2201 STANDARD METHOD OF TEST FOR MEASURING THE WATER CONTENT IN FRESH CONCRETE BY RAPID EVAPORATION (PHOENIX TEST METHOD)

2201.1 SCOPE

1.1. This test method describes the measurement of the total water content of fresh concrete. Using the batch weights and the total water content in the fresh concrete, the water-to-cementitious material ratio (w/cm) can be calculated.

1.2. Unit – the values stated in either SI units or inch-pound units are to be regarded separately as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3. The standard does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations before use.

2201.2 REFERENCE DOCUMENTS

2.1. Robertson, J.B., Ley, M.T., Cook, M. D., Burris, L. E., "Development of Time and Temperature Testing Limits for a Field Water-To-Cement Ratio Test", Materials and Structures, 54(4), 1-12, 2021, https://doi.org/10.1617/s11527-021-01756-0.

2.2. Robertson, J. B., Ley, M. T., Cook, M.D., "Measuring the Change in the Water-To-Cement Ratio in Fresh and Hardened Concrete," Journal of Materials in Civil Engineering, 2022 https://doi.org/10.1061/(ASCE)MT.1943-5533.0004153.

2.3. Robertson, J.B., Ley, M. T. (2020) "Determining the Water to Cement Ratio of Fresh Concrete by Evaporation.," Construction and Building Materials, Vol 242, 2020, https://doi.org/10.1016/j.conbuildmat.2019.117972.

2.4. AASHTO R60, Practice for Sampling Freshly Mixed Concrete

2.5. ASTM C172, Practice for Sampling Freshly Mixed Concrete

2.6. ASTM C192 Practice for Making and Curing Concrete Strength Specimens in the Laboratory

2201.3 SUMMARY OF THE TEST METHOD

3.1. This test method describes a way to measure the total water content and calculate the w/cm of a concrete mixture. A rigid container of a fixed volume is used. The mass of the container is measured before, after filling, and after emptying the concrete sample.

3.2. The sample is transferred to a pan. The mass of the pan is measured before and after filling with the sample. The pan is then placed into the furnace.

3.3. This specimen is inserted into a furnace between 1450°F and 1500°F for approximately 15 min. The mass is weighed again to ensure that the water has been evaporated. The difference in the mass of the specimen before and after the test determines the water content of the specimen. The volumetric relationship of the test specimen with the batched mass of the concrete mixture can be used to find the water content and the w/cm of the concrete mixture can be calculated.

2201.4 SIGNIFICANCE AND USE

4.1. Both water content and w/cm have major impacts on the strength and durability performance of concrete. This test helps provide a method to measure the water content and w/cm of fresh concrete for a wide range of materials and mixtures. The inputs for the test can be easily determined with basic mixture design and aggregate property information. Also, this test method can be used as a quality control tool to monitor the consistency of concrete and help reliably meet the desired performance.

2201.5 APPARATUS

5.1. Scale – A balance or scale accurate, readable, and sensitive to within 0.1 % of the test load at any point within the range of use and within any interval equal to 10 % of the capacity of the balance or scale used to determine the mass. The load indicated shall be accurate within 0.1 % of the difference in mass. For normal-weight concrete, this requires a balance with 0.002 lb (1 g) accuracy.

5.2. Heat Resistant Plate – A ceramic plate that is used on the scale to isolate it from the high temperatures of the pan.

5.3. Container – A metal container that is not reactive to the concrete sample with a diameter of 6 in +/- 0.06” (152 mm +/- 2 mm) and a height of 3.44” +/- 0.06” (87 mm +/- 2 mm).

5.4. Container collar – A hard plastic collar that fits over the container to keep the container clean while filling.

5.5. Strike off Plate – A hard plastic strike off plate with dimensions of at least 7” x 7” (178 mm x 178 mm) is used to ensure a flat and smooth surface of the sample.

5.6. Tamping Rod – Metal tamping rod with 3/8” diameter and at least 12” length.

5.7. Mallet – A mallet with a rubber or rawhide head weighing approximately 1.25 ± 0.50 lb (0.57 ± 0.23 kg) for use with concrete volumes of 0.25 ft^3 (14 L) or smaller.

5.8. Furnace – A 3600 Watt (3600 Joules/s) furnace with internal dimensions of 19.75” wide x 4.5” height x 11” deep (500 mm wide x 114 mm height x 279 mm deep) that is capable of maintaining a heat of 1500°F (815°C).

5.9. Pan – The pan used is made of steel that can resist the temperatures and deterioration in the test. The pan should allow the concrete to be placed in a single ½” (13 mm) layer. The pan should be designed to not warp excessively to not damage the furnace during heating.

5.10. Lid - A mesh lid is used to contain the sample while in the furnace. It is formed and fits on the pan. It must be removable to place the sample inside the pan. This prevents the sample from losing excess mass if an aggregate is ruptured from rapid heating.

5.11. Gloves – Oven gloves are recommended for protection from the furnace heat. The gloves are not to be used to transport the sample by themselves but to be worn while using the steel spatula.

5.12. Cooling Cover – A wire mesh container that allows the heated pan, sample, and lid to cool.

5.13. Silicone Spatula – A solid silicon spatula capable of scraping concrete from the container.

5.14. Pan Fork – A steel fork is used to transfer the pan and sample in and out of the furnace.

2201.6 SAMPLING, TEST SPECIMENS, AND TEST UNITS

6.1. Obtain the sample of freshly mixed concrete in accordance with applicable procedures of R 60. This test can be used to investigate paste, mortar, or concrete mixtures with aggregates up to 2” (50 mm) in size. Mixtures that contain at least 5% of aggregates on a sieve larger than 2” (50 mm) are not applicable for this test. The test can be used on concrete material mixtures immediately after mixing up to the initial set (Robertson et al., 2021). For typical concrete mixtures, this occurs approximately 3h after mixing but can vary based on the materials being tested. The test should not be used to investigate latex modified concrete.

Figure 1. Filled container on a scale covered with a heat resistant plate

Figure 2. Emptying the cylinder sample into the plate

Figure 3. Scraping the cylinder with a spatula

Figure 4. Using a spatula to spread the sample inside the pan

2201.7 PROCEDURE

7.1. Preheat the furnace to a temperature between 1450 ^{o}F to 1500^{o}F before placing the sample in the oven.

Note: This may take at least 20 minutes.

7.2. After preheating the furnace, the door should not remain open more than 10 seconds at any time during the test to minimize the temperature loss for the test and for safety.

7.3. Place the heat resistant plate on the scale.

7.4. Record the tare mass for the dry, empty container [CylTare].

7.5. Place the collar over the opening of the container. The collar should fit tightly around the opening of the container and stop concrete from reaching the sides of the container.

7.6. Fill approximately 50% of the container volume with the concrete sample.

7.7. Rod the cylinder 25 times and tap with a rubber mallet 10-15 times.

7.8. Fill the remainder of the container volume with the concrete sample.

7.9. Rod the cylinder 25 times and tap with a rubber mallet 10-15 times.

7.10. Finish the sample after consolidating by leveling and then striking off the surface of the concrete with the strike off plate by ASTM C192.

7.11. Remove the collar from the mold and remove any concrete on the sides of the container. Protect the specimen from moisture loss or gain until the initial mass is obtained.

7.12. Within 5 minutes of strike off, record the mass of the fresh concrete-filled container [CylFull] (Figure 1a).

7.13. Transfer the concrete out of the cylinder into the pan (Figure 1b). Use the spatula to remove any concrete within the container (Figure 1c) Use the spatula to spread the concrete throughout the pan with a uniform thickness (Figure 1d). The thickness of the material should be ½” +/- 1/4” (13 mm +/- 6 mm).

7.14. Record the empty mass of the cylinder [CylEmpty]. This mass must be within 10 g of the mass of the empty container [CylTare].

Note: This ensures that adequate material was transferred from the cylinder to be tested.

7.15. Cover the concrete filled pan with the lid and then record the mass [PFresh] (Figure 2a).

7.16. Open the door to the furnace and place the concrete filled pan and lid into the furnace by using the pan fork and closing the door (Figure 2b).

Note: The internal temperature in the furnace will decrease when inserting the sample. Over time the furnace temperature may increase but it may not reach the set temperature.

7.17. After 15 minutes; open the chamber door and remove the sample filled pan and lid with the pan fork.

7.18. Remove the pan fork from the pan. Record the mass of the sample filled pan and lid [$PDry_0$] and return to the furnace. The sample should be returned to the chamber within 45 seconds.

7.19. After 2 minutes; remove the sample filled pan and lid with the pan fork.

7.20. Remove the pan fork from the pan. Record the mass of the sample filled pan and lid [$PDry_1$] and return to the furnace. The sample should be returned to the chamber within 45 seconds.

7.21. If the difference between $PDry_0$ and $PDry_1$ is less than 0.0044 lb (2 g) then record $PDry_1$ as the dry mass of the concrete [PDry]. If the difference is larger than 0.0044 lb (2 g) then repeat steps 7.19, 7.20, and 7.21 are repeated until the mass change from 2 minutes of exposure to heat is less than 0.0044 lb (2 g). This mass should be recorded as the dry mass of the concrete [PDry].

7.22. The sample is then cooled and can be removed from the pan and lid. The pan and lid can be cleaned, dried, and then used for the next sample.

Note: After the final mass is determined, it is recommended to either allow the sample to cool in the cooling cover or be quenched in a metal wheelbarrow or metal bucket full of water.

Note: After cleaning, the pan and wire mesh can be dried quickly by placing them on top of the furnace between tests.

Figure 5. Sample filled pan and lid on top of the scale

Figure 6. Pan and lid being transferred to the furnace

2201.8 CALCULATION AND REPORT

8.1. Water loss calculations – After the test, the water loss from the sample represents the total water in the cylinder, this includes the water within the paste and also the absorbed water in the aggregate. For these calculations, it is assumed that the aggregates will absorb the water to reach saturation before reaching the final set.

The measured water is found by subtracting the water loss from the water absorbed within the aggregate [$Cyl_{WaterAbs}$]. This can be shown mathematically as:

$$\text{Measured water} = (PFresh - PDry - Cyl_{WaterAbs}) \quad \{1\}$$

The water to cement ratio can be calculated by dividing the measured water by the calculated binder within the cylinder. This can be shown mathematically as:

$$\text{Calculated w/cm} = \text{Measured water} / (Cyl_{Binder}) \quad \{2\}$$

8.2. The calculated w/cm can be compared with the batched w/cm.

8.3. The batched w/cm is calculated by dividing the mass of the water [M_{Water}] by the mass of the binder [M_{Binder}].

8.4. Reported – The value calculated for w/cm should be reported to the two decimal places or in other words rounded to the nearest 0.01.

Note: The methods to find the water absorbed within the aggregate are in the appendix.

2201.9 PRECISION AND BIAS

9.1. Single-Operator Precision – Based on laboratory and field tests, the average standard deviation is 0.009 w/cm, and the average coefficient of variation is 1.8%. There was no bias in the measurement as the average difference between the batched and measured w/cm is -0.004. Based on laboratory and field data, 88% of the measurements were within +/- 0.01 w/cm of the batched w/cm and 100% of the measurements were within +/- 0.02 w/cm of the batched w/cm (Robertson et al., 2022).

2201.10 KEYWORDS

10.1. Phoenix; Water-to-cementitious ratio; w/cm; Water content of concrete

2201.11 APPENDIX

11.1 A summary of the variables and symbols is provided below.

DESCRIPTION	VARIABLE NAME
BINDER SPECIFIC GRAVITIES	SG_{BINDER}
COARSE AGGREGATE ABSORPTIONS	ABS_{COARSE}
FINE AGGREGATE ABSORPTIONS	ABS_{FINE}
COARSE AGGREGATE SPECIFIC GRAVITIES	SG_{COARSE}
FINE AGGREGATE SPECIFIC GRAVITIES	SG_{FINE}
BATCHED BINDER MASSES	M_{BINDER}
BATCHED COARSE AGGREGATE MASSES	M_{COARSE}
BATCHED FINE AGGREGATE MASSES	M_{FINE}
BATCH WATER MASS	M_{WATER}
BATCHED VOLUME IN MIXER	V_{BATCH}
BATCHED CONCRETE AIR VOLUME	V_{AIR}
TARE MASS OF CYLINDER	CYL_{TARE}
VOLUME OF CYLINDER	V_{CYL}
MASS OF CYLINDER FILLED WITH CONCRETE	CYL_{FULL}
MASS OF CYLINDER AFTER EMPTIED	CYL_{EMPTY}
MASS OF PAN WITH FRESH CONCRETE	P_{FRESH}
MASS OF PAN WITH DRIED CONCRETE	P_{DRY}

11.2 Air Volume – The air volume in the concrete can be found by using the measured density of the concrete. This density can be compared with the theoretical density from the batch information to obtain the air content. This is performed according to ASTM C138 by using the mold in the proposed test method. The density of the concrete in the cylinder can be found as:

$$\text{Cyl Density} = (Cyl_{Full} - Cyl_{Tare}) / V_{Cyl} \qquad \{A1\}$$

11.3 Theoretical density – The theoretical density of the batched concrete can be found as:

Theoretical Density = Total Batched Mass / Absolute Volume Batched (Air Free) {A2}

where

Total Batched Mass = $M_{Binder} + M_{Coarse} + M_{Fine} + M_{Water}$ {A3}

and

Absolute Volume Batched (Air Free) = ((MBinder)/(SGBinder *1000)) + ((MCoarse)/(SGCoarse * 1000)) + ((M_{Fine})/($SGFine$ * 1000)) + M_{Water} /1000 {A4}

For the theoretical density calculation in lbs/ft^3, the mass is replaced by batched weight, and each 1000 is replaced by 62.4 lbs/ft^3.

11.4 Theoretical air content – The theoretical air content can be found from ASTM C231 or by finding the % difference between the theoretical density and the cylinder density. This can be found mathematically as follows:

Air Content (%) = ((Theoretical Density– Cyl Density) / Theoretical Density) * 100 {A5}

Or using equations, Air Content (%) = (({A2} - {A1}) / {A2}) *100

Based on field experience a minimum air volume of 1.5% should be used for this calculation.

11.5 Batched Absolute Volume Calculation – The absolute volume of concrete batched must be calculated for the fresh w/cm determination. This can be calculated with the batched masses and air volume from the batch information. This can be expressed mathematically as:

Absolute Volume Batched = ((M_{Binder}) / (SG_{Binder} *1000)) + ((M_{Coarse}) / (SG_{Coarse} * 1000)) + ((M_{Fine}) / (SG_{Fine} * 1000)) + (M_{Water} / 1000) + (V_{Batch} * (V_{Air} / 100)) {A6}

11.6 Total Water Absorbed - As shown in Equation 1, all the water from the sample is removed from the concrete including the absorbed water in the aggregates. Concrete mixtures are adjusted and batched by assuming the aggregate is saturated surface dry. Although the aggregates are not usually in this condition when placed into a mixer, it is assumed that the aggregates reach a saturated condition before the concrete has been set. Because the test evaporates all of the water from the concrete mixture, the aggregate absorption must be accounted for in the calculations. To account for this the absorbed water for each aggregate in the batch is calculated as follows:

Coarse Aggregate Absorbed Water = $(Abs_{Coarse} / 100) * M_{Coarse}$ {A7}

and

Fine Aggregate Absorbed Water = $(Abs_{Fine} / 100) * M_{Fine}$ {A8}

Where

Total Absorbed Water = Coarse Aggregate Absorbed Water + Fine Aggregate Absorbed Water {A9}

If there are multiple coarse and fine aggregate sizes in the mixture each could be added to these values using the weight and absorption value for every additional aggregate to find the total absorbed water.

11.7 Batched Density –The batched density is calculated by taking the sum of the batched masses divided by the absolute volume of the batch. This can be shown mathematically as:

Batched Density = Total Batched Mass / Absolute Volume Batched {A10}

Or using equations, Batched Density = {A2} / {A6}

11.8 Cylinder Volume Tested – As mentioned before, the mass of material remaining in the mold should be < 10 g of the empty cylinder mass. The material that was placed in the pan is used to obtain the volume in the test. This can be shown mathematically as:

Cylinder Volume Tested = $((CylFull – Cyl_{Empty}) / (Cyl_{Full} – Cyl_{Tare})) * V_{Cyl}$ {A11}

11.9 Water Loss Moss – Next, the water lost in the test is calculated. The water in the concrete cylinder represents the total water in the sample including the absorbed water in the aggregates. This is found by the difference between the mass of the pan with fresh concrete from the mass of the pan with dry concrete. This can be shown mathematically as:

Water Loss Mass = $P_{fresh} – P_{Dry}$ {A12}

11.10 Volume Ratio - The volume ratio is a scale factor to reduce the material weights from a larger volume to the volume in the mold. Multiplying the volume ratio with a batch weight will represent the weight in the mold for that material. This will be used to determine the weight of the binder in the cylinder.

The volume of the sample tested is divided by the absolute volume batched. This can be seen mathematically as:

Volume Ratio = Cylinder Volume Tested / Absolute Volume Batched {A13}

Or using equations, as Volume Ratio = {A11} / {A6}

The weight of the binder in the cylinder can be found by multiplying the volume ratio by M_{Binder}. This can be seen mathematically as:

Cyl_{Binder} = Volume Ratio * M_{Binder} {A14}

where Volume Ratio is equation {A13}.

11.11 Total water absorbed – The total absorbed water for the batch has been calculated in equation {A9}. This value needs to be adjusted to the water absorbed in the sample tested. The $Cyl_{WaterAbs}$ is the volume ratio multiplied by the total absorbed water. This can be seen mathematically as follows:

$Cyl_{WaterAbs}$ = Volume Ratio * Total Absorbed Water {A15}

Or using equations, $Cyl_{WaterAbs}$ = {A13} * {A9}