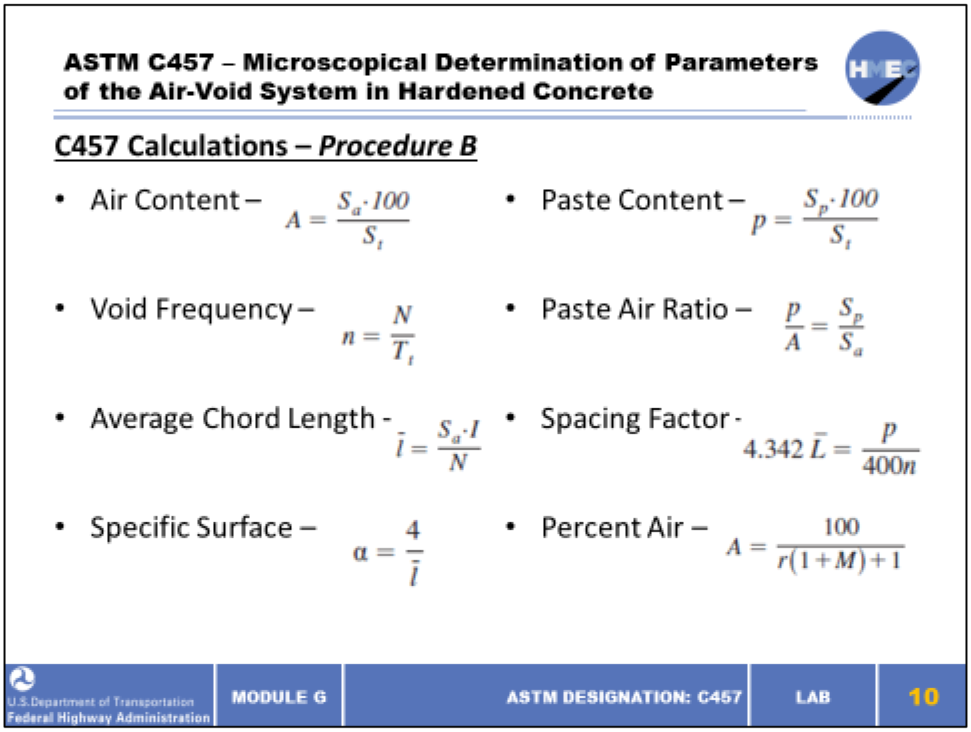
Slide 10


ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete
HMEC
C457 Calculations – Procedure B
Air Content – $A = \frac{S_a \cdot 100}{S_t}$
Paste Content – $p = \frac{S_p \cdot 100}{S_t}$
Void Frequency – $n = \frac{N}{T_t}$
Paste Air Ratio – $\frac{p}{A} = \frac{S_p}{S_a}$
Average Chord Length - $\bar{l} = \frac{S_a \cdot I}{N}$
Spacing Factor - $4.342\ \bar{L} = \frac{p}{400n}$
Specific Surface – $\alpha = \frac{4}{\bar{l}}$
Percent Air – $A = \frac{100}{r(1+M)+1}$
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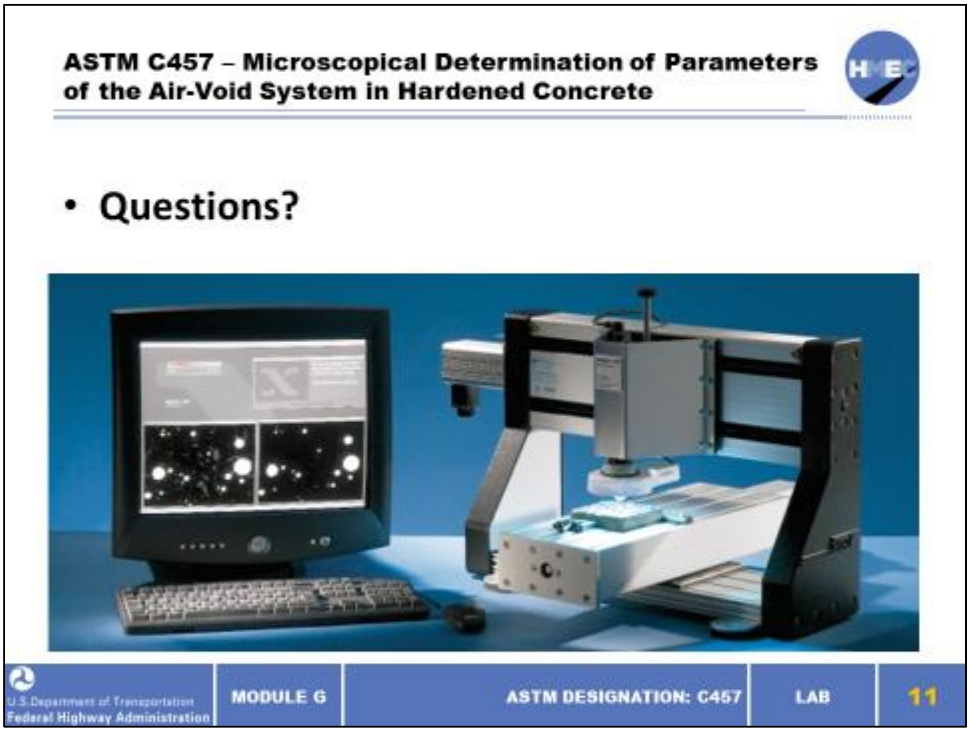
Slide 11


ASTM C457 – Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete
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Slide 12


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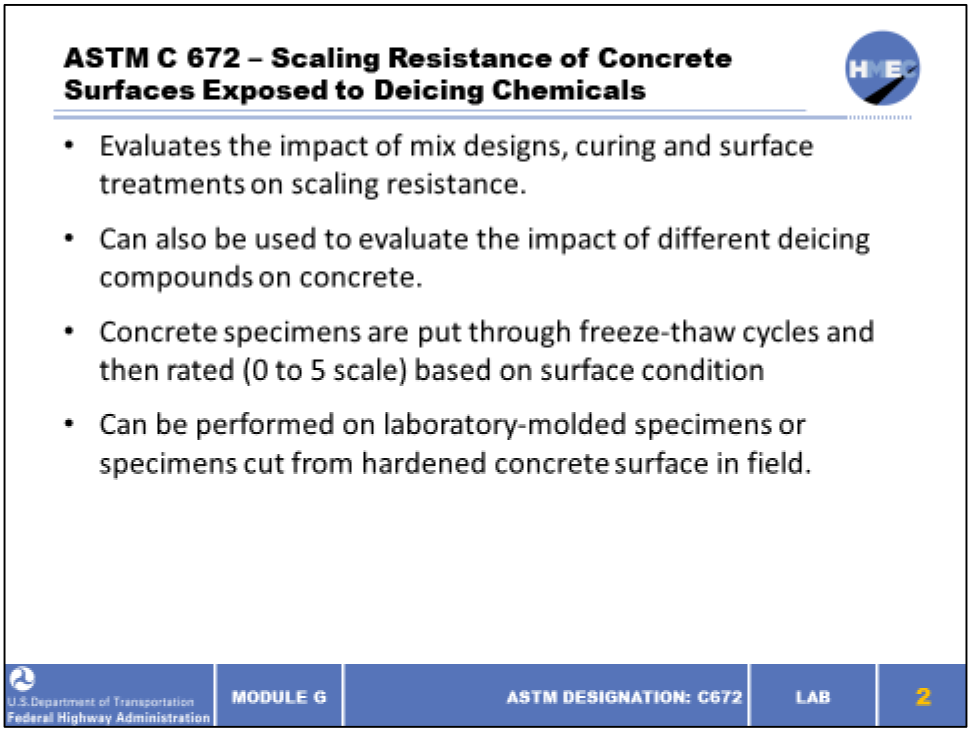
ASTM Designation: C672

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

Slide 1

Slide 2


ASTM C 672 – Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
HMEC
• Evaluates the impact of mix designs, curing and surface treatments on scaling resistance.
• Can also be used to evaluate the impact of different deicing compounds on concrete.
• Concrete specimens are put through freeze-thaw cycles and then rated (0 to 5 scale) based on surface condition
• Can be performed on laboratory-molded specimens or specimens cut from hardened concrete surface in field.
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ASTM C 672 – Equipment

- Freezer maintaining a temperature of -18 ± 3°C (0 ± 5°F) large enough to hold specimens.
- Brine solution of water and 4 g of anhydrous Calcium Chloride in each 100 mL of solution
  - Other solutions can be used if the purpose is to evaluate the impact of a particular deicing compound on the concrete.
- Other equipment listed in method is basic concrete equipment (molds, slump cone, tamping rod, air meter, scales, small tools).

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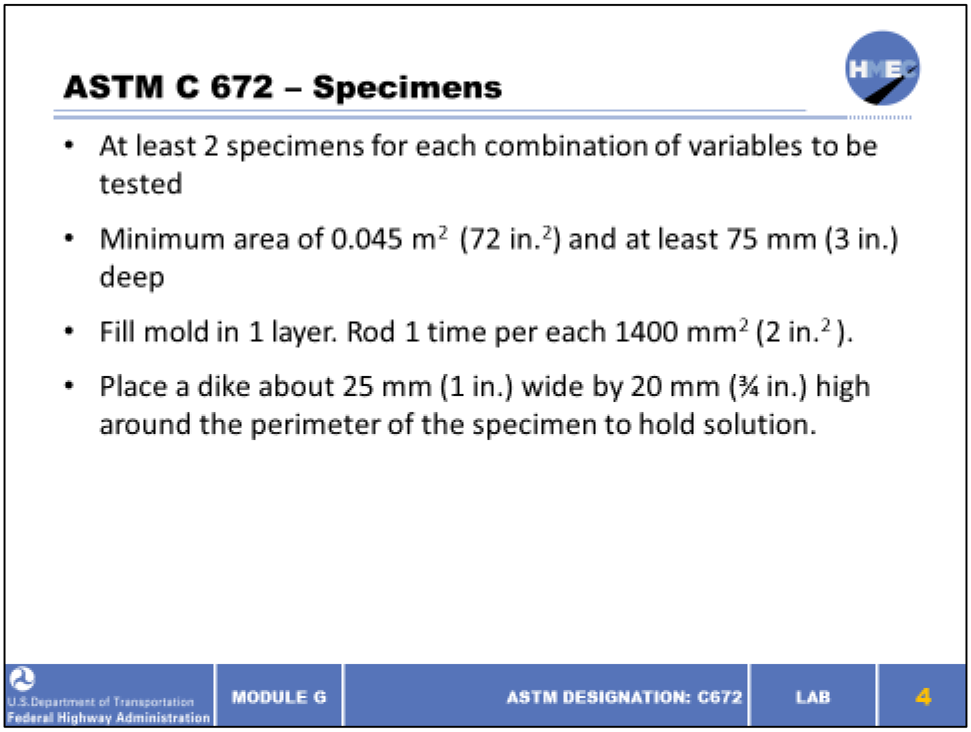
ASTM C 672 – Specimens
HMEC
• At least 2 specimens for each combination of variables to be tested
• Minimum area of 0.045 m² (72 in.²) and at least 75 mm (3 in.) deep
• Fill mold in 1 layer. Rod 1 time per each 1400 mm² (2 in.²).
• Place a dike about 25 mm (1 in.) wide by 20 mm (¾ in.) high around the perimeter of the specimen to hold solution.
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ASTM C 672 – Test specimen
MIG01
FHWA Publication No. FHWA-HRT-06-103, "Material Property Characterization of Ultra-High Performance Concrete," August 2006.
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ASTM C 672 – Curing Specimens

- After molding cover for 20 to 24 hours
- Put in moist room until desired strength level is reached or after age of 14 days has been reached.
- Store in air for 14 days at 23.0 ± 2.0°C (73.5 ± 3.5°F) and 45 to 55 % relative humidity
- If protective coatings are being evaluated, coat the specimens at the age of 21 days.

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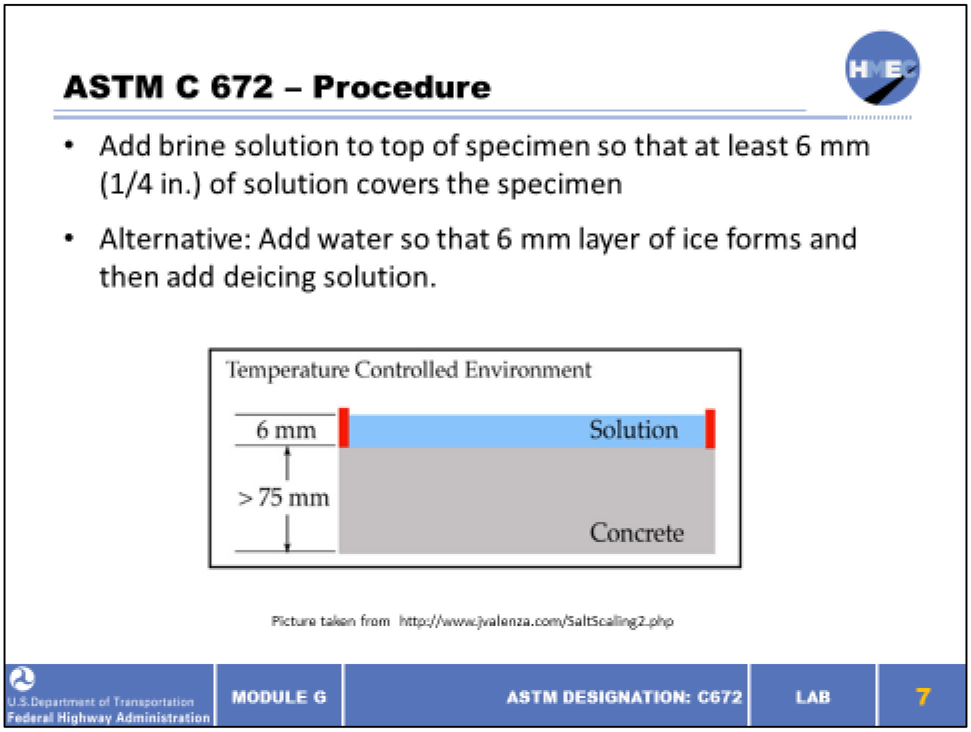
ASTM C 672 – Procedure
HMEC
• Add brine solution to top of specimen so that at least 6 mm (1/4 in.) of solution covers the specimen
• Alternative: Add water so that 6 mm layer of ice forms and then add deicing solution.
Temperature Controlled Environment
6 mm
Solution
> 75 mm
Concrete
Picture taken from http://www.jvalenza.com/SaltScaling2.php
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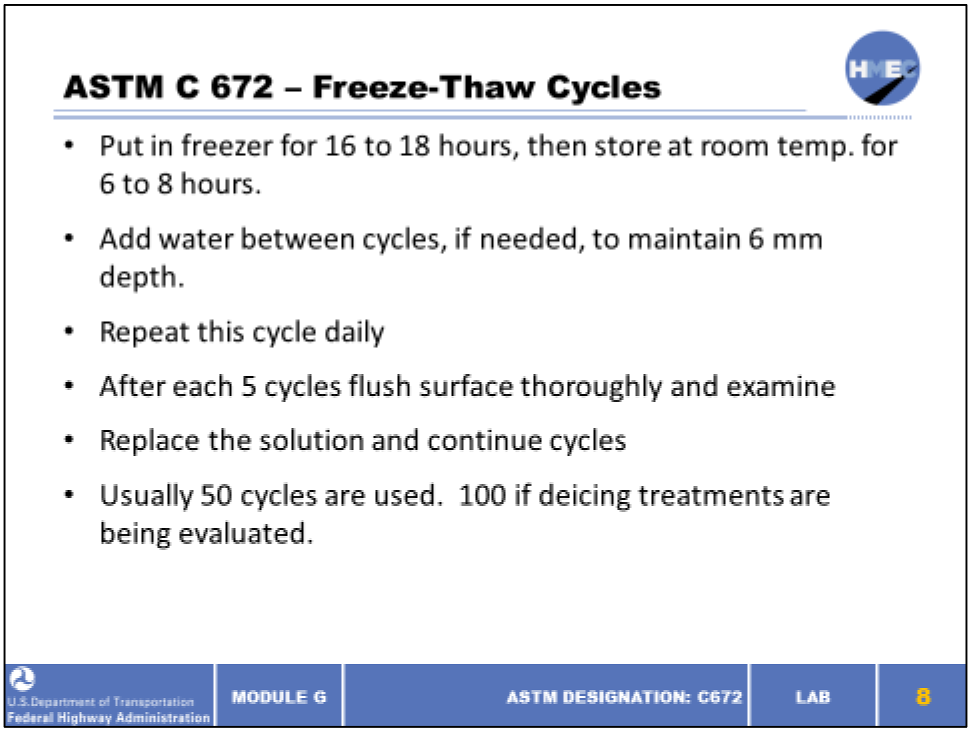
ASTM C 672 – Freeze-Thaw Cycles
Put in freezer for 16 to 18 hours, then store at room temp. for 6 to 8 hours.
Add water between cycles, if needed, to maintain 6 mm depth.
Repeat this cycle daily
After each 5 cycles flush surface thoroughly and examine
Replace the solution and continue cycles
Usually 50 cycles are used. 100 if deicing treatments are being evaluated.
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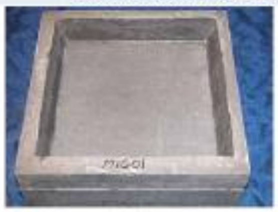
ASTM C 672 – Visual rating scale

Rating	Condition of surface
0	No scaling
1	Very slight scaling (3 mm depth max, no coarse aggregate visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)



FHWA Publication No. FHWA-HRT-06-103, "Material Property Characterization of Ultra-High Performance Concrete," August 2006.

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ASTM C 672 – Another example
Vassiliev, D.G., "Evaluation of Test Methods for De-Icer Scaling Resistance of Concrete," University of Toronto, 2012, pp. 207-209.
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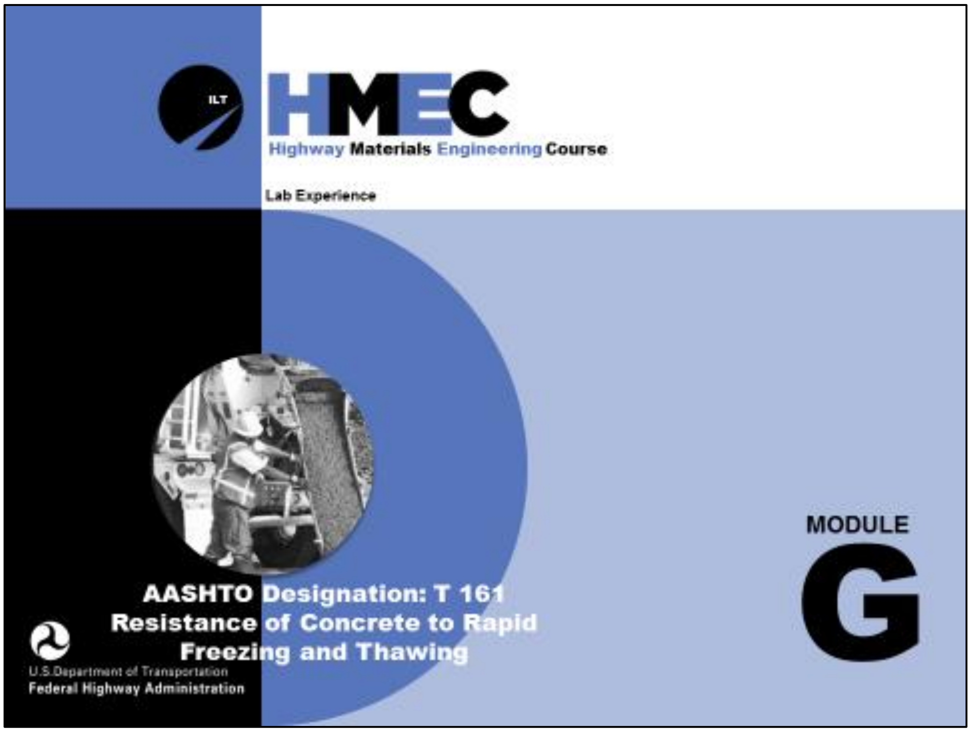
AASHTO Designation: T 161

Resistance of Concrete to Rapid Freezing and Thawing

Slide 1



Slide 2

AASHTO T161 – Resistance of Concrete to Rapid Freezing and Thawing

- This test method is used to determine the effects of variations in both properties and conditioning of concrete in the resistance to freezing and thawing cycles.
  - There are two different procedures allowed in this test method.
    - Procedure A – Rapid Freezing and Thawing in Water.
    - Procedure B – Rapid Freezing in Air and Thawing in Water.

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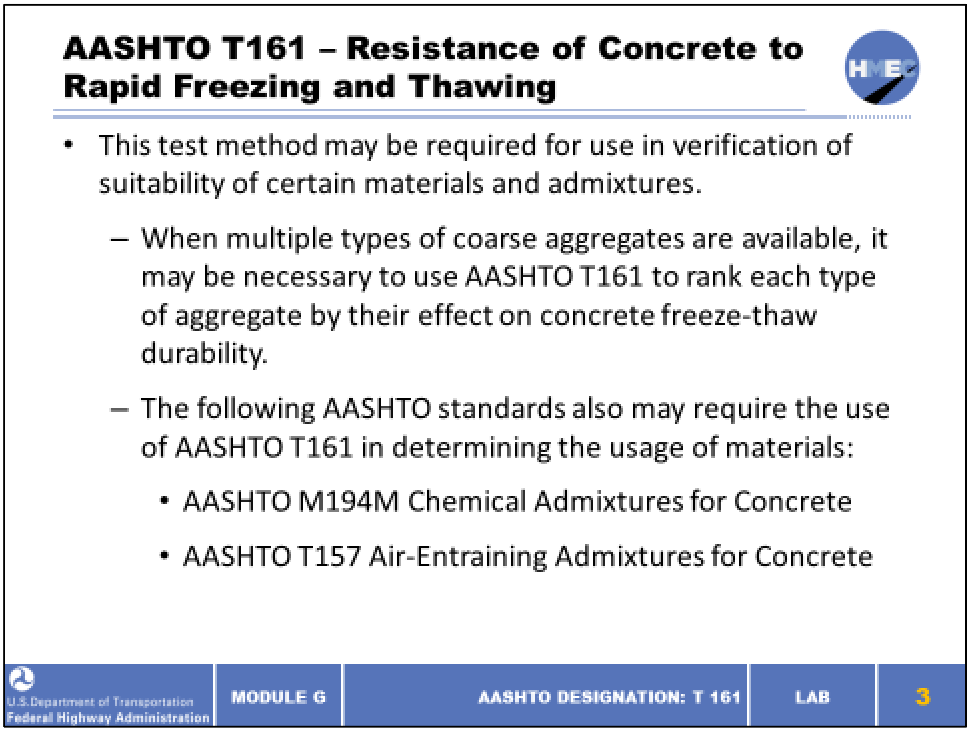
AASHTO T161 – Resistance of Concrete to Rapid Freezing and Thawing
• This test method may be required for use in verification of suitability of certain materials and admixtures.
– When multiple types of coarse aggregates are available, it may be necessary to use AASHTO T161 to rank each type of aggregate by their effect on concrete freeze-thaw durability.
– The following AASHTO standards also may require the use of AASHTO T161 in determining the usage of materials:
• AASHTO M194M Chemical Admixtures for Concrete
• AASHTO T157 Air-Entraining Admixtures for Concrete
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AASHTO T161 – Equipment
HMEC
• Freezing and Thawing Apparatus:
• A chamber used to store the specimens during the freezing and thawing cycles.
• Refrigeration and heating equipment with controls to produce and maintain necessary temperatures to run the test.
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AASHTO T161 – Equipment

- **Dynamic Testing Apparatus:**
  - Conforming to the requirements of ASTM C215 – Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens.

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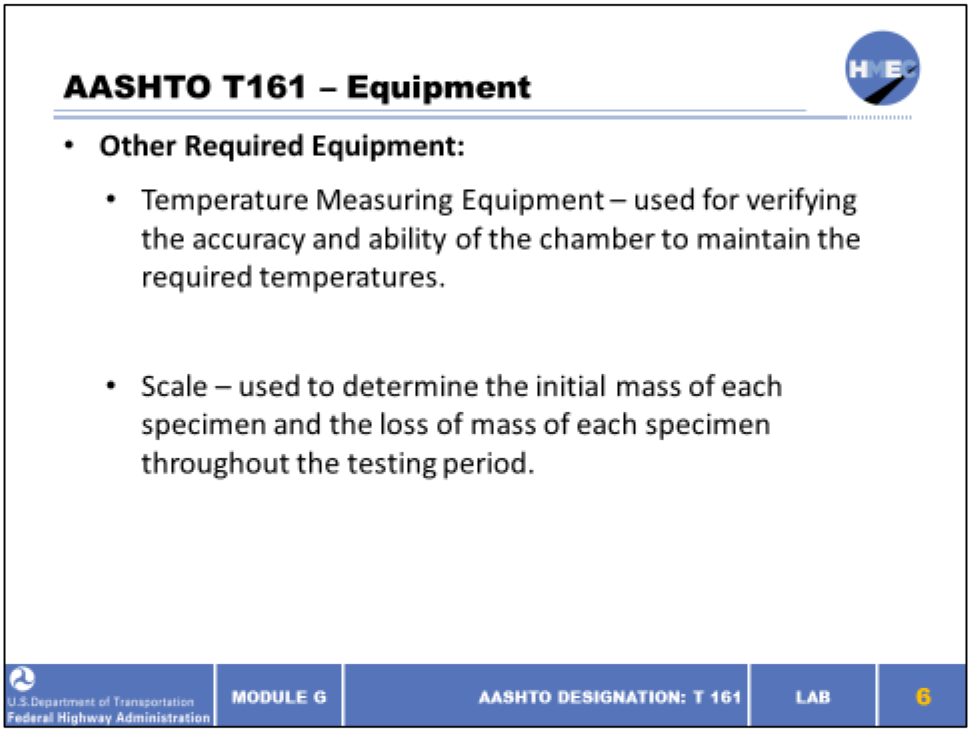
AASHTO T161 – Equipment
• Other Required Equipment:
• Temperature Measuring Equipment – used for verifying the accuracy and ability of the chamber to maintain the required temperatures.
• Scale – used to determine the initial mass of each specimen and the loss of mass of each specimen throughout the testing period.
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AASHTO T161 – Equipment

- **Optional Equipment:**
  - Length Comparator – conforming to the requirements of AASHTO M210 – Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete. Used to measure the length of the test specimens, when desired.
  - Length Reference Bar – used to ensure the consistency of measurements of the Length Comparator.

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AASHTO T161 – Test Specimens

- Test specimens are either prisms or cylinders made in accordance with AASHTO test methods M210 and R39 – Making and Curing Concrete Test Specimens in the Laboratory, or cores or prisms cut from hardened concrete.

- Test specimens are stored in saturated lime water until the testing is begun

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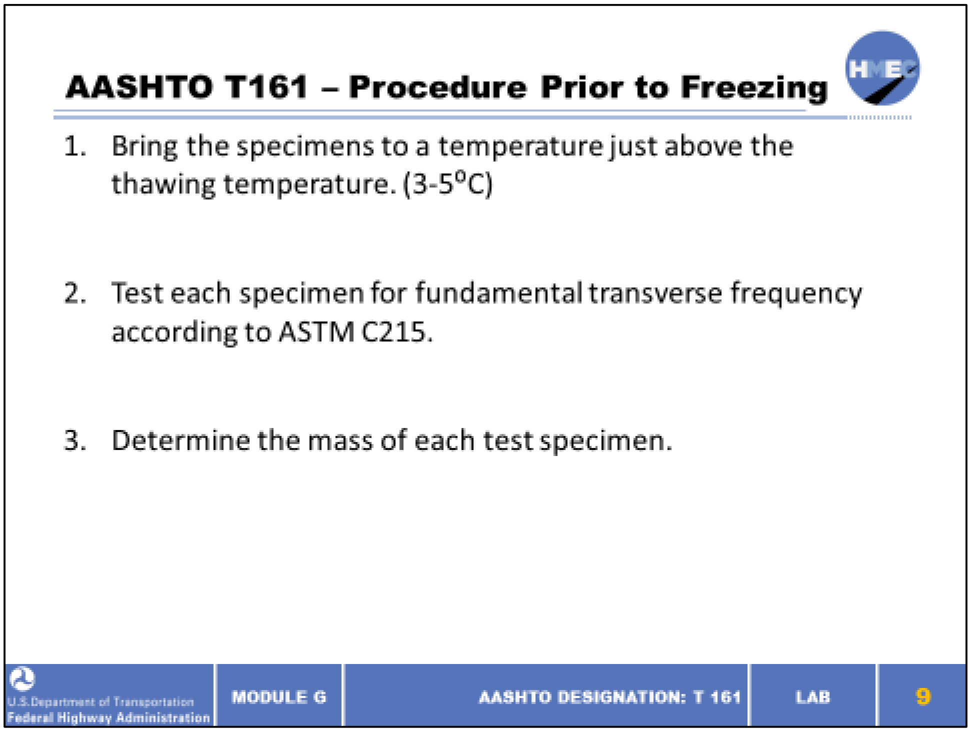
AASHTO T161 – Procedure Prior to Freezing
HMEC
1. Bring the specimens to a temperature just above the thawing temperature. (3-5°C)
2. Test each specimen for fundamental transverse frequency according to ASTM C215.
3. Determine the mass of each test specimen.
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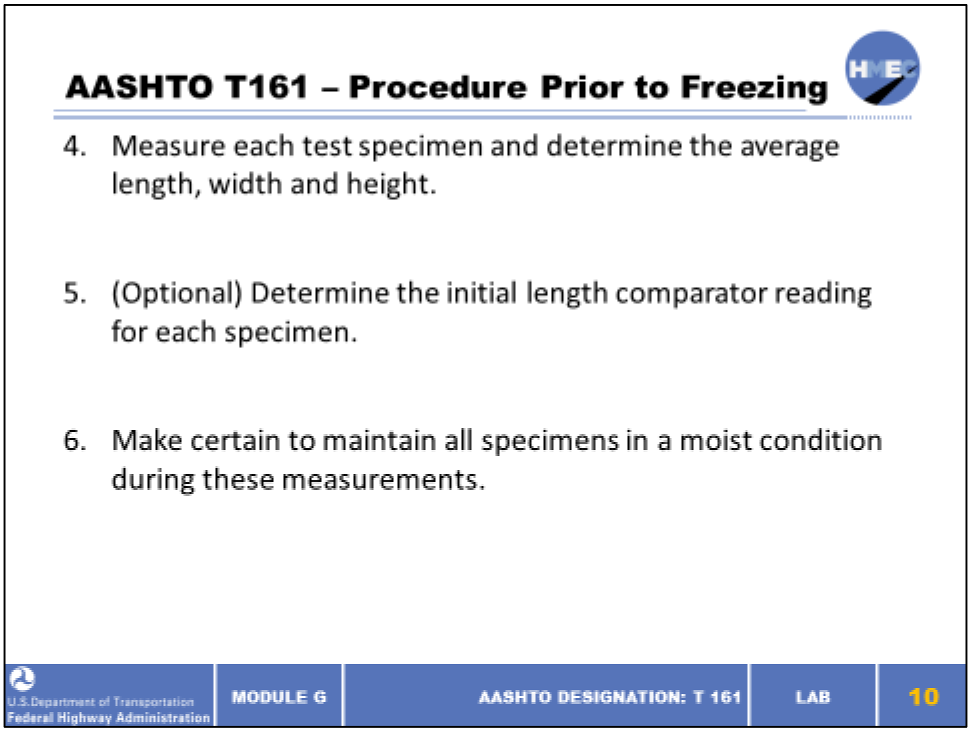
AASHTO T161 – Procedure Prior to Freezing
HMEC
4. Measure each test specimen and determine the average length, width and height.
5. (Optional) Determine the initial length comparator reading for each specimen.
6. Make certain to maintain all specimens in a moist condition during these measurements.
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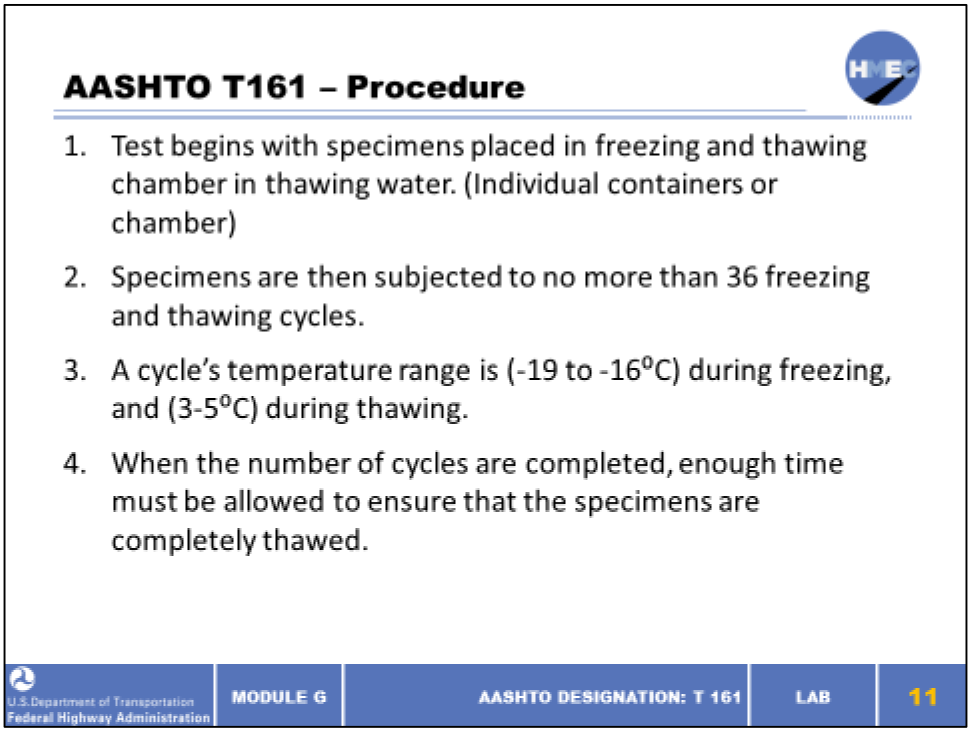
AASHTO T161 – Procedure
HMEC
1. Test begins with specimens placed in freezing and thawing chamber in thawing water. (Individual containers or chamber)
2. Specimens are then subjected to no more than 36 freezing and thawing cycles.
3. A cycle's temperature range is (-19 to -16°C) during freezing, and (3-5°C) during thawing.
4. When the number of cycles are completed, enough time must be allowed to ensure that the specimens are completely thawed.
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AASHTO T161 – Procedure

5. Once thawed, each specimen is retested for fundamental transverse frequency.
6. The mass is then determined for each test specimen.
7. (Optional) Make a length comparator determination for each specimen.
8. Procedure A: Rinse out the chamber or the individual containers that the specimens are placed in, and add new water.

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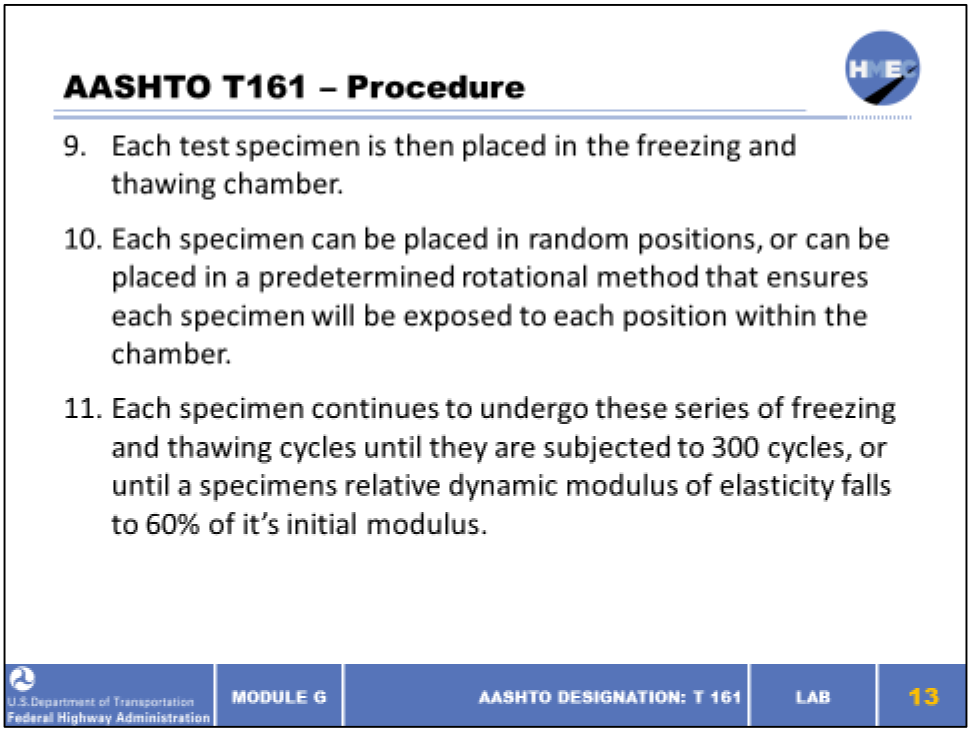
AASHTO T161 – Procedure
9. Each test specimen is then placed in the freezing and thawing chamber.
10. Each specimen can be placed in random positions, or can be placed in a predetermined rotational method that ensures each specimen will be exposed to each position within the chamber.
11. Each specimen continues to undergo these series of freezing and thawing cycles until they are subjected to 300 cycles, or until a specimens relative dynamic modulus of elasticity falls to 60% of it's initial modulus.
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AASHTO T161 – Calculations

Relative Dynamic Modulus of Elasticity:

$$P_c = \left(\frac{n_1^2}{n^2}\right) \times 100$$

P_c = relative dynamic modulus of elasticity, after c cycles of freezing and thawing, percent

n = fundamental transverse frequency at zero cycles of freezing and thawing

n_1 = fundamental transverse frequency after c cycles of freezing and thawing

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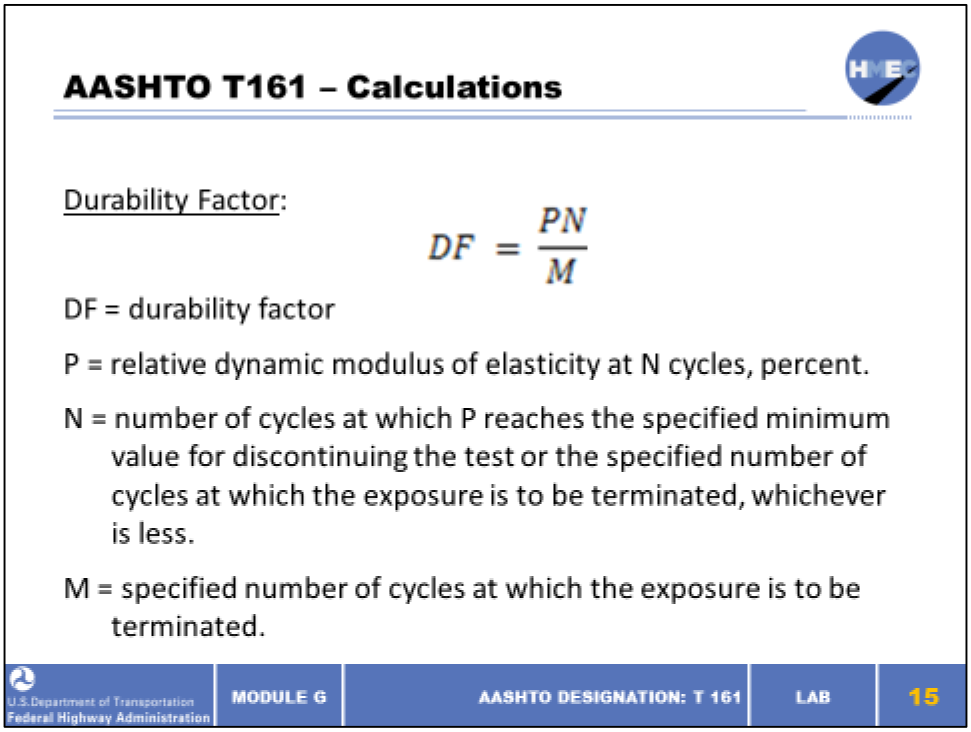
AASHTO T161 – Calculations
Durability Factor:
$DF = \frac{PN}{M}$
DF = durability factor
P = relative dynamic modulus of elasticity at N cycles, percent.
N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less.
M = specified number of cycles at which the exposure is to be terminated.
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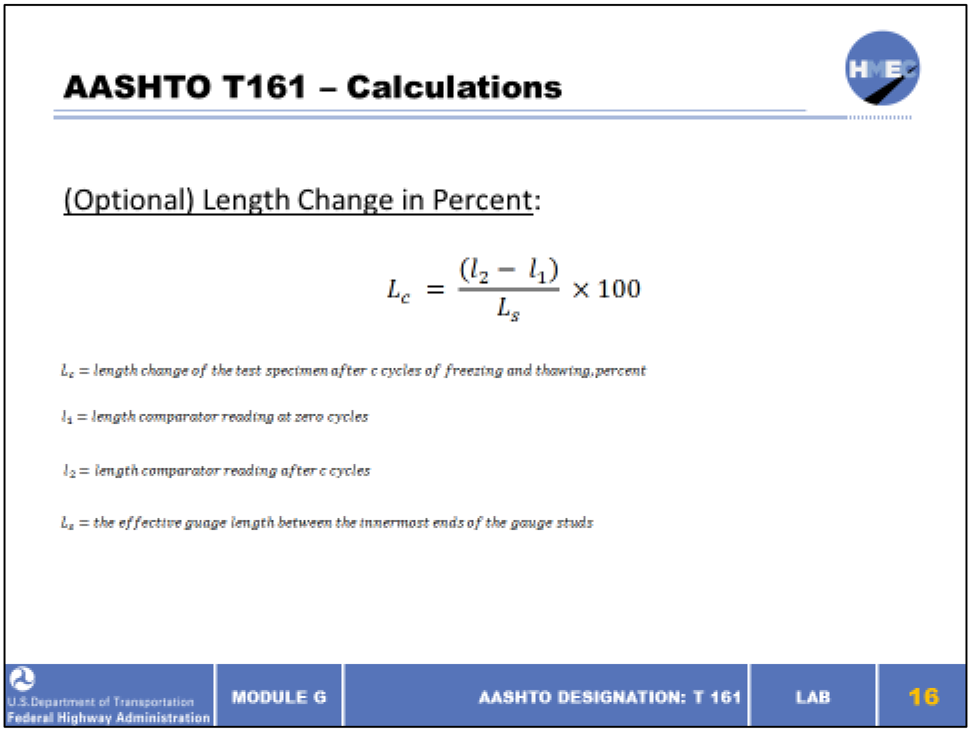
AASHTO T161 – Calculations
(Optional) Length Change in Percent:
$$L_c = \frac{(l_2 - l_1)}{L_s} \times 100$$
L_c = length change of the test specimen after c cycles of freezing and thawing, percent
l_1 = length comparator reading at zero cycles
l_2 = length comparator reading after c cycles
L_s = the effective guage length between the innermost ends of the gauge studs
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AASHTO Designation: T 325

Estimating the Strength of Concrete in Transportation Construction by Maturity Tests

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Estimating the Strength of Concrete in Transportation Construction by Maturity Tests (AASHTO T 325)

- Provides an estimate of concrete strength based on time-temperature data.
- ASTM C1074 – Estimating Concrete Strength by the Maturity Method

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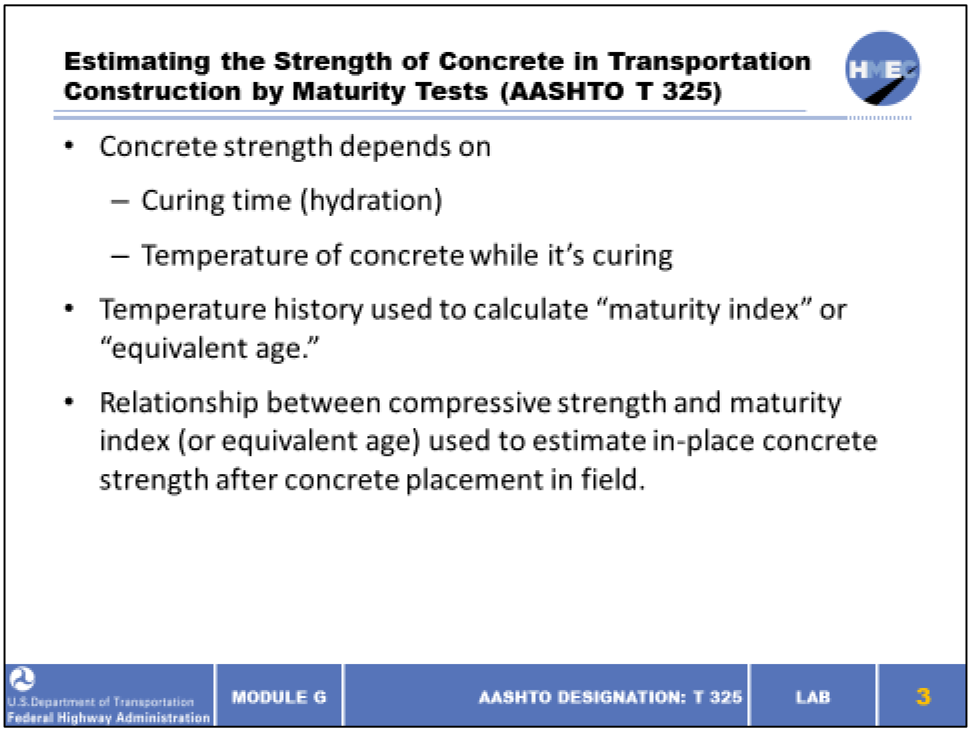
Estimating the Strength of Concrete in Transportation Construction by Maturity Tests (AASHTO T 325)
HMEC
• Concrete strength depends on
– Curing time (hydration)
– Temperature of concrete while it's curing
• Temperature history used to calculate "maturity index" or "equivalent age."
• Relationship between compressive strength and maturity index (or equivalent age) used to estimate in-place concrete strength after concrete placement in field.
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Concrete Maturity Background

- 1940s: method originated in work on steam curing of concrete carried out in England.
- 1970s-1980s: NBS/NIST research during 1970s and 1980s proposed using maturity to estimate in-place strength development.
- 1990s: FHWA through SHRP Project C-204 and mobile laboratory encouraged use of method for highway construction.
- 2000 – present: State DOTs started using maturity to estimate in-place strength development.

Carino, N. J. and Lew, H.S., 2001, "The Maturity Method from Theory To Application," National Institute of Standards and Technology, ASCE Proceedings of the 2001 Structures Congress & Exposition.

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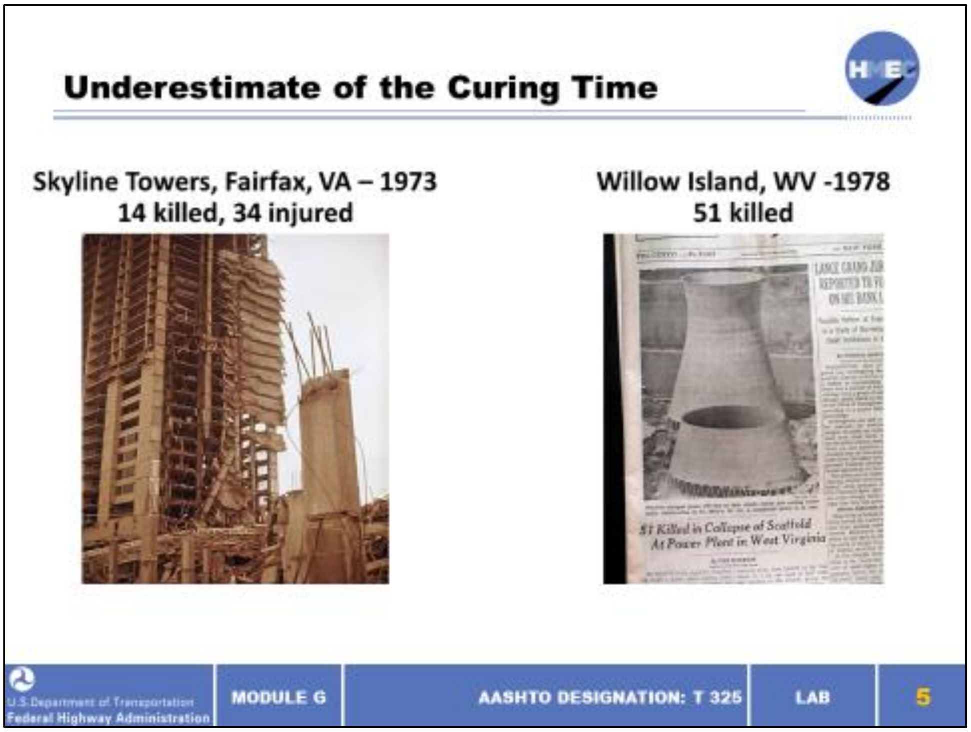
Underestimate of the Curing Time
Skyline Towers, Fairfax, VA – 1973
14 killed, 34 injured
Willow Island, WV -1978
51 killed
51 Killed in Collapse of Scaffold At Power Plant in West Virginia
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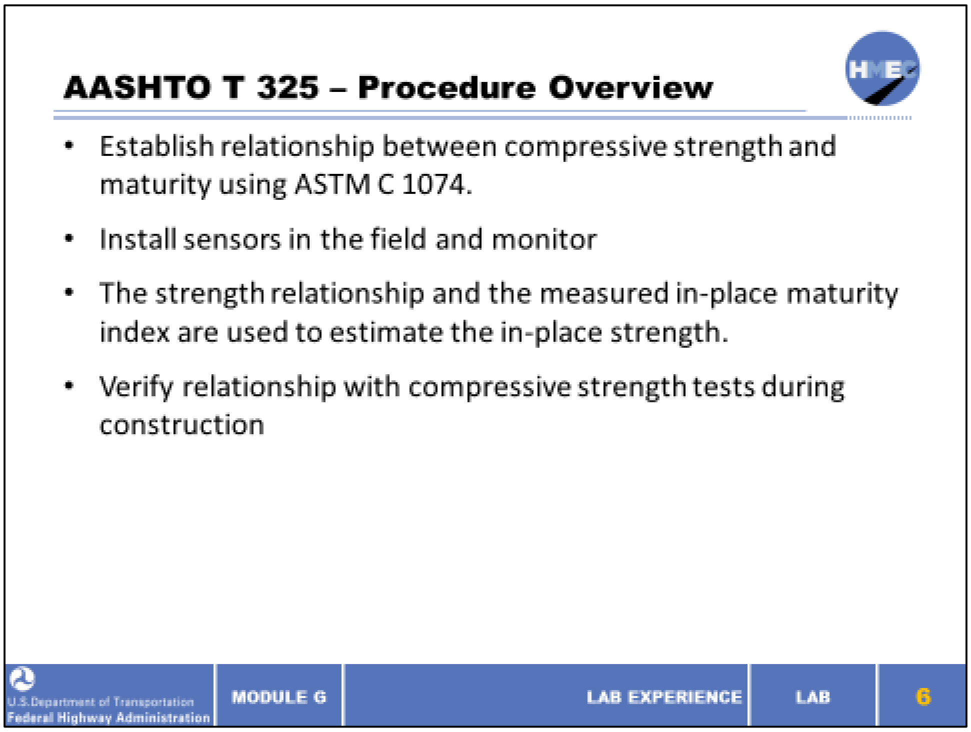
AASHTO T 325 – Procedure Overview
• Establish relationship between compressive strength and maturity using ASTM C 1074.
• Install sensors in the field and monitor
• The strength relationship and the measured in-place maturity index are used to estimate the in-place strength.
• Verify relationship with compressive strength tests during construction
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Develop Your Concrete Mix's Calibrated Strength-Maturity Curve in the Lab

- Prepare a trial batch of the desired concrete mix design that will be used in the structure, pavement, or slab.
- Pour the mix into a series of test specimens (cylinders or beams).
- Insert temperature-monitoring sensors into two of these specimens.
- Cure all the specimens in the same manner (water bath or moist room).
- While curing, read the temperature sensors and calculate the maturity data.
- Test specimens that do not contain the sensors periodically to determine strength at ages of interest.
- Use the data to establish a relationship between maturity and strength.

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ASTM C 1074 – Concrete Maturity Plots

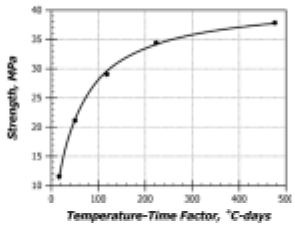

FIG. 1 Example of a Relationship Between Compressive Strength and Temperature-Time Factor

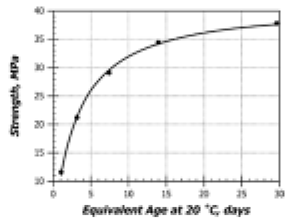

FIG. 2 Example of a Relationship Between Compressive Strength and Equivalent Age at 20 °C

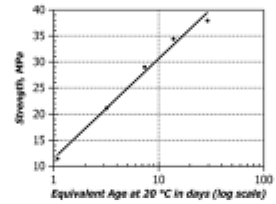

FIG. 3 Example of Compressive Strength as a Function of Logarithm of Equivalent Age

- Sample plots of compressive strength versus maturity or equivalent age.
- Equivalent age can also be plotted as a straight line plot if it is plotted on a log scale.

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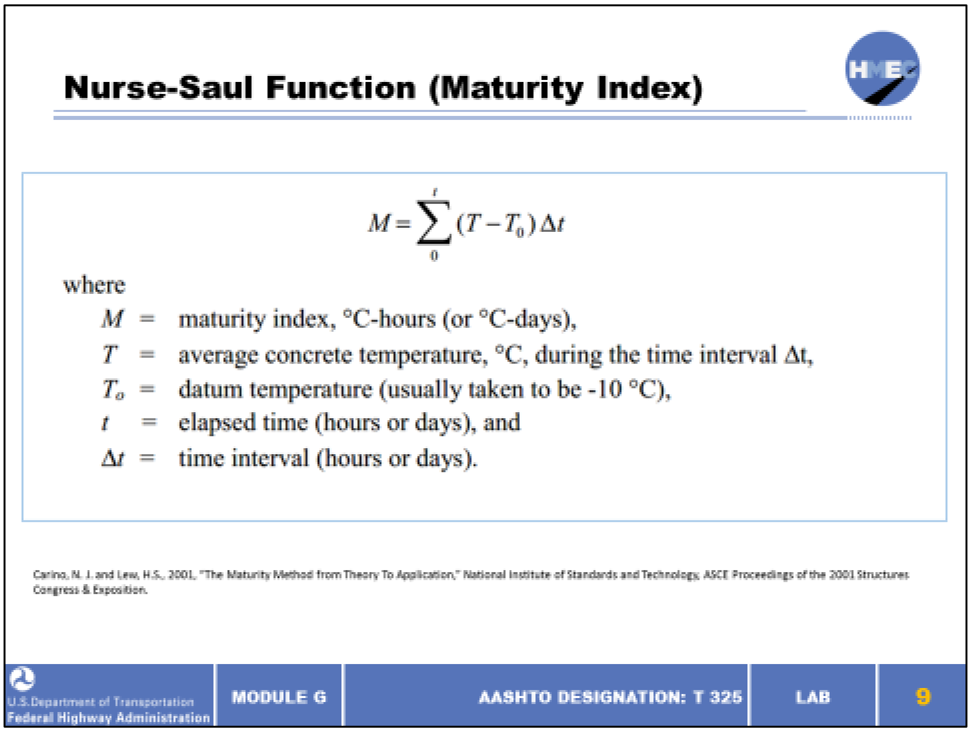
Nurse-Saul Function (Maturity Index)
$M = \sum_{0}^{t} (T - T_0)\,\Delta t$
where
M = maturity index, °C-hours (or °C-days),
T = average concrete temperature, °C, during the time interval Δt,
T_o = datum temperature (usually taken to be -10 °C),
t = elapsed time (hours or days), and
Δt = time interval (hours or days).
Carino, N. J. and Lew, H.S., 2001, "The Maturity Method from Theory To Application," National Institute of Standards and Technology, ASCE Proceedings of the 2001 Structures Congress & Exposition.
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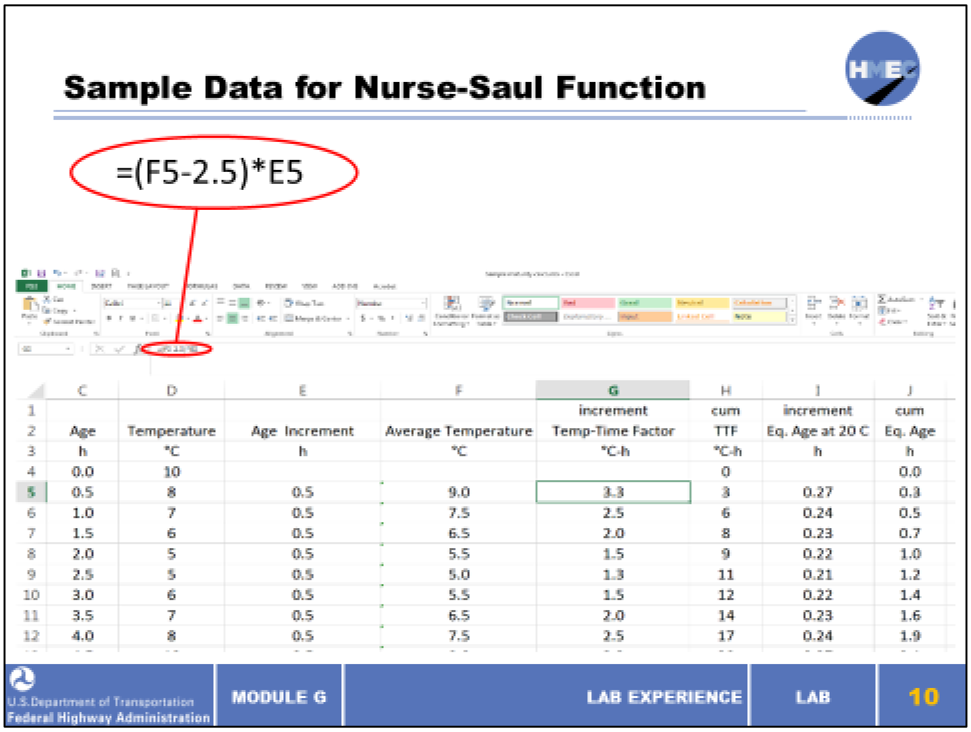
Sample Data for Nurse-Saul Function
=(F5-2.5)*E5

	C	D	E	F	G	H	I	J
1					increment	cum	increment	cum
2	Age	Temperature	Age Increment	Average Temperature	Temp-Time Factor	TTF	Eq. Age at 20 C	Eq. Age
3	h	°C	h	°C	°C-h	°C-h	h	h
4	0.0	10				0		0.0
5	0.5	8	0.5	9.0	3.3	3	0.27	0.3
6	1.0	7	0.5	7.5	2.5	6	0.24	0.5
7	1.5	6	0.5	6.5	2.0	8	0.23	0.7
8	2.0	5	0.5	5.5	1.5	9	0.22	1.0
9	2.5	5	0.5	5.0	1.3	11	0.21	1.2
10	3.0	6	0.5	5.5	1.5	12	0.22	1.4
11	3.5	7	0.5	6.5	2.0	14	0.23	1.6
12	4.0	8	0.5	7.5	2.5	17	0.24	1.9

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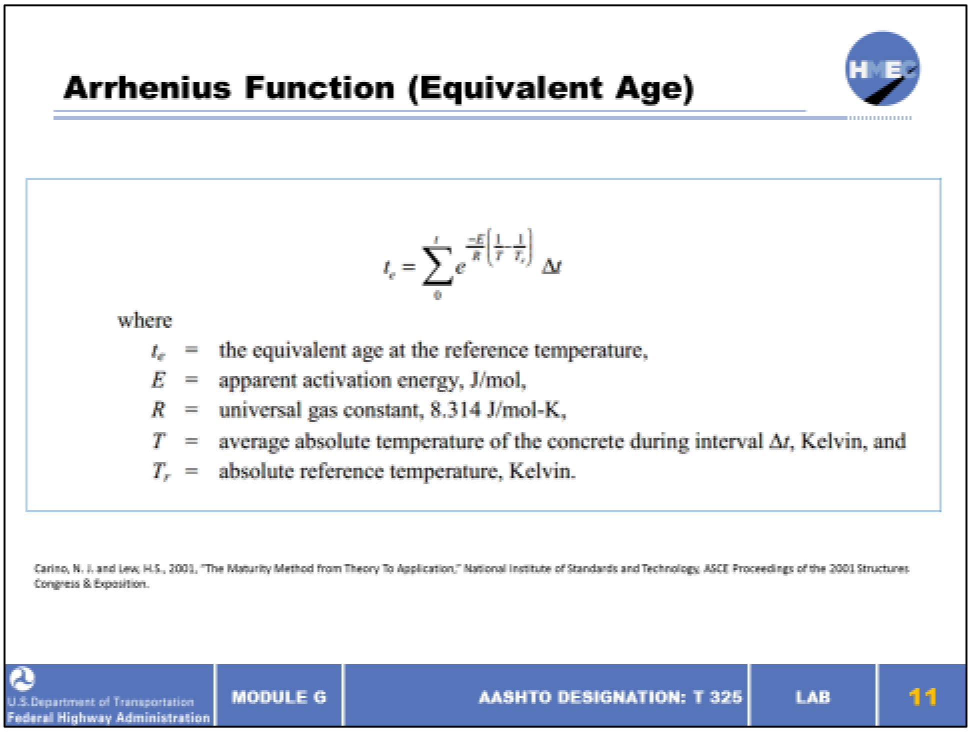
Arrhenius Function (Equivalent Age)
HMEC
$t_e = \sum_0^t e^{\frac{-E}{R}\left(\frac{1}{T}-\frac{1}{T_r}\right)} \Delta t$
where
t_e = the equivalent age at the reference temperature,
E = apparent activation energy, J/mol,
R = universal gas constant, 8.314 J/mol-K,
T = average absolute temperature of the concrete during interval Δt, Kelvin, and
T_r = absolute reference temperature, Kelvin.
Carino, N. J. and Lew, H.S., 2001, "The Maturity Method from Theory To Application," National Institute of Standards and Technology, ASCE Proceedings of the 2001 Structures Congress & Exposition.
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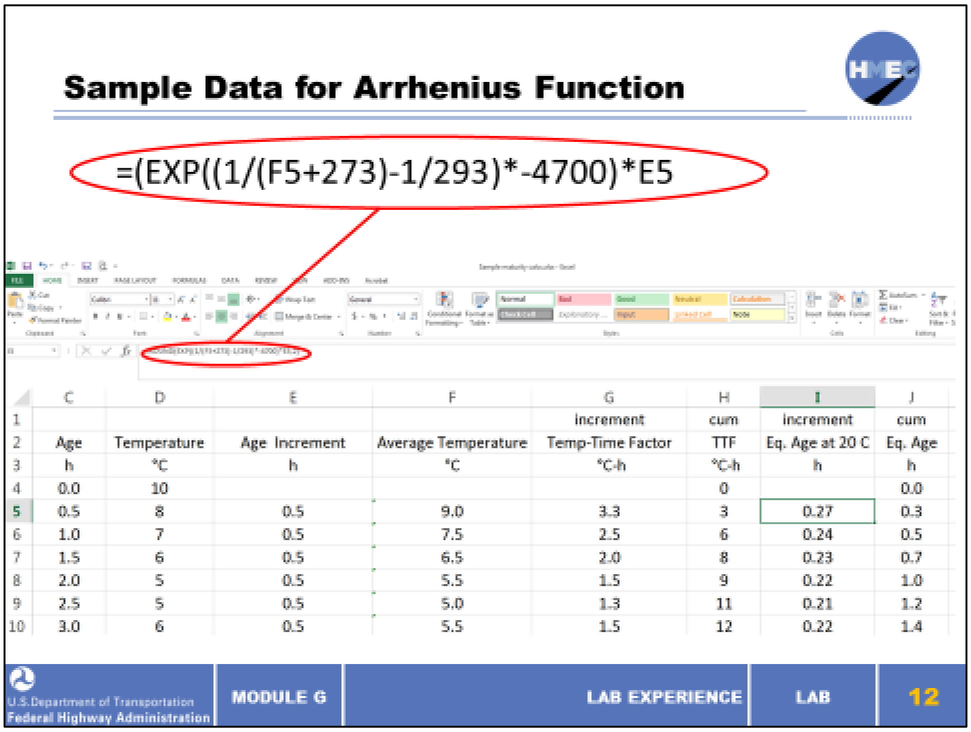
Sample Data for Arrhenius Function
HMEC
=(EXP((1/(F5+273)-1/293)*-4700)*E5
C D E F G H I J
increment cum increment cum
Age Temperature Age Increment Average Temperature Temp-Time Factor TTF Eq. Age at 20 C Eq. Age
h °C h °C °C-h °C-h h h
0.0 10 0 0.0
0.5 8 0.5 9.0 3.3 3 0.27 0.3
1.0 7 0.5 7.5 2.5 6 0.24 0.5
1.5 6 0.5 6.5 2.0 8 0.23 0.7
2.0 5 0.5 5.5 1.5 9 0.22 1.0
2.5 5 0.5 5.0 1.3 11 0.21 1.2
3.0 6 0.5 5.5 1.5 12 0.22 1.4
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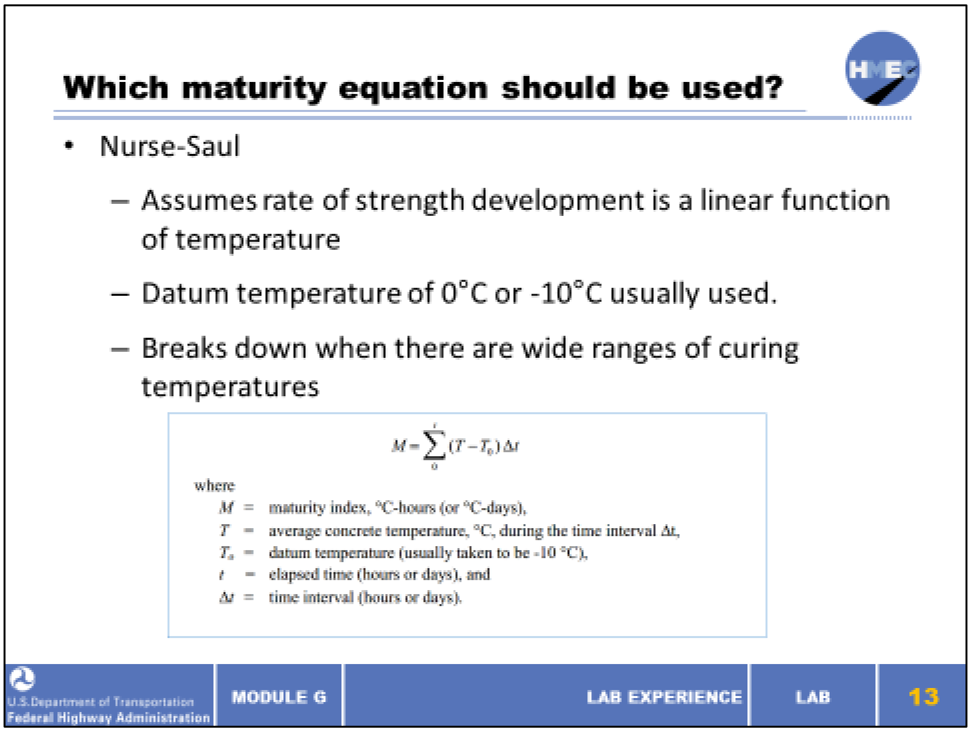
Which maturity equation should be used?
• Nurse-Saul
– Assumes rate of strength development is a linear function of temperature
– Datum temperature of 0°C or -10°C usually used.
– Breaks down when there are wide ranges of curing temperatures
$M = \sum_0^t (T - T_0)\,\Delta t$
where
M = maturity index, °C-hours (or °C-days),
T = average concrete temperature, °C, during the time interval Δt,
T_o = datum temperature (usually taken to be -10 °C),
t = elapsed time (hours or days), and
Δt = time interval (hours or days).
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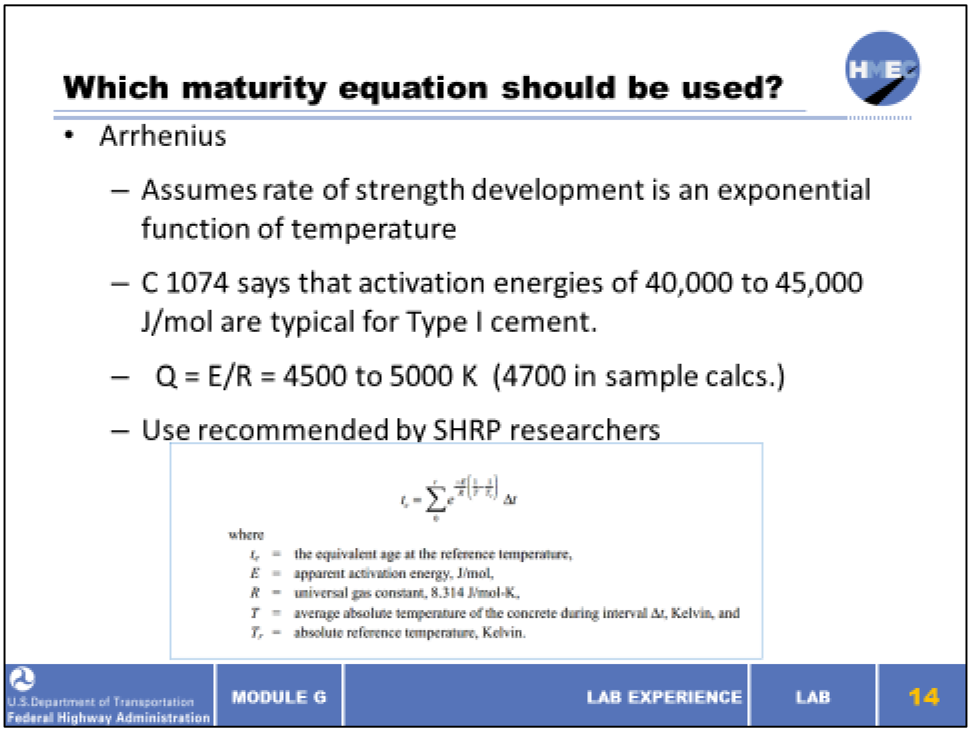
Which maturity equation should be used?
• Arrhenius
– Assumes rate of strength development is an exponential function of temperature
– C 1074 says that activation energies of 40,000 to 45,000 J/mol are typical for Type I cement.
– Q = E/R = 4500 to 5000 K (4700 in sample calcs.)
– Use recommended by SHRP researchers
$t_e = \sum_0^t e^{\frac{-E}{R}\left(\frac{1}{T}-\frac{1}{T_r}\right)} \Delta t$
where
t_e = the equivalent age at the reference temperature,
E = apparent activation energy, J/mol,
R = universal gas constant, 8.314 J/mol-K,
T = average absolute temperature of the concrete during interval Δt, Kelvin, and
T_r = absolute reference temperature, Kelvin.
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T 325 – Sensor Placement
HMEC
• Place sensors 50 to 100 mm from any concrete surface.
• Placement of minor importance if concrete surface is protected from a high rate of heat loss.
• Mid-depth in pavement overlays.
• Tie to reinforcing steel to stabilize if sensor is placed prior to pouring.
www.fhwa.gov
www.fhwa.gov
http://www.forconstructionpros.com/article/10834106/how-to-estimate-in-place-strength-of-concrete
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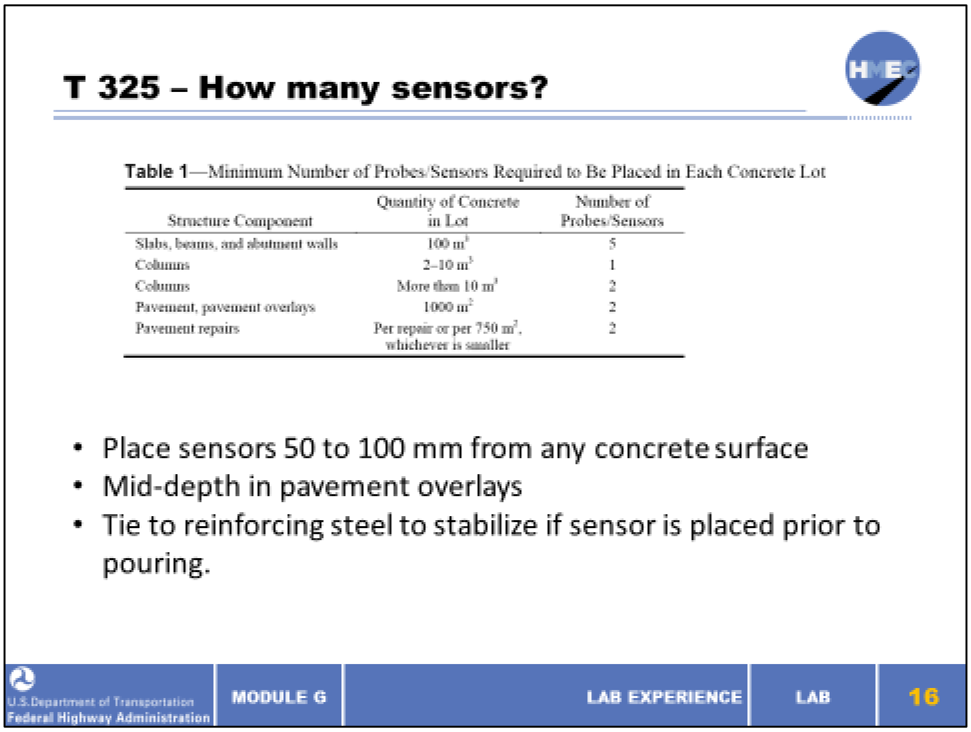

Table 1—Minimum Number of Probes/Sensors Required to Be Placed in Each Concrete Lot

Structure Component	Quantity of Concrete in Lot	Number of Probes/Sensors
Slabs, beams, and abutment walls	100 m^3	5
Columns	2–10 m^3	1
Columns	More than 10 m^3	2
Pavement, pavement overlays	1000 m^2	2
Pavement repairs	Per repair or per 750 m^2, whichever is smaller	2

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Maturity Meters and Sensors
Figure 2-14: Humboldt system 4101 concrete maturity meter
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ASTM C 1074 – Concrete Maturity

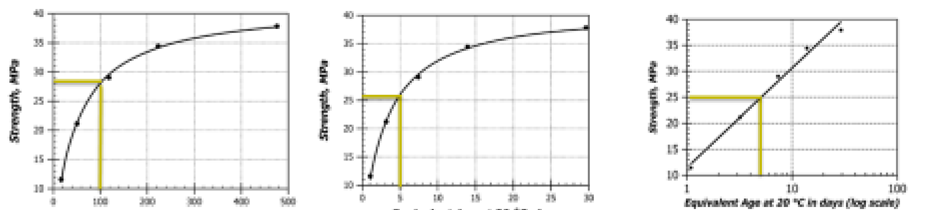

FIG. 1 Example of a Relationship Between Compressive Strength and Temperature-Time Factor

FIG. 2 Example of a Relationship Between Compressive Strength and Equivalent Age at 20 °C

FIG. 3 Example of Compressive Strength as a Function of Logarithm of Equivalent Age

- Sample plots of compressive strength versus maturity or equivalent age.
- Equivalent age can also be plotted as a straight line plot if it is plotted on a log scale.
- Calculate maturity/equivalent age from the temperature-time data or read it directly from a maturity meter.
- Read the corresponding compressive strength on the plot.

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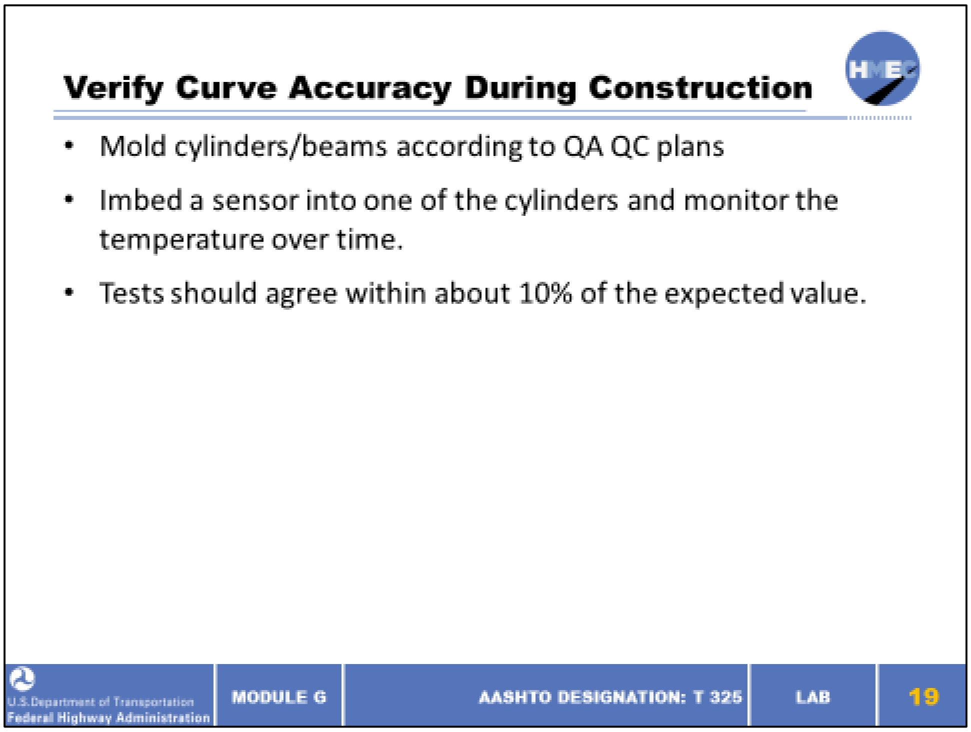
Verify Curve Accuracy During Construction
HMEC
• Mold cylinders/beams according to QA QC plans
• Imbed a sensor into one of the cylinders and monitor the temperature over time.
• Tests should agree within about 10% of the expected value.
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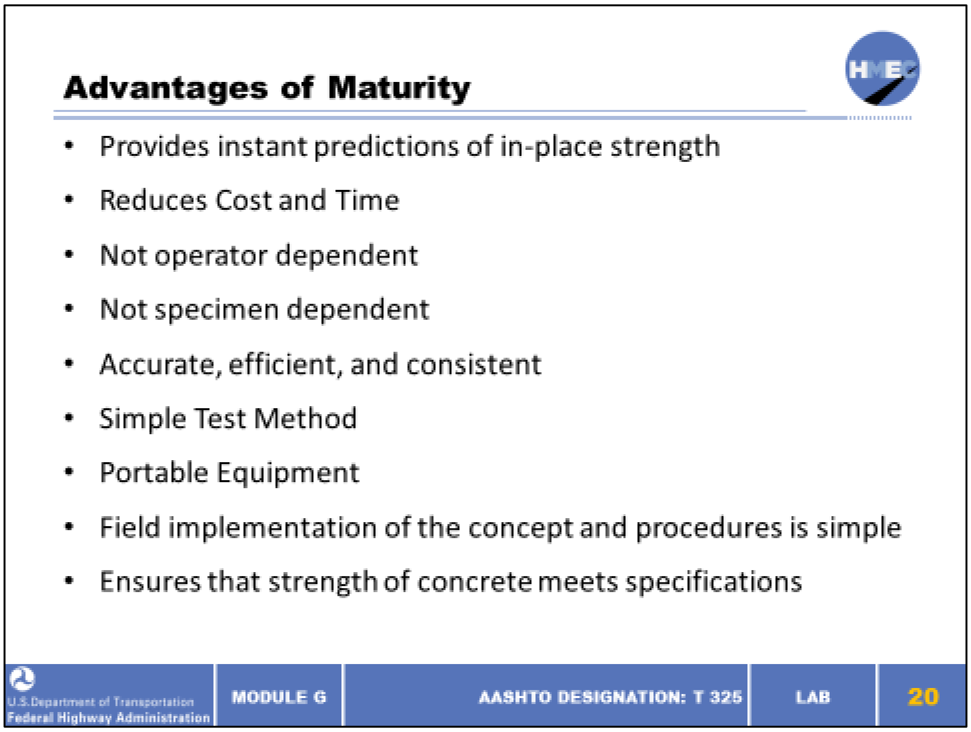
Advantages of Maturity
• Provides instant predictions of in-place strength
• Reduces Cost and Time
• Not operator dependent
• Not specimen dependent
• Accurate, efficient, and consistent
• Simple Test Method
• Portable Equipment
• Field implementation of the concept and procedures is simple
• Ensures that strength of concrete meets specifications
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Limitations of Maturity

- Maturity measures only time and temperature, so other factors that could affect strength are not considered.
- The concrete mixture proportions and materials being monitored shall not deviate from the ones used to develop the strength-maturity relationship, such as:
  - Brand of cement
  - Source and type of fly ash
  - Source of aggregates
  - Water to cement ratio

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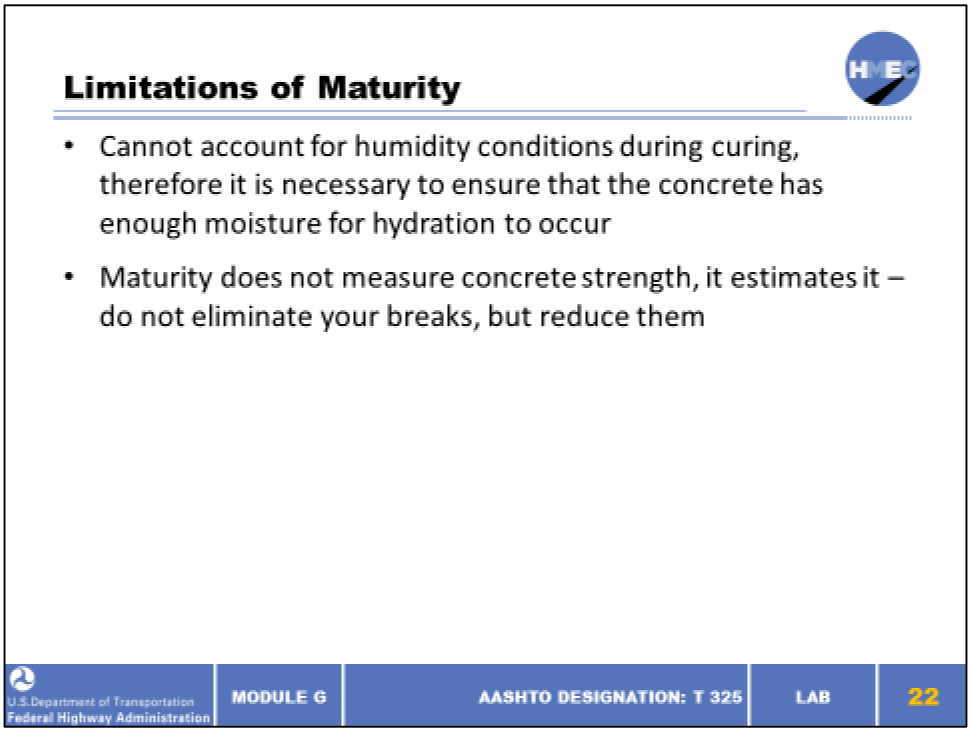
Limitations of Maturity
HMEC
• Cannot account for humidity conditions during curing, therefore it is necessary to ensure that the concrete has enough moisture for hydration to occur
• Maturity does not measure concrete strength, it estimates it – do not eliminate your breaks, but reduce them
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Questions?
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