ARIZONA ROCK
PRODUCTS ASSOCIATION

CERTIFICATION OF READY MIXED CONCRETE PRODUCTION FACILITIES

COMPANY	**PLANT NO.**
City Plant Location	
Engineer	
Inspection Date	**Expiration Date**

The Plant Certification Plan adopted by the Arizona Rock Products Association is identical to the copyrighted plan of the National Ready Mixed Concrete Association and is used with permission.
The Arizona Rock Products Association agrees with the statement of the National Ready Mixed Concrete Association which appears on the next page.

NRMCA QC Manual Plant Certification

Foreword

Concrete is a manufactured product the quality and uniformity of which depend upon control over its manufacture. It must be compounded of suitable ingredients accurately combined to specific proportions. These must be thoroughly blended and the finished product delivered without damage. Although success depends upon several factors, a vital prerequisite is the availability of proper equipment well maintained.

This publication describes a system for establishing that production facilities of ready-mixed concrete plants are satisfactory. The system permits a qualified plant to display a Certificate of Conformance which assures the purchaser that the physical capability of furnishing good concrete is available.

To be eligible for a Certificate, the plant must be inspected by a registered professional engineer for conformance with the Check List contained herein. In addition to carrying the signature and seal of the inspecting engineer, the Certificate must also be signed by the principal company executive attesting to his intention of seeing that all equipment is maintained within requirements of the Check List.

The system of certification was developed by and is maintained by the Research, Engineering, and Standards Committee of the National Ready Mixed Concrete Association. Expert assistance in developing the Check List was provided by representatives of the Truck Mixer Manufacturers Bureau and the Concrete Plant Manufacturers Bureau. Advice on detail requirements as well as on operational features of the plan was also derived from outside sources variously associated with concrete production and use. The plan was reviewed by the NRMCA Board of Directors and approved without dissenting vote at its meeting of September 28, 1965. The following revisions have been approved by the Board of Directors:

Second Revision, January 1, 1972
Third Revision, January 1, 1976
Fourth Revision, January 1, 1984
Fifth Revision, March 1, 1992
Sixth Revision, October 15, 1994

Certification may be obtained by any producer of ready-mixed concrete in accordance with the procedures and limitations described herein. There is a nominal charge for the Association's service. The company must, also, engage the registered engineer to perform the inspection. Since many best qualified for this duty are already employed in the industry, it is not required that the Check List be executed by an engineer from outside the company. It should be noted in this connection that inspecting engineers, in signing the Certificate, stake their professional reputation on the evaluation having been objective and thorough. At any time, a purchaser may compare plant attributes with the Check List to verify that the Certificate provides valid evidence of productive capability. The same prerogative exists with regard to the company official's pledge to maintain the equipment properly.

This booklet is intended to serve a two fold purpose: first, to acquaint the producer and the inspecting engineer with the mechanics of securing the Certificate of Conformance and provide the forms therefore; and second, to familiarize concrete purchasers and specifiers with the system and its significance. The Check List and forms contained herein are intended for use in actual certification.

No claim is made that certification of plant facilities will assure delivery of high quality concrete. As indicated above, proper equipment is only one of several factors involved in concrete control, although a very essential one. The presence of a Certificate of Conformance should, therefore, be accepted precisely for what it is – evidence that certain capabilities exist. The existence of those capabilities will reduce the likelihood of deficiencies in quality when normal inspection is exercised within requirements of usual sales agreements.

Engineering Division
NATIONAL READY MIXED CONCRETE ASSOCIATION
900 Spring Street, Silver Spring, Maryland 20910

1965, 1967, 1968, 1971, 1975, 1980, 1984, 1992 and 1994
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Plant Certification
STATEMENT BY THE ARIZONA ROCK PRODUCTS ASSOCIATION

PURPOSE

The production and delivery to the job site of the ready-mixed concrete of high uniform quality is dependent on many factors. Important among these is the capability and condition of the producer's plant facilities and delivery equipment. Facilities capable of properly and accurately handling, proportioning, mixing and discharging the concrete ingredients and the concrete mix are essential to the production of uniform good quality concrete in and ready-mix operation. To provide the concrete user a convenient means of assuring that a ready-mix producer's plant facilities are capable of producing concrete of a uniform quality, the Arizona Rock Products Association has instituted a plant certification program open to all producers of ready-mix concrete. The achievement of good quality concrete construction requires the full cooperation and concern of all parties involved including: the architect-engineer, the contractor, the cement and aggregate producer, the ready-mix producers, the testing agency, and the construction inspector. Each must be concerned and prepared to give assurance that his phase of the overall concrete construction operation is properly performed to ensure that the completed construction will be of the quality specified and required. Certification of the capabilities of his production facilities constitutes one means whereby the responsible ready-mix concrete producer can give assurance to his customers of his interest and willingness in supplying uniform concrete of the quality specified or required.

Specifiers who require concrete to be produced by plants certified under the Arizona Rock Products Association Plant Certification Program will have the assurance that:

1) The producers' plant and delivery equipment is capable of producing a uniform quality product and will meet accepted minimum standards.

2) That the producers' plant facilities have been inspected, tested and evaluated by a registered professional engineer who has certified that the facilities comply with the established standards.

3) That the producer has pledged to maintain his plant facilities within the requirements of the program and standards.

CHECK LIST FOR READY MIXED CONCRETE PRODUCTION FACILITIES

General

This list itemizes requirements for plant facilities and equipment used in the production of ready-mixed concrete. A separate Check List must be completed by a registered professional engineer for each plant inspected. Three copies of the forms may be obtained for each plant to be inspected. Each item in the Check List is to be checked by or under the supervision of a registered professional engineer who will in each case enter the appropriate symbol in the space provided, as follows:

" ✓ " if the requirement is met.

" F " if the requirement is not met. (An accompanying number may be used to refer to appended explanation where considered desirable. However, a certificated cannot be issued to a plant not meeting all of the applicable items. If possible, deficiencies should be corrected before the inspection is completed).

" N " if the particular item is not applicable to the type of plant being inspected.

The examining engineer's initials should appear on each page on which entries have been made. His signature and seal, and the date of completion of the inspection must be entered on the Verification of Inspection (Section 6, page 17). Also, an official of the producer company must complete the Agreement to regularly Check Scales and Volumetric Batching Devices and Dispensers (Section 7, page 18).

The original copy of the Check List and the Checking Agreement should be submitted to: ARPA, 916 West Adams Street, Phoenix, AZ 85007. A second copy of each should be provided to the owner of the plant for his record and for such use as a reference as he may find appropriate. The third copy is to be retained by the inspecting engineer for his files. In order to save paperwork it is permissible to make photo copies of the original Check List for the files of the engineer and producer. However, the original should be submitted to ARPA. The engineer must also submit once to ARPA a completed copy of the Engineer Information Form (Section 9, page 20).

Conformance with relevant requirements of the Qualification Chart (Section 10) will make the plant eligible for a Certification of Conformance furnished ARPA, to be validated by the signature and seal of the inspecting engineer and by the signature of the principal company executive. The Certificate will carry an expiration date of two years from the inspection date.

The references listed in Section 8, page 19, may be of help to the engineer and producer.

1. Material Storage and Handling

1.1 **Cement**

1.1.1 Bins or silos tight and provide for free movement to discharge opening. ☐

1.1.2 Where storage is provided for different types of cement pr cementitous materials, different materials isolated to prevent intermingling or contamination. ☐

1.2 **Aggregates**

1.2.1 Procedures for unloading aggregates such as to prevent harmful segregation and breakage. ☐

1.2.2 Procedures for building stockpiles such as to prevent harmful segregation and breakage. ☐

1.2.3 Stockpiles located to prevent contamination; arranged to assure that each aggregate as removed from it stockpile is distinct and not intermingled with others. ☐

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1.2.4 Intraplant handling and transportation such as to prevent harmful segregation. ☐

1.2.5 Separate storage bins or compartments for each size and type of aggregate properly constructed and charged to prevent mixing of different sizes or types. ☐

1.3 **Water**

1.3.1 Adequate supply, with pressures sufficiently constant or regulated to prevent interference with accuracy of measurement. ☐

1.3.2 Where concrete is placed regularly during sub-freezing weather, minimum heating capacity for water and/or aggregate of 15 boiler horsepower per 100 cubic yard average daily cold weather production. (May be reduced to 10 bph if storage capacity permits round-the-clock operation of heating equipment.) One boiler horsepower = 33,500 BTU per hour transferred to the water. (Note 1) ☐

> Note 1: If this requirement is not met and the facility is in an area where NOAA weather records show an average of more than 5 days per year when the minimum temperature is 32EF (0 C) or below the Certificate of Conformance will carry the notation that the "Facility does not meet all requirements for furnishing concrete in subfreezing weather."

1.4 **Admixtures**

1.4.1 Storage and handling system for liquid admixtures sufficiently protected to prevent freezing of admixtures at any time. (Freezing can cause ingredients of some liquid admixtures to separate and, therefore, affect concrete quality control.) ☐

1.4.2 Admixtures protected to prevent damage from contamination. ☐

1.4.3 Agitation provided for liquid admixtures that are not stable solutions. ☐

2.1 **Scales**

2.1.1 Each scale comprised of a suitable system of levers or load cells which will weigh consistently within the tolerances given in 2.1.2, with loads indicated either by means of a beam with balance indicator, a full-reading dial, or a digital read-out or display. For all types of batching systems, manual through automatic, the batchman must be able to read the load indicating devices from his normal station. Where the controls are remotely located with respect to the batching equipment, monitors or scale-follower devices may be used if they repeat the indication of the master scale within $\pm$ 0.2 percent of scale capacity. ☐

2.1.2 Each scale accurate (Note 2) within $\pm$ 0.20 percent of scale capacity throughout the range of use. For direct digital read-out, the tolerance shall be increased to $\pm$ 0.25 percent to allow for tracking restriction (Note 3). ☐

> Note 2: The engineer supervising inspection the inspection may accept scale calibrations made by the state or other agencies if these calibrations demonstrate compliance with the requirements of 2.1 and subsections.

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Note 3: The purpose of this increased tolerance is to allow for the fact that digital readings are limited to whole-number values which cannot reproduce weight indications closer than ± 0.05 percent of capacity.

2.1.3 At least 500 pounds of suitable test weights (each accurate within ± 0.01 percent of indicated value) readily available for checking accuracy of scales. Company official agrees to recheck scales not less frequently than every 6 months and arrange for prompt recalibration and correction in accordance with 2.1.2 if the plant is moved or noncompliance is indicated in the 6-month rechecking. Signed statement by responsible official is attached; see Section 7, page 17 (Note 4). ☐

2.1.4 Lever system scales so designed that center of gravity of gross load always lies between load pivots. ☐

2.1.5 *Beam-Indicating Scales:*

2.1.5.1 Provide with zero balance beam, balance indicator, and separate weighing beam for each ingredient of a batch to be weighed on the same scale. ☐

2.1.5.2 Beam poises corrosion resistant, equipped with positive and accurate holding devices, and capable of being set to the minimum graduated interval which shall be no greater that 0.1 percent of capacity with a clear interval of not less than 0.03 in. ☐

2.1.5.3 Balance indicators sufficiently sensitive to show movement when weight corresponding to 0.10 percent of scale capacity is placed in the batch hopper at load equal to or above 50 percent of scale capacity; pointer travel of balance indicators at least 5 percent of net-rated capacity of largest weigh beam or 200 pounds, whichever is less, for underweight and 4 percent or 100 pounds, whichever is less, for overweight; provision made for damping oscillation of indicator pointer. ☐

2.1.6 *Dial-Indicating Scales:*

2.1.6.1 Dial head mechanism enclosed so as to be dust tight. ☐

2.1.6.2 Dials indicate load in batcher continuously from zero balance to full weighing capacity of the scale. ☐

2.1.6.3 Dial faces have minimum of 1000 graduations on circular reading line at clear interval of not less than 0.03 in. ☐

2.1.7 *Digital-Indicating Scales:* Digital indicator or display protected from dust with numbers large enough for good readability; minimum numerical increment equal to or less that 0.1 percent of scale capacity. ☐

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2.1.8 *Load-cell Scales:* Arrange to transmit load to one or more cells, directly or through a system of levers, in such a way that the cell system registers the entire load accurately on the load-indicating device; load cells indicated by manufacturer to be accurate throughout the range of temperatures to which normally exposed during plant operation. ☐

2.2 **Weigh Batchers**

2.2.1 Batchers for weighing cement, aggregates, and also water or admixtures (if measured by weight) consist of suitable containers freely suspended from scale, equipped with necessary charging and discharging mechanisms. ☐

2.2.2 Cement and other cementitious materials weighed on scales and in weigh hoppers which are independent of scales and weigh hoppers used for non-cementitious ingredients. ☐

2.2.3 Batchers capable of receiving rated load without contact of the weighed material with the charging mechanism. ☐

2.2.4 Company has an established operating procedure, known to the batchman, that is used to assure compliance with Section 2.5 "accuracy of plant batching" when material is accidentally overweighed. ☐

2.2.5 Cement batchers provided with dust seal between charging mechanism and hopper, installed in such a way as not to affect weighing accuracy; weigh hopper vented to permit escape of air; hopper self-cleaning and fitted with means to assure complete discharge. ☐

2.2.6 Batcher charging mechanism capable of stopping the flow of material within batching tolerances specified in 2.5 and preventing loss of material when closed. ☐

2.2.7 Vibrators or other appurtenances installed in such a way as not to affect accuracy of weighing. ☐

2.2.8 Wind protection sufficient to prevent interference with weighing accuracy. ☐

2.3 **Volumetric Batching Devices for Water**

2.3.1 *Water Meters:*

2.3.1.1 Equipped with a cut-off device capable of stopping the flow within the tolerances specified in 2.5.3; cut-off device free from leaks when closed. ☐

2.3.1.2 Equipped with a volume-setting device capable of being set to increments at least as small as one gallon or a register capable of being read to one gallon, or both (Note 5). ☐

Note 5: For water-measuring equipment which is graduated in pounds instead of gallons, use 10 pounds as the basic increment instead of one gallon.

2.3.1.3 Provide an indication, visible to the batchman, of the volume batched at any point in the metering operation. ☐

2.3.2 Equipped with necessary filling and discharge valves which are leak-free when closed; fill valve capable of stopping flow within the tolerance specified in Section 2.5.3. ☐

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2.3.2.2 Have a gage or other device in the view of the batchman which indicates the volume of water in the tank from zero point to capacity of the batcher and which can be read to one gallon (Note 5); tank equipped with an overflow pipe at batcher capacity level if it is less than tank capacity. ☐

2.3.2.3 Equipped with a valve to remove overloads. ☐

2.4 **Dispensers for Liquid Admixtures** (Note 6)

Note 6: A dispenser is a device for batching liquid admixtures by weight or volume and must be affixed to the plant. Dispensing methods which involve hand-carried containers for the measurement and discharge of admixtures do not qualify. Volumetric dispenser requirements are in 2.4 and dispensers which are weigh batchers must meet the applicable requirements of 2.2.

2.4.1 Separate dispenser for each liquid admixture in regular use, except that more than one admixture can be batched through a single dispenser if the admixtures are compatible or if the dispenser is flushed with water after each cycle (Note 7, Note 8). ☐

Note 7: If more than one admixture is being used through a single dispenser without flushing of the dispenser with water after each cycle, the engineer should ascertain that the admixtures in actual use are compatible with each other and that the mixing of the admixtures prior to introduction into the concrete will not be detrimental.

Note 8: When the company operating the batch plant or delivery units regularly batches an admixture at the job site, the dispenser must comply with the requirements of 2.4 and subsection 2.5.4. Occasional addition of admixtures at the job site to adjust entrained air content, etc., is not subject to the dispenser requirements of 2.4.

2.4.2 Piping free of leaks and properly valved to prevent backflow or siphoning and to insure that the measured amount is discharged. ☐

2.4.3 Each volumetric dispenser provided with an accurately calibrated container in which the admixture may be collected when it is desired to check the accuracy of measurement as indicated in 2.5.4. ☐

2.4.4 For admixtures other than calcium chloride used at less than 50 oz. per 100 lb. of cement, each volumetric dispenser equipped with a visual or other means of providing a gross check to the batchman of the amount of admixture batched during each cycle, within $\pm$ 20 percent. The gross check shall be independent of the accuracy, function, or operation of the primary metering device (Note 9). ☐

Note 9: This gross check is required to help the batchman prevent large overdoses or deficiencies of admixture due to dispenser malfunction in any batch, which could cause great changes in fresh and/or hardened concrete properties. Following are examples of how the gross check might be provided: (a) collecting the measured quantity of admixture in a calibrated container during each cycle and holding it for a short period to permit a visual check; (b) measuring the dispensed quantity through the use of an independent meter to

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obtain a rough check on the amount measured by observation of a volumetric indicator. Admixtures used at rates of 50 oz. per 100 lb. of cement or greater are exempt from the independent check required in 2.4.4. Silica fume slurry, corrosion inhibitors and some accelerators may be used at rates exceeding 50 oz. per 100 lb. of cement.

2.4.5 Volumetric admixture dispensers provide visible indication of the quantity batched or interlock cutoff when liquid admixture supply is not available to the dispenser. (This is to prevent dispensing air instead of admixture). ☐

2.5 **Accuracy of Plant Batching** (Note 10)

Note 10: For weighed ingredients, accuracy of batching is determined by comparison between the desired weight* and the actual scale reading; for volumetric measurement of water and admixtures, accuracy is determined by checking the discharge quantity either by weight on a scale or by volume in an accurately calibrated container.

2.5.1 Cement and other cementitious materials measured by weight within ± 1 percent of the desired weight* in individual batchers, or ± 1 percent of the desired intermediate and final cumulative weights* in cumulative batchers, but, in either case, the minimum accuracy of batching applying to small loads is ± 0.3 percent of scale capacity (which governs for weights below 30 percent of scale capacity. ☐

2.5.2 Aggregate measured by weight within ± 2 percent of the desired weight* in individual aggregate batchers, or ± 1 percent of the desired intermediate and final cumulative weights* in cumulative aggregate batchers, but, in either case, the minimum accuracy of batching applying to small loads is ± 0.3 percent of scale capacity (which governs for weights below 15 percent and 30 percent of scale capacity, respectively). See Note 11 and Note 12. ☐

Note 11: If the weight-setting system provides compensation for moisture on aggregates, the tolerance applies to the accuracy of measurement of the corrected weight.

Note 12: In some instances the accurate control of concrete containing lightweight aggregate is more feasible if the lightweight coarse aggregate is batched by bulk volume rather that by weight. When this is judged to be the case, the provisions of 2.5.2 can be waived for lightweight coarse aggregate.

2.5.3 Water measured by volume or weight within ± 1.5 percent** of the desired amount*, or ± 1 gallon (Note 5, page 6), whichever is greater. Company official agrees to recheck batching accuracy of the volumetric water batching devices (including water meters) not less frequently than every 90 days. See Agreement to Regularly Check Scales on page 17. ☐

2.5.4 Admixtures measured to within ± 3 percent of the desired amount* or ± the minimum dosage rate per 100 lb. of cement, whichever is greater (Note 13). Company official agrees to recheck batching accuracy of volumetric admixture dispensers at least every 90 days. See Agreement to Regularly Check Scales on page 17. ☐

*As indicated to the batchman, corrected for aggregate moisture, if required.
**This corresponds approximately to an accuracy of ± 1 percent based on total mixing water typical aggregate moisture levels.

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Note 13: Liquid admixtures are to be measured by volume or weight and powdered admixtures are to be measured by weight. Where it cannot be determined what liquid admixture will normally be used in a volumetric dispenser, assume that the dosage will be at a rate of at least 1 fl. oz. per 100 lbs. of cement; admixtures with lower rates can be reconstituted to the point where the rate is 1 fl. oz. per 100 lbs. or more.

2.5.5 Compensation for free moisture on aggregates as it affects aggregate weights and slump control

2.5.5.1 Suitable combination of pre-batching storage and manual or automatic measurement of aggregate moisture to provide aggregate of fairly consistent moisture content to the batcher and to detect changes of 1 percent in the moisture content of fine aggregate; procedure for adjustment of aggregate batch weights for changes in their moisture content of 1 percent by weight of dry aggregate. ☐

2.5.5.2 Suitable procedures of maintaining control of slump (Note 14). ☐

Note 14: For central, shrink or truck mixing operations, this can be a visual or other method of estimating the slump of the concrete during mixing with consequent adjustments in added water made by the batchman or truck mixer driver; as an alternative, slump can be controlled by a method based on determination of aggregate free moisture to an accuracy of about ± 1 ½ gallons per cubic yard of concrete so that the correct amount of added water can be batched to obtain the desired slump.

2.6 **Batching System**

2.6.1 *Definitions and Requirements of Component Individual Batcher Controls.*
Batching controls are the part of the batching equipment that provides means for operating the batching device for an individual material. They may be mechanical, hydraulic, pneumatic, electrical, etc. or a combination of these means. A batching system is a combination of batching devices and batching controls necessary to the accurate and consistent batching of concrete ingredients in the desired proportions. Normally a batching system would include batching devices and controls for cement, aggregates, water, and admixtures. Some may not include admixtures if they are not used at the plant or may not have batching equipment for water if it is entirely batched through the truck mixer water system.

2.6.1.1 Weigh Batcher Controls (Cement and aggregates must be batched by weight; water and admixtures may be batched in a weigh-batcher or by volume in a volumetric device covered in 2.6.1.2. For lightweight coarse aggregate, see Note 12).

(1) Manual Control – Manual weigh-batcher control exists when the batching devices are actuated manually, with the accuracy of the batching operation dependent on the operator's observation of a scale. The batching devices may be actuated by hand or by hydraulic, pneumatic, or electrical power assists (Note 15).

Note 15: Any weigh-batcher control which does not fully meet the requirements for semi-automatic, semi-automatic interlocked, or automatic weigh-batcher controls is considered manual if it can be operated to meet the requirements of this section.

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(2) Semi-Automatic Control – When actuated by a starting mechanism a semi-automatic weigh-batcher control shall start the weighing operation of the material and stop the flow automatically when the designated weight has been reached. No interlocks are required.

(3) Semi-Automatic Interlocked Control – When actuated by a starting mechanism a semi-automatic interlocked weigh-batcher control shall start the weighing operation of the material and stop the flow automatically when the designated weight has been reached. It shall be interlocked to assure that the discharge mechanism cannot be opened until the weight is within the tolerance specified in 2.5.

(4) Automatic Control – When actuated by a single starting signal, an automatic weigh-batcher control shall start the weighing operation of cement, aggregate, water, or admixture, and stop the flow automatically when the designated weight has been reached. It shall be interlocked to assure that:

(a) The charging gate or valve cannot be opened until the scale has returned to zero balance within ± 0.3% of the scale capacity;

(b) The charging gate or valve cannot be opened if the discharge mechanism is open;

(c) The discharge mechanism cannot be actuated if the charging gate or valve is open; and

(d) The discharge mechanism cannot be actuated until the weight of material is within the tolerance specified in 2.5

2.6.1.2 Volumetric Batching Device Controls (This pertains to the controls used for measurement of admixtures in a volumetric admixture dispenser or the measurement of water with a water meter or a volumetric batcher tank.

(1) Manual Control – Manual volumetric control for water or admixture exists when the volumetric measuring device is actuated manually with the accuracy of the measuring operation being dependent on the operator's visual observation of a volumetric indicator (such as a digital meter display or a sight gage) and his manual cut-off of the flow at the desired volume. The flow of liquid may be controlled by hand or by pneumatic, hydraulic, or electric power assists (Note 16).

Note 16: Any volumetric control which does not fully meet the requirements for automatic volumetric controls is considered manual if it can be operated to meet the requirements of this section.

(2) Automatic Control – When actuated by a single starting signal, an automatic volumetric control shall start the measuring operation and stop the flow automatically when the designated volume has been reached.

2.6.2 *System Requirements*

2.6.2.1 Manual System: A combination of the necessary individual weigh-batchers and volumetric batching devices (if any volumetric measuring of water or admixture is performed at the plant) to proportion concrete properly, the controls of which are all manual with the possible exception of semi-automatic or automatic controls for admixture and/or water. ☐

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2.6.2.2 Partially Automatic System: A combination of the necessary individual weigh-batchers and volumetric batching devices (if any volumetric measuring of water or admixtures is performed at the plant), the controls of which are a combination of manual, semi-automatic, semi-automatic interlocked, and automatic controls not meeting the requirements of semi-automatic or automatic systems below; at least one of the non-manual controls shall be for controlling the batching of cement or aggregates. ☐

2.6.2.3 Semi-Automatic System: A combination of the necessary individual weigh-batchers and volumetric batching devices (if water or admixture is measured volumetrically), the controls of which are either all semi-automatic interlocked, a combination of semi-automatic interlocked and automatic, or all automatic controls (in accordance with 2.6.1.1(3), 2.6.1.1(4), or 2.6.1.2(2) but not meeting all the system requirements for the automatic system as given below. ☐

2.6.2.4 Automatic System: A combination if the necessary individual weigh-batchers and volumetric batching devices (if water or admixture is measured volumetrically in the plant), the controls of which are all automatic (in accordance with 2.6.1.1(4) or 2.6.1.2(2) and meet the following automatic-system requirements: ☐

(a) All batching equipment activated by a single starting mechanism, except that a separate starting mechanism is permitted for volumetric batching of water and/or admixture not batched at the time of weighing the other ingredients.
(b) The discharge of any weighed ingredient in the system may not start unless batching controls for all weigh batchers have been cleared of the previous batch, with scales returning to zero tolerance, and until all weighed ingredients have been weighed within the required tolerances.
(c) Volumetric admixture dispenser controls (if any) interlocked with volumetric water batching controls or the controls of at least one weigh batcher to prevent the discharge of both admixture and the interlocked ingredient(s) unless both the admixture dispenser and the interlocked batching device(s) have been cleared of the previous batch.

2.7 Recorders: Devices which provide a permanent record of the quantity of cement, aggregate, or water measured into a particular batch of concrete.

They shall:	Cem.	Agg.	Water
2.7.1 Be properly protected. Graphical and photographic recorders also capable of being locked,	☐	☐	☐
2.7.2 Provide for identifying the particular batch with the corresponding delivery ticket,	☐	☐	☐
2.7.3 Register empty balance for weighed ingredients,	☐	☐	☐
2.7.4 Register the quantity of ingredient or ingredients batched,	☐	☐	☐
2.7.5 In the case of graphical recorders, register scale readings within ± 2 percent of total scale capacity,	☐	☐	☐
2.7.6 In the case of the photographic or digital recorders, reproduce the scale reading within ± 0.1 percent of scale capacity.	☐	☐	☐

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3. Central Mixer

Definition: A stationary mixer installed at the plant for the purpose of mixing the concrete completely (central mixing) or partially (shrinking mixing).

3.1 **For Central Mixing Operations,** the mixer at the plant shall be:

3.1.1 capable of producing uniform concrete (Note 17) in the mixing time regularly employed at the plant or in the time designated in ASTM Specification C 94-90 for Ready Mixed Concrete (Note 18), whichever is less, when operated with a capacity batch in accordance with the method regularly employed on operation of the plant. ☐

Note 17: The concrete is considered uniform if samples taken after discharge of approximately 15 percent and 85 percent of the load do not differ more than the following: (1) in slump, 1 inch if the average slump is 4 inches or less, 1 ½ inches if the average slump is 4 to 6 inches; and (2) in coarse aggregate content, 6 percent by weight of the concrete. Procedures for measuring uniformity of mixed concrete are discussed in References 1, 6 and 7, page 18.

Note 18: The mixing time designated in C 94090 is 1 minute for mixes with capacities of 1 cubic yard or less plus 15 seconds for each additional cubic yard or fraction thereof.

3.1.2 equipped with a timing device that will not permit the batch to be discharged before the predetermined mixing time has elapsed. ☐

3.2 **For Shrink Mixing Operations,** the mixer at the plant shall be capable of partially blending the concrete ingredients to reduce their total bulk volume before discharge into a truck mixer. ☐

4. Ticketing System

Provision on delivery ticket for the following information: ☐

4.1 Name of ready-mixed concrete company.

4.2 Plant designation where batched if company operates more than one plant.

4.3 Serial number of ticket.

4.4 Truck number or designation.

4.5 Name of contractor or other purchaser.

4.6 Specific designation of job (name and location).

4.7 Specific class or designation of concrete identifiable with terminology employed in the job specifications.

4.8 Amount of concrete in cubic yards.

4.9 Date.

4.10 Time when batch was loaded.

4.11 Extra water added at the request of the receiver of the concrete and his signature or initials.

4.12 Type and name of admixture and amount batched.

_____
Initials

5. Delivery Fleet

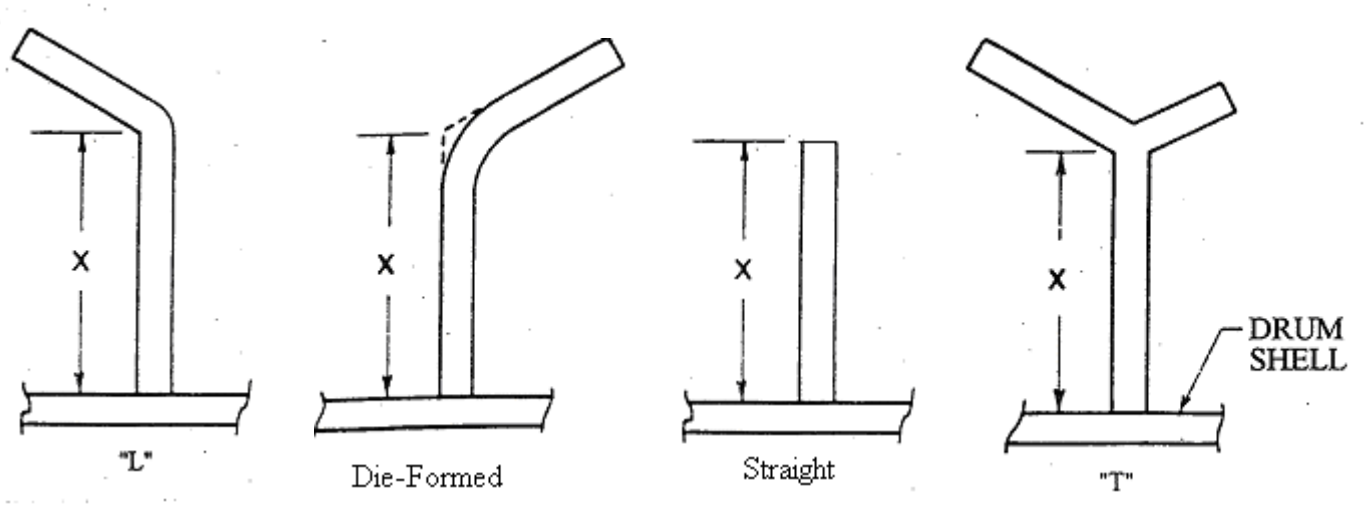
The inspecting engineer will examine and evaluate all truck mixers, agitators and nonagitating units used to deliver concrete from the plant for conformance with the requirements given in 5.1, 5.2, and 5.3, respectively. Each unit will be listed in either the acceptable or unacceptable category in the appropriate section of the Summary of Fleet Condition (5.4, page 15). Agitators and nonagitating units are permitted only for central mixing operations. Certification will not be granted if (1) for a truck-mixing or shrink-mixing operation, 10 percent or more of the truck mixers are listed as unacceptable; or (2) for central-mixing operation, 10 percent or more of the total agitators and nonagitating units are listed acceptable. It is assumed that purchasers of concrete will forbid delivery in units which are allowed to remain defective, but will permit use of new units added to the fleet or of units restored to acceptable condition subsequent to execution of the Check List. It is assumed that units qualifying as truck mixers will also qualify as agitators.

5.1 **Truck Mixers**

Definition: Concrete mixers mounted on trucks or other vehicle, used for the complete mixing of concrete ingredients after they have been batched at the plant.

Each acceptable truck mixer shall conform with the following requirements:

5.1.1 Interior condition satisfactory: no appreciable accumulation of hardened concrete; blades free of excessive wear. Blade wear shall be checked at the point of maximum drum diameter nearest to the drum head. When the height of the blade at this point, measured from the drum shell, less than 90 percent of the original radial height (dimension "X" in sketch of applicable blade type), the blade is considered excessively worn. The manufacturer of the mixer will furnish original blade dimensions on request.



MIXER BLADE TYPES

5.1.2 Charging and discharge openings and chute in good condition: free from appreciable accumulations of cement or concrete; hopper and chute surfaces clean and smooth.

5.1.3 Drum or container of such size that the rating as a mixer (in volume of mixed concrete) does not exceed 63 percent of the gross volume of the mixer, disregarding blades. (This requirement is met by all mixers carrying a rating plate of the Truck Mixer Manufacturer Bureau.)

5.1.4 Provided with a plate showing the mixer manufacturer's recommended operating speed for mixing, which must be in the range of not less that 4 nor more than 22 rpm; demonstrated capability to operate satisfactorily at recommended speed.

5.1.5 Equipped with a counter in working condition to indicate the number of revolutions of the drum or blades.

5.1.6 On units equipped to batch mixing water, equipment to be proper working condition: gage glasses or water meters clean and legibly graduated; water pump or injection system in good working order with nozzles unobstructed and without leakage into mixer; water measurement spot-checked and found accurate within ± 1 percent of mixing water capacity or ± 1 gallon (Note 5, page 6), whichever is greater.

5.2 **Agitators**

Definition: Drums or containers, mounted on trucks or other vehicles, in which central-mixed concrete is kept sufficiently in motion during delivery to prevent segregation.

Each acceptable agitator shall conform with the following requirements:

5.2.1 Interior condition satisfactory: no appreciable accumulation of hardened concrete.

5.2.2 Charging and discharge openings and chute in good condition: free from appreciable accumulations of cement or concrete; hopper and chute surfaces clean and smooth.

5.2.3 Drum or container of such size that the rating as an agitator (in volume of mixed concrete) does not exceed 80 percent of the gross volume of the container, disregarding blades. (This requirement is met by all units carrying a rating plate of the Truck Mixers Manufacturers Bureau.)

5.2.4 Provided with a plate showing the mixer manufacturer's recommended maximum agitating speed which must not exceed 6 rpm; demonstrated capability to operate satisfactorily at the recommended speed.

5.2.5 Equipped with a counter in working condition to indicate the number of revolutions of the drum or blades.

5.3 **Nonagitating Units**

Definition: Containers, mounted on trucks or other vehicles, for delivering central-mixed concrete, not constructed or equipped to keep the mass of concrete in motion in the container.

Each acceptable nonagitating unit shall conform with the following requirements:

5.3.1 Interior surface smooth and watertight, with rounded corners.

5.3.2 Gates or other means provided to control the concrete discharge.

5.3.3 Interior free from excessive accumulation of hardened concrete and from other obstruction or deterioration sufficient to interfere with proper discharge of concrete.

5.4 **Summary of Fleet Condition**

(all available units must be checked; over 90 percent must be acceptable to qualify for Certification)

Total Number of units available for use: _____

Number of units checked and found acceptable: _____

Number of units checked and found unacceptable: _____

Truck No. or Designation of Individual Unit Examined [1]

Acceptable						Unacceptable give reason [2]	
Truck Mixer Units [3]							
Agitator Units [4]							
Non-Agitating Units [5]							

[1] Number of units listed in Tabulation must check with totals above.
[2] By reference to Check List paragraph number.
[3] See 5.1 for requirements.
[4] See 5.2 for requirements; only permitted for central mixing operations.
[5] See 5.3 for requirements; only permitted for central mixing operations.

_____
Initials

6. Verification of Inspection and Application for Certification

The undersigned, a registered professional engineer in_____
(state, territory, or jurisdiction)
has conducted the inspection of the ready-mixed concrete plant described as_____

_____

(please print specific designation and location of plant)

_____

and asserts, in his professional judgment, the information provided on this Check List is accurate and complete. Application is hereby made for the issuance of a certificate for this plant, to be classified as follows:

General Operation	Batching System	Recording (if any)
☐ Truck Mixing	☐ Manual	☐ Cement
☐ Central Mixing	☐ Partially Automatic	☐ Aggregate
☐ Shrink Mixing	☐ Semi-Automatic	☐ Water
	☐ Automatic	

(See Qualification Chart in Section 10, page 21, to determine classification requirements. A Certificate of Conformance cannot be issued if there is an "F" in any of the required sections. An "N" is permitted in a required section only if the item is not applicable to the particular plant.)

_____ (date)

_____ (signature)

_____ (name, please print)

_____ (business address, please print)

_____

_____ (zip code)

_____ (phone number)

(SEAL)

(Print to help us provide an accurate certificate)

7. Agreement to Regularly Check Scales and Volumetric Batching Devices and Dispensers

(To be completed by ready-mixed concrete company official.)

The undersigned agrees that all scales in the plant described below will be checked at intervals not exceeding 6 months for conformance with Item 2.1.2 of the "Check List for Ready Mixed Concrete Production Facilities." Any failure to meet the scale tolerance (± 0.20 percent of scale capacity throughout the range of use) will be corrected promptly. If correction is delayed for any reason, batch weights of any concrete delivered will be adjusted to assure positively against a deficiency in unit cement content or an excess in water-cement ratio. The undersigned also agrees that the batching accuracy of all volumetric admixture dispensers and all volumetric water batching devices (including water meters) in the plant will be checked at intervals not exceeding 90 days for conformance with the batching accuracy requirements for liquid admixtures and water contained in Items 2.5.3 and 2.5.4 of the Check List. Any failure to meet the required batching accuracy will be corrected promptly. (Checks may be made by qualified company personnel or by outside agencies or scale checking companies.)

_____

(signature of responsible company official) (date)

_____

(name and title, please print)

_____

(plant designation and location, please print)

_____

_____

(company and address, please print)

_____

(zip code)

_____

(phone number)

8. References

1. Book of ASTM Standards, Volume 04.02, Concrete and Mineral Aggregates, ASTM, 1916 Race Street, Philadelphia PA 19103.

2. Concrete Plant Standards, Ninth Revision, January, 1990, Concrete Plant Manufacturers Bureau, 900 Spring Street, Silver Spring, Maryland 20910.

3. Truck Mixer and Agitator Standards. Thirteenth Revision, May 30, 1989, Truck Mixer Manufacturers Bureau, 900 Spring Street, Silver Spring, Maryland 20910.

4. Guide for Measuring, Mixing, Transporting, and Placing Concrete (ACI 304R-89). Available in the ACI Manual of Concrete Practice, Volume 2, or as a separate from American Concrete Institute, P.O. Box 19150, Redford Station Detroit, Michigan 48219.

5. Factors Affecting the Homogeneity of Ready Mixed Concrete, Report No. 1 (Phase 1, 1969) by D.L. Bloem and R.D. Gaynor. Available from NRMCA. Also, a Summary Paper appeared in the Journal of the American Concrete Institute July, 1971.

6. Mixing Concrete in a Truck Mixer by Richard D. Gaynor and Jon I Mullarky, NRMCA Publication No. 148, January 1975.

7. Ready Mixed Concrete, Chapter 29, by R.D. Gaynor, Significance of Tests and Properties of Concrete and Concrete Making Materials, ASTM STP 169B, 1978 pp. 471-502 (also NRMCA Publication No. 175).

8. Concrete Plant Operator's Manual, NRMCA Publication No. 159, February, 1979.

9. ARPA Plant Certification Program
Engineer Information Form

(This form need be submitted only once to ARPA.)

To be submitted to the Arizona Rock Products Association, 1825 W. Adams, Phoenix, Arizona 85007 with completed copy of Check List for Ready Mixed Concrete Production Facilities. Once a copy of this form is on file with ARPA, the engineer need not submit it again for other plants he inspects.

Name:_____

Address:_____

_____

Registration No:_____ State:_____

Major Branch:_____
(civic, etc., as designated in state directory)

Resume of experience (relevant to qualification for checking ready-mixed concrete production facilities):

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

_____
(signature of P.E)

_____
(date)

(SEAL)

10. Qualification Chart for Ready Mixed Concrete Plants

Based upon submittal of properly executed "Check List for Ready Mixed Concrete Production Facilities," a certification will be furnished by ARPA, to be signed by the inspecting engineer and principal company executive, indicating:

(1) the general operating method of the ready-mixed concrete plant as "Truck Mixing," "Central Mixing," or "Shrink Mixing."
(2) The batching system as "Manual," "Partially Automatic," "Semi-Automatic," or "Automatic."
(3) If recording is provided, to what extent.

Certification for a given classification requires a " ✓ " for items in the Check List groups designated on the chart below by "X" except that " N " for "not applicable" is permissible in certain cases where such permissibility is implicit in the item itself. (e.g. " N " would be appropriate for 1.2.3 in a semi-tropical climate since concrete would never be delivered in freezing temperature. Similarly, the requirements for beam-indicating scales in 2.1.5 would not apply in a plant having only dial-indicating scales.)

Check List Items	Truck Mixing				Shrink Mixing				Central Mixing			
	Manual	Partial Auto	Semi-Auto	Automatic	Manual	Partial Auto	Semi-auto	Automatic	Manual	Partial Auto	Semi-auto	Automatic
1	X	X	X	X	X	X	X	X	X	X	X	X
2.1	X	X	X	X	X	X	X	X	X	X	X	X
2.2	X	X	X	X	X	X	X	X	X	X	X	X
2.3	X	X	X	X	X	X	X	X	X	X	X	X
2.4	X	X	X	X	X	X	X	X	X	X	X	X
2.5	X	X	X	X	X	X	X	X	X	X	X	X
2.6.2.1	X				X				X			
2.6.2.2		X				X				X		
2.6.2.3			X				X				X	
2.6.2.4				X				X				X
2.7	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
3.1									X	X	X	X
3.2					X	X	X	X				
4	X	X	X	X	X	X	X	X	X	X	X	X
5.1	X	X	X	X	X	X	X	X				
5.2 and/or 5.3									X	X	X	X

(1) Description on Certificate will indicate extent of recording provided, if any.

Designation: C 33 – 03

Standard Specification for Concrete Aggregates[1]

This standard is issued under the fixed designation C 33; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification defines the requirements for grading and quality of fine and coarse aggregate (other than lightweight or heavyweight aggregate) for use in concrete.[2]

1.2 This specification is for use by a contractor, concrete supplier, or other purchaser as part of the purchase document describing the material to be furnished.

NOTE 1—This specification is regarded as adequate to ensure satisfactory materials for most concrete. It is recognized that, for certain work or in certain regions, it may be either more or less restrictive than needed. For example, where aesthetics are important, more restrictive limits may be considered regarding impurities that would stain the concrete surface. The specifier should ascertain that aggregates specified are or can be made available in the area of the work, with regard to grading, physical, or chemical properties, or combination thereof.

1.3 This specification is also for use in project specifications to define the quality of aggregate, the nominal maximum size of the aggregate, and other specific grading requirements. Those responsible for selecting the proportions for the concrete mixture shall have the responsibility of determining the proportions of fine and coarse aggregate and the addition of blending aggregate sizes if required or approved.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate[3]

C 40 Test Method for Organic Impurities in Fine Aggregates for Concrete[3]

C 87 Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar[3]

C 88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate[3]

C 117 Test Method for Material Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing[3]

C 123 Test Method for Lightweight Particles in Aggregate[3]

C 125 Terminology Relating to Concrete and Concrete Aggregates[3]

C 131 Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[3]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[3]

C 142 Test Method for Clay Lumps and Friable Particles in Aggregates[3]

C 150 Specification for Portland Cement[4]

C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)[3]

C 289 Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)[3]

C 294 Descriptive Nomenclature for Constituents of Concrete Aggregates[3]

C 295 Guide for Petrographic Examination of Aggregates for Concrete[3]

C 311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete[3]

C 330 Specification for Lightweight Aggregates for Structural Concrete[3]

C 331 Specification for Lightweight Aggregates for Concrete Masonry Units[3]

C 332 Specification for Lightweight Aggregates for Insulating Concrete[3]

C 342 Test Method for Potential Volume Change of Cement-Aggregate Combinations[5]

C 441 Test Method for Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved June 10, 2003. Published July 2003. Originally approved in 1921. Last previous edition approved in 2002 as C 33 – 02a.

[2] For lightweight aggregates, see Specifications C 331, C 332, and C 330; for heavyweight aggregates see Specification C 637 and Descriptive Nomenclature C 638.

[3] *Annual Book of ASTM Standards,* Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.01.

[5] Discontinued; see *2001 Annual Book of ASTM Standards*, Vol 04.02.

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

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Expansion of Concrete Due to the Alkali-Silica Reaction[3]
C 535 Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[3]
C 586 Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)[3]
C 595 Specification for Blended Hydraulic Cements[4]
C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete[3]
C 637 Specification for Aggregates for Radiation-Shielding Concrete[3]
C 638 Descriptive Nomenclature of Constituents of Aggregates for Radiation-Shielding Concrete[3]
C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing[3]
C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars[3]
C 1105 Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction[3]
C 1157 Performance Specification for Hydraulic Cement[4]
C 1240 Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout[3]
C 1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)[3]
C 1293 Test Method for Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali-Silica Reaction[3]
D 75 Practice for Sampling Aggregates[6]
D 3665 Practice for Random Sampling of Construction Materials[6]
E 11 Specification for Wire–Cloth and Sieves for Testing Purposes[7]

TABLE 1 Limits for Deleterious Substances in Fine Aggregate for Concrete

Item	Mass Percent of Total Sample, max
Clay lumps and friable particles	3.0
Material finer than 75-µm (No. 200) sieve:	
Concrete subject to abrasion	3.0[A]
All other concrete	5.0[A]
Coal and lignite:	
Where surface appearance of concrete is of importance	0.5
All other concrete	1.0

[A] In the case of manufactured sand, if the material finer than the 75-µm (No. 200) sieve consists of the dust of fracture, essentially free of clay or shale, these limits are permitted to be increased to 5 and 7 %, respectively.

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology C 125.

4. Ordering and Specifying Information

4.1 The direct purchaser of aggregates shall include the information in 4.2 in the purchase order as applicable. A project specifier shall include in the project documents information to describe the aggregate to be used in the project from the applicable items in 4.3.

4.2 Include in the purchase order for aggregates the following information, as applicable:

4.2.1 Reference to this specification, as C 33____,

4.2.2 Whether the order is for fine aggregate or for coarse aggregate,

4.2.3 Quantity, in metric tons or tons,

4.2.4 When the order is for fine aggregate:

4.2.4.1 Whether the restriction on reactive materials in 7.3 applies,

4.2.4.2 In the case of the sulfate soundness test (see 8.1) which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used,

4.2.4.3 The appropriate limit for material finer than 75-µm (No. 200) sieve (see Table 1). If not stated, the 3.0 % limit shall apply,

4.2.4.4 The appropriate limit for coal and lignite (see Table 1). If not stated, the 1.0 % limit shall apply,

4.2.5 When the order is for coarse aggregate:

4.2.5.1 The grading (size number) (see 10.1 and Table 2), or alternate grading as agreed between the purchaser and aggregate supplier.

4.2.5.2 The class designation (see 11.1 and Table 3),

4.2.5.3 Whether the restriction on reactive materials in 11.2 applies,

4.2.5.4 In the case of the sulfate soundness test (see Table 3), which salt is to be used. If none is stated, either sodium sulfate or magnesium sufate shall be used, and

4.2.6 Any exceptions or additions to this specification (see Note 1).

4.3 Include in project specifications for aggregates the following information, as applicable:

4.3.1 Reference to this specification, as C 33____.

4.3.2 When the aggregate being described is fine aggregate:

4.3.2.1 Whether the restriction on reactive materials in 7.3 applies,

4.3.2.2 In the case of the sulfate soundness test (see 8.1) which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used.

4.3.2.3 The appropriate limit for material finer than the 75-µm (No. 200) sieve (see Table 1). If not stated, the 3.0 % limit shall apply, and

4.3.2.4 The limit that applies with regard to coal and lignite (Table 1). If not stated, the 1.0 % limit shall apply.

4.3.3 When the aggregate being described is coarse aggregate, include:

4.3.3.1 The nominal maximum size or sizes permitted, based on thickness of section or spacing of reinforcing bars or other criteria. In lieu of stating the nominal maximum size, the specifier shall designate an appropriate size number or numbers (see 10.1 and Table 2). Designation of a size number to indicate a nominal size shall not restrict the person responsible for selecting proportions from combining two or more gradings of

[6] *Annual Book of ASTM Standards,* Vol 04.03.
[7] *Annual Book of ASTM Standards,* Vol 14.02.

TABLE 2 Grading Requirements for Coarse Aggregates

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Mass Percent													
		100 mm (4 in.)	90 mm (3½ in.)	75 mm (3 in.)	63 mm (2½ in.)	50 mm (2 in.)	37.5 mm (1½ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	12.5 mm (½ in.)	9.5 mm (⅜ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No.50)
1	90 to 37.5 mm (3½ to 1½ in.)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...	...
2	63 to 37.5 mm (2½ to 1½ in.)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...	...
3	50 to 25.0 mm (2 to 1 in.)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
357	50 to 4.75 mm (2 in. to No. 4)	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...	...
4	37.5 to 19.0 mm (1½ to ¾ in.)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...	...
467	37.5 to 4.75 mm (1½ in. to No. 4)	...	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...	...
5	25.0 to 12.5 mm (1 to ½ in.)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...	...
56	25.0 to 9.5 mm (1 to ⅜ in.)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...	...
57	25.0 to 4.75 mm (1 in. to No. 4)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...	...
6	19.0 to 9.5 mm (¾ to ⅜ in.)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...	...
67	19.0 to 4.75 mm (¾ in. to No. 4)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...	...
7	12.5 to 4.75 mm (½ in. to No. 4)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...	...
8	9.5 to 2.36 mm (⅜ in. to No. 8)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5	...
89	9.5 to 1.18 mm (⅜ in. to No. 16)	...	...	...	...	...	...	...	...	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5
9[A]	4.75 to 1.18 mm (No. 4 to No. 16)	...	...	...	...	...	...	...	...	...	100	85 to 100	10 to 40	0 to 10	0 to 5

[A] Size number 9 aggregate is defined in Terminology C 125 as a fine aggregate. It is included as a coarse aggregate when it is combined with a size number 8 material to create a size number 89, which is a coarse aggregate as defined by Terminology C 125.

TABLE 3 Limits for Deleterious Substances and Physical Property Requirements of Coarse Aggregate for Concrete

NOTE 1—See Fig. 1 for the location of the weathering regions and Note 9 for guidance in using the map. The weathering regions are defined as follows:

(S) Severe Weathering Region—A cold climate where concrete is exposed to deicing chemicals or other aggressive agents, or where concrete may become saturated by continued contact with moisture or free water prior to repeated freezing and thawing.

(M) Moderate Weathering Region—A climate where occasional freezing is expected, but where concrete in outdoor service will not be continually exposed to freezing and thawing in the presence of moisture or to deicing chemicals.

(N) Negligible Weathering Region—A climate where concrete is rarely exposed to freezing in the presence of moisture.

Class Designation	Type or Location of Concrete Construction	Maximum Allowable, %						
		Clay Lumps and Friable Particles	Chert (Less Than 2.40 sp gr SSD)	Sum of Clay Lumps, Friable Particles, and Chert (Less Than 2.40 sp gr SSD)	Material Finer Than 75-µm (No. 200) Sieve	Coal and Lignite	Abrasion[A]	Magnesium Sulfate Soundness (5 cycles)[B]
		Severe Weathering Regions						
1S	Footings, foundations, columns and beams not exposed to the weather, interior floor slabs to be given coverings	10.0	...	...	1.0[C]	1.0	50	...
2S	Interior floors without coverings	5.0	...	...	1.0[C]	0.5	50	...
3S	Foundation walls above grade, retaining walls, abutments, piers, girders, and beams exposed to the weather	5.0	5.0	7.0	1.0[C]	0.5	50	18
4S	Pavements, bridge decks, driveways and curbs, walks, patios, garage floors, exposed floors and porches, or waterfront structures, subject to frequent wetting	3.0	5.0	5.0	1.0[C]	0.5	50	18
5S	Exposed architectural concrete	2.0	3.0	3.0	1.0[C]	0.5	50	18
		Moderate Weathering Regions						
1M	Footings, foundations, columns, and beams not exposed to the weather, interior floor slabs to be given coverings	10.0	...	...	1.0[C]	1.0	50	...
2M	Interior floors without coverings	5.0	...	...	1.0[C]	0.5	50	...
3M	Foundation walls above grade, retaining walls, abutments, piers, girders, and beams exposed to the weather	5.0	8.0	10.0	1.0[C]	0.5	50	18
4M	Pavements, bridge decks, driveways and curbs, walks, patios, garage floors, exposed floors and porches, or waterfront structures subject to frequent wetting	5.0	5.0	7.0	1.0[C]	0.5	50	18
5M	Exposed architectural concrete	3.0	3.0	5.0	1.0[C]	0.5	50	18
		Negligible Weathering Regions						
1N	Slabs subject to traffic abrasion, bridge decks, floors, sidewalks, pavements	5.0	...	...	1.0[C]	0.5	50	...
2N	All other classes of concrete	10.0	...	...	1.0[C]	1.0	50	...

[A] Crushed air-cooled blast-furnace slag is excluded from the abrasion requirements. The rodded or jigged bulk density (unit weight) of crushed air-cooled blast-furnace slag shall be not less than 1120 kg/m^3 (70 lb/ft^3). The grading of slag used in the bulk density (unit weight) test shall conform to the grading to be used in the concrete. Abrasion loss of gravel, crushed gravel, or crushed stone shall be determined on the test size or sizes most nearly corresponding to the grading or gradings to be used in the concrete. When more than one grading is to be used, the limit on abrasion loss shall apply to each.

[B] The allowable limits for soundness shall be 12 % if sodium sulfate is used.

[C] This percentage under either of the following conditions: (*1*) is permitted to be increased to 1.5 if the material is essentially free of clay or shale; or (*2*) if the source of the fine aggregate to be used in the concrete is known to contain less than the specified maximum amount passing the 75-µm (No. 200) sieve (Table 1) the percentage limit *(L)* on the amount in the coarse aggregate is permitted to be increased to $L = 1 + [(P)/(100 - P)]\ (T - A)$, where P = percentage of sand in the concrete as a percent of total aggregate, T = the Table 1 limit for the amount permitted in the fine aggregate, and A = the actual amount in the fine aggregate. (This provides a weighted calculation designed to limit the maximum mass of material passing the 75-µm (No. 200) sieve in the concrete to that which would be obtained if both the fine and coarse aggregate were supplied at the maximum tabulated percentage for each of these ingredients.)

aggregate to obtain a desired grading, provided that the gradings are not otherwise restricted by the project specifier and the nominal maximum size indicated by the size number is not exceeded,

4.3.3.2 The class designation (see 11.1 and Table 3),

4.3.3.3 Whether the restriction on reactive materials in 11.2 applies,

4.3.3.4 In the case of the sulfate soundness test (see Table 3), which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used, and

4.3.4 The person responsible for selecting the concrete proportions if other than the concrete producer.

4.3.5 Any exceptions or additions to this specification (see Note 1).

FINE AGGREGATE

5. General Characteristics

5.1 Fine aggregate shall consist of natural sand, manufactured sand, or a combination thereof.

6. Grading

6.1 *Sieve Analysis*—Fine aggregate, except as provided in 6.2 and 6.3 shall be graded within the following limits:

Sieve (Specification E 11)	Percent Passing
9.5-mm (⅜-in.)	100
4.75-mm (No. 4)	95 to 100
2.36-mm (No. 8)	80 to 100
1.18-mm (No. 16)	50 to 85
600-µm (No. 30)	25 to 60
300-µm (No. 50)	5 to 30
150-µm (No. 100)	0 to 10

NOTE 2—Concrete with fine aggregate gradings near the minimums for percent passing the 300 µm (No.50) and 150 µm (No.100) sometimes have difficulties with workability, pumping or excessive bleeding. The addition of entrained air, additional cement, or the addition of an approved mineral admixture to supply the deficient fines, are methods used to alleviate such difficulties.

6.2 The fine aggregate shall have not more than 45 % passing any sieve and retained on the next consecutive sieve of those shown in 6.1, and its fineness modulus shall be not less than 2.3 nor more than 3.1.

6.3 Fine aggregate failing to meet these grading requirements shall meet the requirements of this section provided that the supplier can demonstrate to the purchaser or specifier that concrete of the class specified, made with fine aggregate under consideration, will have relevant properties (see Note 4) at least equal to those of concrete made with the same ingredients, with the exception that the reference fine aggregate shall be selected from a source having an acceptable performance record in similar concrete construction.

NOTE 3—Fine aggregate that conforms to the grading requirements of a specification, prepared by another organization such as a state transportation agency, which is in general use in the area, should be considered as having a satisfactory service record with regard to those concrete properties affected by grading.

NOTE 4—Relevant properties are those properties of the concrete that are important to the particular application being considered. STP 169C[8] provides a discussion of important concrete properties.

6.4 For continuing shipments of fine aggregate from a given source, the fineness modulus shall not vary more than 0.20 from the base fineness modulus. The base fineness modulus shall be that value that is typical of the source. The purchaser or specifier has the authority to approve a change in the base fineness modulus.

NOTE 5—The base fineness modulus should be determined from previous tests, or if no previous tests exist, from the average of the fineness modulus values for the first ten samples (or all preceding samples if less than ten) on the order. The proportioning of a concrete mixture may be dependent on the base fineness modulus of the fine aggregate to be used. Therefore, when it appears that the base fineness modulus is considerably different from the value used in the concrete mixture, a suitable adjustment in the mixture may be necessary.

7. Deleterious Substances

7.1 The amount of deleterious substances in fine aggregate shall not exceed the limits prescribed in Table 1.

7.2 *Organic Impurities*:

7.2.1 Fine aggregate shall be free of injurious amounts of organic impurities. Except as herein provided, aggregates subjected to the test for organic impurities and producing a color darker than the standard shall be rejected.

7.2.2 Use of a fine aggregate failing in the test is not prohibited, provided that the discoloration is due principally to the presence of small quantities of coal, lignite, or similar discrete particles.

7.2.3 Use of a fine aggregate failing in the test is not prohibited, provided that, when tested for the effect of organic impurities on strength of mortar, the relative strength at 7 days, calculated in accordance with Test Method C 87, is not less than 95 %.

7.3 Fine aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, use of the fine aggregate is not prohibited when used with a cement containing less than 0.60 % alkalies calculated as sodium oxide equivalent (Na_2O + 0.658K_2O) or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Appendix X1.)

8. Soundness

8.1 Except as provided in 8.2 and 8.3, fine aggregate subjected to five cycles of the soundness test shall have a weighted average loss not greater than 10 % when sodium sulfate is used or 15 % when magnesium sulfate is used.

8.2 Fine aggregate failing to meet the requirements of 8.1 shall be regarded as meeting the requirements of this section provided that the supplier demonstrates to the purchaser or

[8] *Significance of Tests and Properties of Concrete and Concrete Making Materials, STP 169C*, ASTM, 1994.

specifier that concrete of comparable properties, made from similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

8.3 Fine aggregate not having a demonstrable service record and failing to meet the requirements of 8.1 shall be regarded as meeting the requirements of this section provided that the supplier demonstrates to the purchaser or specifier it gives satisfactory results in concrete subjected to freezing and thawing tests (see Test Method C 666).

COARSE AGGREGATE

9. General Characteristics

9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic-cement concrete (see Note 6), or a combination thereof, conforming to the requirements of this specification.

NOTE 6—Although crushed hydraulic-cement concrete has been used as an aggregate with reported satisfactory results, its use may require some additional precautions. Mixing water requirements may be increased because of the harshness of the aggregate. Partially deteriorated concrete, used as aggregate, may reduce freeze-thaw resistance, affect air void properties or degrade during handling, mixing, or placing. Crushed concrete may have constituents that would be susceptible to alkali-aggregate reactivity or sulfate attack in the new concrete or may bring sulfates, chlorides, or organic material to the new concrete in its pore structure.

10. Grading

10.1 Coarse aggregates shall conform to the requirements prescribed in Table 2 for the size number specified.

NOTE 7—The ranges shown in Table 2 are by necessity very wide in order to accommodate nationwide conditions. For quality control of any specific operation, a producer should develop an average grading for the particular source and production facilities, and should control the production gradings within reasonable tolerances from this average. Where coarse aggregate size numbers 357 or 467 are used, the aggregate should be furnished in at least two separate sizes.

11. Deleterious Substances

11.1 Except for the provisions of 11.3, the limits given in Table 3 shall apply for the class of coarse aggregate designated in the purchase order or other document (see Note 8 and Note 9). If the class is not specified, the requirements for Class 3S, 3M, or 1N shall apply in the severe, moderate, and negligible weathering regions, respectively (see Table 3 and Fig. 1).

NOTE 8—The specifier of the aggregate should designate the class of coarse aggregate to be used in the work, based on weathering severity, abrasion, and other factors of exposure. (See Table 3 and Fig. 1.) The limits for coarse aggregate corresponding to each class designation are expected to ensure satisfactory performance in concrete for the respective type and location of construction. Selecting a class with unduly restrictive limits may result in unnecessary cost if materials meeting those requirements are not locally available. Selecting a class with lenient limits may result in unsatisfactory performance and premature deterioration of the concrete. While concrete in different parts of a single structure may be

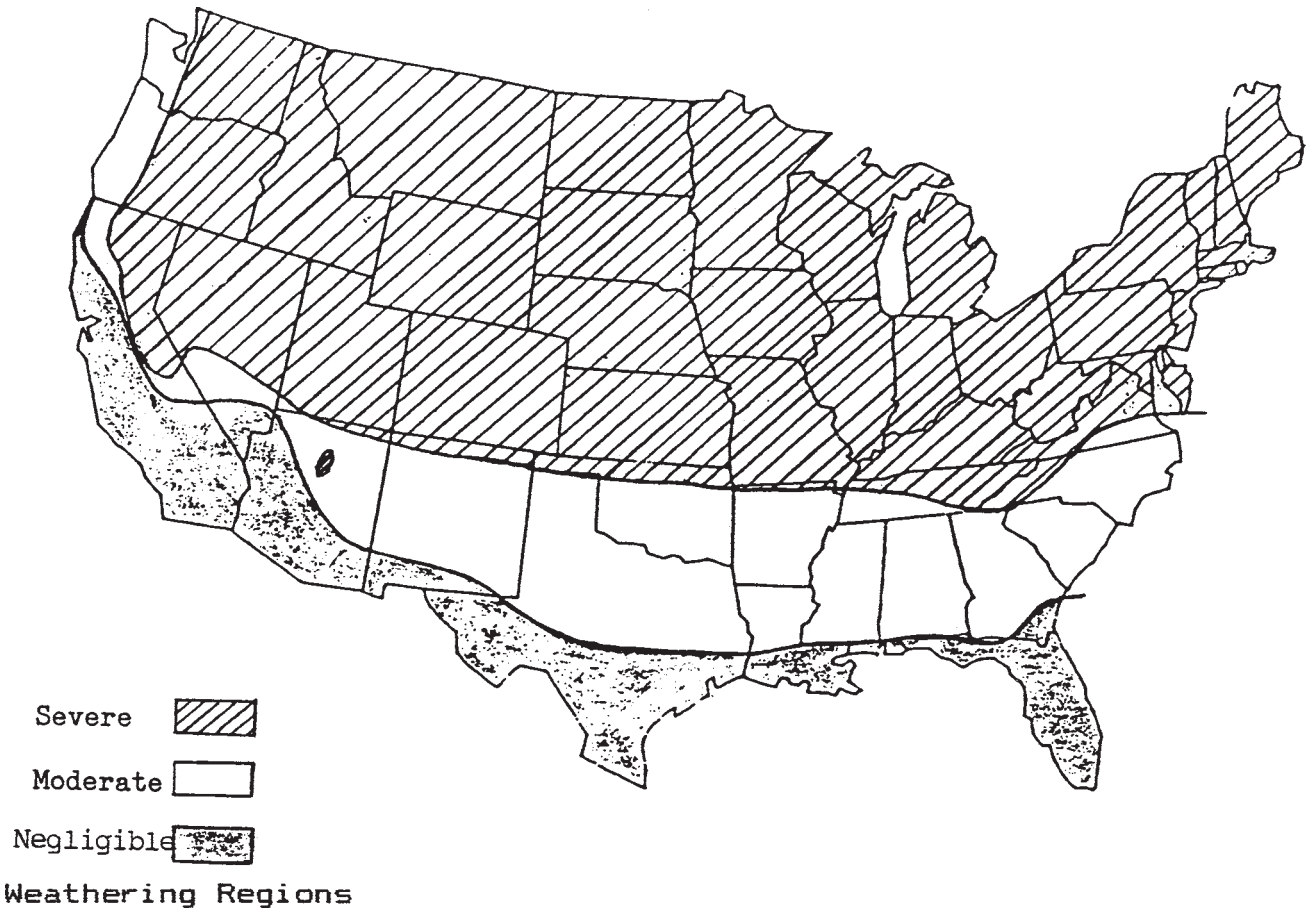

FIG. 1 Location of Weathering Regions

adequately made with different classes of coarse aggregate, the specifier may wish to require the coarse aggregate for all concrete to conform to the same more restrictive class to reduce the chance of furnishing concrete with the wrong class of aggregate, especially on smaller projects.

NOTE 9—For coarse aggregate in concrete exposed to weathering, the map with the weathering regions shown in Fig. 1 is intended to serve only as a guide to probable weathering severity. Those undertaking construction, especially near the boundaries of weathering regions, should consult local weather bureau records for amount of winter precipitation and number of freeze-thaw cycles to be expected, for determining the weathering severity for establishing test requirements of the coarse aggregate. For construction at altitudes exceeding 1520 m (5000 ft) above sea level, the likelihood of more severe weathering than indicated by the map should be considered. In arid areas, severity of weathering may be less than that indicated. In either case, the definitions of weathering severity in Table 3 would govern. If there is doubt in choosing between two regions, select the more severe weathering region.

11.2 Coarse aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete except that if such materials are present in injurious amounts, the coarse aggregate is not prohibited when used with a cement containing less than 0.60 % alkalies calculated as sodium oxide equivalent ($Na_2O + 0.658K_2O$) or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Appendix X1.)

11.3 Coarse aggregate having test results exceeding the limits specified in Table 3 shall be regarded as meeting the requirements of this section provided the supplier demonstrates to the purchaser or specifier that concrete made with similar aggregate from the same source has given satisfactory service when exposed in a similar manner to that to be encountered; or, in the absence of a demonstrable service record, provided that the aggregate produces concrete having satisfactory relevant properties (see Note 4).

METHODS OF SAMPLING AND TESTING

12. Methods of Sampling and Testing

12.1 Sample and test the aggregates in accordance with the following methods, except as otherwise provided in this specification. Make the required tests on test specimens that comply with requirements of the designated test methods. It is not prohibited to use the same test specimen for sieve analysis and for determination of material finer than the 75-µm (No. 200) sieve. The use of separated sizes from the sieve analysis is acceptable for soundness or abrasion tests, however, additional test specimen preparation is required (see Note 10). For other test procedures and the evaluation of potential alkali reactivity, when required, use independent test specimens.

NOTE 10—The material used for the soundness test requires resieving to allow proper test specimen preparation as specified in Test Method C 88.

12.1.1 *Sampling*—Practice D 75 and Practice D 3665.

12.1.2 *Grading and Fineness Modulus*—Test Method C 136.

12.1.3 *Amount of Material Finer than 75-µm (No. 200) Sieve*—Test Method C 117.

12.1.4 *Organic Impurities*—Test Method C 40.

12.1.5 *Effect of Organic Impurities on Strength*—Test Method C 87.

12.1.6 *Soundness*—Test Method C 88.

12.1.7 *Clay Lumps and Friable Particles*— Test Method C 142.

12.1.8 *Coal and Lignite*—Test Method C 123, using a liquid of 2.0 specific gravity to remove the particles of coal and lignite. Only material that is brownish-black, or black, shall be considered coal or lignite. Coke shall not be classed as coal or lignite.

12.1.9 *Bulk Density (Unit Weight) of Slag*—Test Method C 29/C 29M.

12.1.10 *Abrasion of Coarse Aggregate*—Test Method C 131 or Test Method C 535.

12.1.11 *Reactive Aggregates*—See Appendix X1.

12.1.12 *Freezing and Thawing*—Procedures for making freezing and thawing tests of concrete are described in Test Method C 666.

12.1.13 *Chert*—Test Method C 123 is used to identify particles in a sample of coarse aggregate lighter than 2.40 specific gravity, and Guide C 295 to identify which of the particles in the light fraction are chert.

13. Keywords

13.1 aggregates; coarse aggregate; concrete aggregates; fine aggregate

APPENDIX

(Nonmandatory Information)

X1. METHODS FOR EVALUATING POTENTIAL FOR DELETERIOUS EXPANSION DUE TO ALKALI REACTIVITY OF AN AGGREGATE

X1.1 Introduction

X1.1.1 *Laboratory Methods*—Many test methods for evaluating the potential for deleterious expansion due to alkali reactivity of an aggregate have been proposed and some have been adopted as ASTM standards. However, there is no general agreement on the relation between the results of these tests and the amount of expansion to be expected or tolerated in service. Therefore, evaluation of the suitability of an aggregate should be based upon judgment, interpretation of test data, and results of examinations of concrete structures containing the same aggregates and similar cementitious materials having similar levels of alkalies. Results of the tests referred to in this appendix may assist in making the evaluation. When interpreting expansion of laboratory specimens, consideration should be given not only to expansion values at specific ages, but also to the shape of the expansion curve, which may indicate whether the expansion is leveling off or continuing at a constant or accelerating rate.

X1.1.2 *Service Record Evaluation*—Valid, comparable concrete service record data, if available, should take precedence over laboratory test results in most cases. To be considered valid, a record of satisfactory service should be available for at least 10 years for aggregates, cementitious materials, and exposures sufficiently similar to those in which an aggregate is being considered for future use. Longer periods of documented service may be required for proposed work designed for a particularly long service life in moist conditions, or if laboratory test results show that the aggregate may be deleteriously reactive.

X1.1.3 *Mitigation of Alkali-Aggregate Reaction*—If an aggregate has been judged to be potentially deleteriously reactive in concrete either through laboratory or service record evaluation, use of the aggregate should be considered with measures known to prevent excessive expansion due to alkali-aggregate reaction. See the mitigation sections in this appendix under X1.3 Alkali-Silica Reaction and X1.4 Alkali-Carbonate Rock Reaction and References cited for discussion of prevention strategies for new concrete.

X1.2 Background

X1.2.1 Background information on alkali-aggregate reaction can be found in Ref **(1)**[9], Descriptive Nomenclature C 294, and Guide C 295 as discussed as follows. Additional discussion is included in Refs **(2)** **(3)**. These references address both alkali-silica reaction and alkali-carbonate rock reaction.

X1.2.1.1 *Descriptive Nomenclature C 294 for Constituents of Concrete Aggregates*—This nomenclature provides descriptions of constituents of mineral aggregates and includes discussion of which have been associated with deleterious expansion due to alkali reaction.

X1.2.1.2 *Guide C 295 (Petrographic Examination of Aggregates)*—This guide outlines the procedures for examining an aggregate sample or a sample from a potential aggregate source to determine whether substances that are potentially deleteriously reactive are present; and, if so, in what amounts.

X1.2.1.3 *Alkali-Silica Reaction*—Certain materials are known to be potentially deleteriously alkali-silica reactive. These include forms of silica such as opal, chalcedony, tridymite, and cristobalite; cryptocrystalline and microcrystalline, strained, or highly fractured quartz; and intermediate to acid (silica-rich) volcanic glass such as is likely to occur in rhyolite, andesite, or dacite. Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity. An aggregate can be potentially deleteriously reactive when some of these materials, such as opal, are present in very small quantities (for example, 1 %).

X1.2.1.4 *Alkali-Carbonate Rock Reaction*—The reaction of dolomite in certain carbonate rocks with alkalies has been associated with deleterious expansion of concrete containing such rocks as coarse aggregate. The most rapidly reactive carbonate rocks possess a characteristic texture in which relatively large crystals of dolomite are scattered in a finer-grained matrix of calcite and clay. These rocks also have a composition in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. Certain purely dolomitic rocks also may produce slow expansion in concrete.

X1.3 Alkali-Silica Reaction

X1.3.1 *Test Method C 289 (Chemical Method)*—The results of the test are values for the quantities of dissolved silica (S_c) and reduction in alkalinity (R_c) for each of the three test portions from the prepared aggregate test sample. Aggregates represented by plotted points (S_c, R_c), which lie on the deleterious side of the solid curve of Fig. X1.1 of Test Method C 289 usually should be considered potentially reactive. Three regions are delineated in the figure: (*1*) aggregates considered innocuous; (*2*) aggregates considered potentially deleterious; and (*3*) aggregates considered deleterious. Aggregates represented by points lying in the potentially deleterious region above the dashed line in Fig. X1.1 of Test Method C 289 may give relatively low expansions in mortar or concrete even though they are extremely reactive with alkalies. The test can be made quickly and can provide helpful information, except for slowly reactive rocks such as some granitic gneiss and quartzite. Also, as pointed out in the appendix to Test Method C 289, the results may not be correct for aggregates containing

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

carbonates or magnesium silicates, such as antigorite (serpentine), or constituents producing late-slow reactivity. See the appendix to Test Method C 289 for a discussion of the interpretation of results and applicable references. If test results indicate deleterious or potentially deleterious character, the aggregates should be tested in accordance with Test Methods C 227 or C 1293 to verify the potential for expansion in concrete.

X1.3.2 *Test Method C 227 (Mortar-Bar Method for Cement-Aggregate Combinations)*—The results of this test method, when a high-alkali cement is used, furnish information on the likelihood of potentially deleterious expansion occurring. The alkali content of the portland cement should be at least 0.8 %, expressed as percent sodium oxide equivalent ($\%Na_2O + 0.658 \times \%K_2O$). Combinations of aggregate and cementitious materials that have produced excessive expansions in this test method should be considered potentially reactive. While the line of demarcation between innocuous and potentially deleterious combinations is not clearly defined, expansion is generally considered to be excessive if it exceeds 0.05 % at 3 months or 0.10 % at 6 months. Expansions greater than 0.05 % at 3 months should not be considered excessive when the 6-month expansion remains below 0.10 %. Data for the 3-month tests should be considered only when 6-month results are not available. The limits may not be conservative for slowly reactive aggregates. Test Method C 227 is not suitable for slowly reactive aggregates, and its use for this purpose is not advised (**1, 2**). Aggregates suspected of being slowly reactive should be evaluated using Test Method C 1260 or Test Method C 1293. Test Method C 227 is also used with a specific reactive glass aggregate to verify the mitigation effectiveness of blended cements meeting Specification C 595, with the Table 2 optional mortar expansion requirement, and meeting Performance Specification C 1157 with Option R. These procedures are similar to the provisions of Test Method C 441 discussed as follows for mineral admixtures and ground slag.

X1.3.3 *Test Method C 342 (Mortar Bars Subjected to Changes in Moisture and Temperature)*—This withdrawn test method was intended for research concerning the potential expansion of cement-aggregate combinations involving selected aggregates found in parts of Oklahoma, Kansas, Nebraska, and Iowa. Due to the specimen conditioning procedures, the expansion of mortar bars in this test method may not be related to alkali-silica reaction under normal-temperature conditioning. Data on the use of this test method are given in the references cited in a footnote in the test method. It is indicated that cement-aggregate combinations tested by this procedure in which expansion equals or exceeds 0.20 % at an age of 1 year may be considered unsatisfactory for use in concrete exposed to wide variations of temperature and degree of saturation with water. This test method is not recommended for use in regions other than previously cited.

X1.3.4 *Test Method C 1260 (Mortar-Bar Method for Potential Alkali Reactivity of Aggregate)*—This test method is an accelerated screening technique developed for the detection of materials that develop deleterious expansions slowly over a long period of time. Some aggregates that perform well in the field have been shown to fail this test (**4, 5**). Results of this test method should not be used for rejection of aggregates unless it has been established using the sources of supplementary information cited in the test method that the detected expansion is actually due to alkali-silica reaction. There is good agreement in the published literature cited in the test method for the expansion limits: (*1*) expansions of less than 0.10 % at 16 days after casting are indicative of innocuous behavior in most cases; (*2*) expansions of more than 0.20 % at 16 days are indicative of potentially deleterious expansion; and (*3*) expansions between 0.10 and 0.20 % at 16 days include both aggregates that are known to be innocuous and deleterious in field performance. If test results indicate expansion greater than 0.10 % at 16 days, the aggregate should be tested in accordance with Test Method C 1293 unless appropriate field experience demonstrates that it does not cause deleterious expansion in concrete. (See X1.3.7.)

X1.3.5 *Test Method C 1293 (Concrete Prism Method for Alkali-Silica Reactivity)*—The test method evaluates the aggregates for potential alkali-silica reaction expansion using concrete prisms. The test method is accelerated by using an elevated alkali content and Test Method C 227 exposure conditions. The appendix to Test Method C 1293 provides guidance on interpretation of the results. Aggregates with expansions equal to or greater than 0.04 % at one year are considered potentially deleteriously reactive. This test method is considered to be the most reliable procedure among ASTM Test Methods for the evaluation of aggregates for alkali-silica reaction.

X1.3.6 *Test Method C 441 (Mortar-Bar Method for Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction)*—In general, the potential for expansion due to alkali-silica reactivity can be controlled by using a sufficient amount of an effective pozzolan or ground granulated blast-furnace slag as a portion of the cementitious material component in concrete, or by using a cement of a low alkali content. In the case of pozzolan, it is necessary to establish its effectiveness using a standard test; and the only ASTM test method that evaluates the effectiveness of pozzolan or slag is Test Method C 441. This test method uses mortar bars as in Test Method C 227. Specification C 618 provides a criterion for its use as applied to fly ash and raw or calcined natural pozzolans when sampled and tested in accordance with Test Methods C 311. Specification C 1240 provides criteria for the use of Test Method C 441 to evaluate silica fume for controlling expansion. Appendix X3 to Specification C 989 describes its use for ground granulated blast-furnace slag.

X1.3.7 *Mitigation of Alkali-Silica Reaction*—Normally if an aggregate is shown to be nonreactive or innocuous by producing little or no expansion in Test Method C 1260 or Test Method C 1293, no mitigation is necessary. Similarly, if the aggregate has a long satisfactory service record with similar cementitious materials having similar or higher alkali levels, no mitigation is necessary. On the other hand, use of aggregates judged to be potentially deleteriously alkali-silica reactive should be considered with the use of measures known to prevent excessive expansion. These include measures such as: low-alkali cement (Specification C 150 with the low-alkali

option); blended cements (Specification C 595 with the Table 2 optional mortar expansion requirement or Performance Specification C 1157 with Option R); pozzolanic materials (meeting the optional physical requirement on effectiveness in controlling alkali-silica reaction in Specification C 618 or reactivity with cement alkalies in Specification C 1240 for silica fume); or ground slag (shown to be effective in preventing excessive expansion of concrete due to alkali-aggregate reaction as discussed in Appendix X3 of Specification C 989). The effectiveness of the cementitious materials or admixtures, or both, chosen to mitigate a potentially reactive aggregate should be demonstrated through tests of the individual materials, or tests of the proposed combination in concrete.

X1.4 Alkali-Carbonate Rock Reaction

X1.4.1 *Test Method C 586 (Rock Cylinders Method for Alkali-Carbonate Rock Reaction)*—Rocks that are capable of potentially deleterious carbonate rock reaction are relatively infrequent and seldom constitute a significant proportion of a deposit of rock being considered for use in making aggregate for concrete. Test Method C 586 has been successfully used in research and in preliminary screening of aggregate sources to indicate the presence of material with a potential for deleterious expansions when used in concrete.

X1.4.2 *Test Method C 1105 (Concrete-Prism Method for Alkali-Carbonate Rock Reaction)*—This test method is intended to evaluate specific combinations of materials in concrete when the aggregate is regarded as susceptible to deleterious expansion in service due to the alkali-carbonate rock reaction. The appendix to Test Method C 1105 provides general information and references concerning the interpretation of results. A cement-aggregate combination might reasonably be classified as potentially deleteriously reactive if the average expansion of six concrete specimens is equal to or greater than: 0.015 % at 3 months; 0.025 % at 6 months; or 0.030 % at 1 year. Data for later ages are preferred.

X1.4.3 *Mitigation of Alkali-Carbonate Rock Reaction*—Normally, if a carbonate rock does not show the characteristic texture and composition associated with this type of reaction, or if it does not produce expansion in rock cylinders (Test Method C 586) or concrete prisms (Test Method C 1105), no mitigation is necessary for alkali-carbonate rock reaction. Similarly, if the aggregate has a long satisfactory service record with similar materials and conditions, no mitigation is necessary. On the other hand, use of aggregates judged to be potentially deleteriously alkali-carbonate reactive in concrete is not recommended unless it can be shown that mitigation methods will be effective. Pozzolans generally have not been found to control alkali-carbonate rock reaction. Measures suggested for mitigation includes: avoiding reactive carbonate rocks; selective quarrying; diluting reactive rock to less than 20 % of the aggregate in the concrete; use of smaller maximum size; and the use of very low alkali cement.

REFERENCES

(1) *Significance of Tests and Properties of Concrete and Concrete-Making Materials*, Klieger, Paul and Lamond, Joseph F., Eds, *ASTM STP 169C*, 1994, 623 pages. See Chapter 31 on "Petrographic Evaluation of Concrete Aggregates," by Richard C. Mielenz, Chapter 32 on "Alkali-Silica Reactions in Concrete" by David Stark, and Chapter 33 on "Alkali-Carbonate Rock Reaction" by Michael A. Ozol.

(2) "State-of-the-Art Report on Alkali-Aggregate Reactivity" by ACI Committee 221 on Aggregates, ACI 221.1R-98, American Concrete Institute, Farmington Hills, MI, 1998, 31 pages.

(3) *Alkali-Aggregate Reaction in Concrete,* Berube, M. A., Fournier, B., and Durand, Eds, *Proceedings of the 11th International Conference,* Quebec City, Canada, June 2000, 1402 pages. (Note—This conference and proceedings includes information on ASR and ACR in concrete by researchers and experts from all over the world. Copies of the volume can be obtained from the International Centre for Sustainable Development of Cement and Concrete, 405 Rochester Street, Ottawa, Ontario, Canada, K1A 0G1.)

(4) Hooton, R.D., and Rogers, C.A., "Evaluation of Rapid Test Methods for Detecting Alkali-Reactive Aggregates," *Proceedings of Eighth International Conference on Alkali-Aggregate Reaction,* Kyoto, 1989, pp. 439–444.

(5) Fournier, B., and Berube, M.A.," Application of the NBRI Accelerated Mortar Bar Test to Siliceous Carbonate Aggregates Produced in the St. Lawrence Lowlands, Part 2: Proposed Limits, Rates of Expansion, and Microstructure of Reaction Products," *Cement and Concrete Research*, Vol 21, 1991, pp. 1069–1082.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C 33 – 02a) that may impact the use of this standard. (Approved June 10, 2003.)

(*1*) Revised Appendix X1.3.6 to clarify the term pozzolans and to include Specification C 1240 in references to Test Method C 441.

Committee C09 has identified the location of selected changes to this standard since the last issue (C 33 – 02) that may impact the use of this standard. (Approved July 10, 2002.)

(*1*) Revised paragraph 12.1.9.

(*2*) Revised Footnote A of Table 3.

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Designation: C 1602/C 1602M – 06

Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete[1]

This standard is issued under the fixed designation C 1602/C 1602M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers the compositional and performance requirements for water used as mixing water in hydraulic cement concrete. It defines sources of water and provides requirements and testing frequencies for qualifying individual or combined water sources. In any case where the requirements of the purchaser differ from these in this specification, the purchaser's specification shall govern.

1.2 This specification does not purport to cover methods of storage, transportation, or blending of water, or to address the development and maintenance of quality control programs sponsored or managed by the manufacturer.

1.3 The values stated in either SI units, shown in brackets, or inch-pound units are to be regarded separately as standard. The values stated in each system may not be 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.

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

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field

C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 94/C 94M Specification for Ready-Mixed Concrete

C 114 Test Methods for Chemical Analysis of Hydraulic Cement

C 125 Terminology Relating to Concrete and Concrete Aggregates

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 403/C 403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance

C 1603 Test Method for Measurement of Solids in Water

2.2 *ACI Documents:*[3]

ACI 318 Building Code Requirements for Structural Concrete and Commentary

3. Terminology

3.1 *Definitions:* For definitions of terms used in this specification, refer to Terminology C 125

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *combined water*—a mixture of two or more sources of water blended together, before or during introduction into the mixture, for use as mixing water in the production of concrete.

3.2.2 *hydration stabilizing admixtures*—extended set retarding admixtures that control the hydration of cement in applications of managing returned concrete and water from concrete production

3.2.3 *non-potable*—water sources that are not fit for human consumption, or if it contains quantities of substances that discolor it or make it smell or have objectionable taste but does not contain water from concrete production operations.

3.2.4 *potable water*—water suitable for human consumption

3.2.5 *water from concrete production operations*—water recovered from processes of hydraulic cement concrete production that includes wash water from mixers or that was a part of a concrete mixture; water collected in a basin as a result of storm water runoff at a concrete production facility; or water that contains quantities of concrete ingredients.

4. Requirements for Use

4.1 Mixing water shall consist of:

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.40 on Ready-Mixed Concrete.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

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

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4.1.1 Batch water (water weighed or metered through the batch plant),

4.1.2 Ice,

4.1.3 Water added by truck operator,

4.1.4 Free moisture on the aggregates, and

4.1.5 Water introduced in the form of admixtures when this water increases the water-cementitious materials ratio by more than 0.01.

4.2 Potable water is permitted to be used as mixing water in concrete without testing for conformance with the requirements of this specification.

4.3 Mixing water that is wholly or partially composed of sources of water that are non-potable or from concrete production operations are permitted to be used in any proportions to the limits qualified to meet the requirements of Table 1. At the option of the purchaser and when appropriate for the construction, any of the optional limits found within Table 2 shall be specified at the time of concrete ordering according to the section on *Ordering Information* of Specification C 94/C 94M.

4.3.1 Non-potable sources of water shall be qualified for use in accordance with 5.1. When the non-potable water source is blended with a potable source, the qualification of the mixing water shall be at the highest percentage of the non-potable source in the combined mixing water anticipated during production.

4.3.2 Combined water blended from two or more sources, where one of the sources includes that from concrete production, shall be qualified for use in accordance with 5.2. The combined water shall be qualified at the highest solids content in the total mixing water anticipated during production. Mixing water containing total solids equal to or less than the level qualified by testing shall be permitted.

5. Testing and Requirements

5.1 For sources of non-potable mixing water (as defined in 3.2.3) proposed for use as total mixing water or in the combined mixing water (as defined in 3.2.1), the following shall apply to the total combined mixing water:

5.1.1 Water shall be tested for compliance with Table 1 before first use and thereafter every three months or more often when there is reason to believe that a change has occurred in the characteristics of the source. Testing is permitted to be at a lower frequency, but not less than annually when results from four consecutive tests indicate compliance with Table 1.

5.1.2 The manufacturer shall maintain documented evidence that the characteristics of the combined mixing water are in compliance with Table 2. These tests shall be conducted before first use and thereafter every 6 months or more often when there is reason to believe that a change has occurred in the characteristics of the source. These records shall be provided to the purchaser on request.

TABLE 1 Concrete Performance Requirements for Mixing Water

	Limits	Test Methods
Compressive strength, min % control at 7 days[A,B]	90	C 31/C 31M, C 39/C 39M
Time of set, deviation from control, h: min[A]	From 1:00 early to 1:30 later	C 403/C 403M

[A] Comparisons shall be based on fixed proportions for a concrete mix design representative of questionable water supply and a control mix using 100 % potable water or distilled water. (See Annex A1).

[B] Compressive strength results shall be based on at least two standard test specimens made from a composite sample.

5.2 For sources of water from concrete production operations (as defined in 3.2.5) proposed for use as the total mixing water or in the combined mixing water (as defined in 3.2.1), the following shall apply to the total combined mixing water:

5.2.1 The density of the source of water from ready mixed concrete shall be tested at least on a daily basis in accordance with Test Method C 1603 or monitored with a hydrometer that has been verified in accordance with Test Method C 1603. Manufacturers that use automated devices shall maintain at the production facility documentation on the procedures and calibration of systems, as needed (See Note 1).

NOTE 1—Blending proportions of water sources can be determined in accordance with Appendix A1 of Test Method C 1603 for achieving a target solids content.

5.2.2 Combined water shall be tested for compliance with the requirements of Table 1 at the highest solids content anticipated to be used during production in accordance with the following testing frequencies:

5.2.2.1 When the density of the combined water is less than 1.01 g/mL, the water shall be tested before first use and thereafter once every six months. Testing frequency is permitted to be reduced to once every 12 months when the results of two consecutive tests indicate compliance with the requirements of Table 1 (See Note 2).

NOTE 2—This condition is intended to cover the use of clarified wash water that has been passed through a settling pond system.

5.2.2.2 When the density of the combined water is between 1.01 and 1.03, the water shall be tested before first use and thereafter monthly. Testing frequency is permitted to be reduced to once every three months when the results of 4 consecutive tests indicate compliance with the requirements of Table 1 (See Note 3).

NOTE 3—Water density of 1.03 approximately represents a total solids content of 50,000 ppm.

5.2.2.3 When the density of the combined water exceeds 1.03, the water shall be tested weekly or more often when there is reason to believe that there is a change in the water characteristics for compliance with the requirements of Table 1. Testing frequency is permitted to be reduced to once every month when the results of two months of consecutive tests indicate compliance with the requirements of Table 1.

5.2.2.4 Testing for water with density exceeding 1.05 shall be the same as that of 5.2.2.3 whether the water includes or does not include a set stabilizing admixture (See Note 4).

NOTE 4—Water density exceeding approximately 1.05, where the solids are essentially composed of cementitious materials, may require the use of hydration stabilizing admixtures to maintain compliance with the requirements of Table 1. The producer should have a documented process in place to verify the effectiveness of the admixtures and dosages employed.

5.2.3 The manufacturer shall maintain documentation on the characteristics of the water in compliance with the requirements of Table 2, other than the total solids requirement. These requirements shall apply to the combined water at the highest

TABLE 2 Optional Chemical Limits for Combined Mixing Water[A]

	Limits	Test Method
Maximum concentration in combined mixing water, ppm[B]		
A. Chloride as Cl^-, ppm		
1 in prestressed concrete, bridge decks, or otherwise designated	500[C]	C 114
2 other reinforced concrete in moist environments or containing aluminum embedments or dissimilar metals or with stay-in-place galvanized metal forms	1000[C]	C 114
B. Sulfate as SO_4, ppm	3000	C 114
C. Alkalies as (Na_2O + 0.658 K_2O), ppm	600	C 114
D. Total solids by mass, ppm	50 000	C 1603

[A]Specification limits from this table are not prohibited from being specified as individual items or as a whole per paragraph 4.1.6 of Specification C 94/C 94M.
[B]ppm is the abbreviation for parts per million
[C]The requirements for concrete in ACI 318 shall govern when the manufacturer can demonstrate that these limits for mixing water can be exceeded. For conditions allowing the use of calcium chloride ($CaCl_2$) accelerator as an admixture, the chloride limitation is permitted to be waived by the purchaser.

solids content anticipated for use. These tests shall be conducted before first use and thereafter once every 6 months. These records shall be provided to the purchaser on request (See Note 5).

5.3 Concrete testing to verify compliance with the requirements of Table 1 shall be conducted on concrete samples obtained from production batches or in laboratory batches in accordance with Practice C 192/C 192M (See Note 5).

NOTE 5—The sampling of total combined water in its final form from either the batch plant or transportation unit is impractical. Therefore, for the purposes of testing for compliance to the requirements of Table 1 and Table 2, it is acceptable to sample, proportion, and combine the individual sources of water to produce a test sample that is representative of the actual combined mixing water used in production.

6. Keywords

6.1 combined water; density; hydration stabilizing admixture; mixing water; recycled water

ANNEX

(Mandatory Information)

A1. GUIDE FOR THE COMPARISON BETWEEN TWO CONCRETE MIXTURES NECESSARY FOR COMPLIANCE WITH Table 1

INTRODUCTION

To comply with the performance requirements in Table 1, comparison between two concrete mixtures is required: one as a control batch using a potable water source, and a second as a test batch using the water source(s) proposed for use. The following shall apply:

A1.1 Water for the test batch as defined in 3.2 with a density greater than 1.01 g/mL, or as close in approximation to density as used during actual production.

A1.2 Water for the test batch as defined in 3.2 shall be as close as possible to the actual age of water used during actual production.

A1.3 Air entraining and water reducing admixtures are permitted in test and control batches. The air-entraining admixture shall be adjusted to produce the target air content with a tolerance of ±1.5 %. The dosage of water reducing admixture shall be the same in both batches.

A1.4 Hydration stabilizing admixtures are permitted for use in the mixing water for the test batch. No other set controlling admixtures are permitted.

A1.5 Mixing water content of the test batch shall not be less than the mixing water content of the control batch.

A1.6 Mixture proportions shall be made available upon request.

A1.7 Each batch for concrete comparison purposes to determine compliance with Table 1 shall be within ± 1 °C at the time of mixing and shall be conditioned the same for the duration of the test.

APPENDIX

(Nonmandatory Information)

X1. GUIDE FOR TESTING FREQUENCY AS RELATED TO WATER SOURCE USED IN MIXING WATER.

Water Sources	Combined Water Density (g/mL)	Testing Frequency		
		Density, C 1603	Table 1	Table 2
Potable	N/A	N/A	N/A	N/A
Non-Potable[A]	N/A	N/A	3 months; after 4 tests annually (5.1.1)	6 months (5.1.2)
Concrete	<1.01	Daily (5.2.1)	6 months; annually after 2 tests (5.2.2.1)	6 months (5.2.3)
Production[A]	1.01 – 1.03		Monthly; 3 months after 4 tests (5.2.2.2)	
	> 1.03		Weekly; monthly after 8 tests (5.2.2.3)	

[A]Testing frequencies apply to the combined mixing water when it is wholly or partially composed of the listed source as defined in Section 3.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this specification since the last issue, C 1602/C 1602M – 05, that may impact the use of this specification. (Approved February 15, 2006)

(*1*) Added new footnote A in Table 2.

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Designation: C 979 – 05

Standard Specification for Pigments for Integrally Colored Concrete[1]

This standard is issued under the fixed designation C 979; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers the basic requirement for colored and white pigments in powder form to be used as admixtures in concrete for the purpose of producing integrally colored concrete. Where the pigments are a constituent of a multicomponent admixture, this specification applies to the pigment constituent of the admixture. This specification is not intended to establish compatibility of pigments with any other concrete admixtures unless they are tested in combination in accordance with 3.7.

1.2 This specification does not include the determination of pigment stability when elevated temperature using low-pressure (atmospheric) or high-pressure (autoclave) steam is used to accelerate the curing process.

1.3 In addition to tests defining the pigments themselves, a limited number of tests on concrete are included to define the effects on setting times, air content, and compressive strength. If more extensive information is required for a particular job, additional testing criteria and procedures should be agreed upon between the seller and user.

1.4 The maximum prescribed dosage rate of a pigment, established in accordance with 3.7, shall be equal to or less than 10 mass % of cement. When a combination of pigments is used to produce the desired color and color intensity, the total dosage rate of all pigments combined shall not exceed any of the individual maximum dosage rates of the component pigments.

1.5 The values stated in SI units are to be regarded as the standard. The inch-pound units in parentheses are for information purposes only.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 33 Specification for Concrete Aggregates

C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 143/C 143M Test Method for Slump of Hydraulic Cement Concrete

C 150 Specification for Portland Cement

C 173 Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C 260 Specification for Air-Entraining Admixtures for Concrete

C 403/C 403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance

D 50 Test Methods for Chemical Analysis of Yellow, Orange, Red, and Brown Pigments Containing Iron and Manganese

D 1208 Test Methods for Common Properties of Certain Pigments

D 1535 Practice for Specifying Color by the Munsell System

G 23 Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[3]

2.2 *ACI Standards:*

211.1 Recommended Practice for Selecting Proportions for Normal and Heavyweight Concrete[4]

3. General Requirements

3.1 *Water Wettability*—The pigment shall be water wettable when tested in accordance with 7.1.

3.2 *Alkali Resistance*—The pigment treated with sodium hydroxide shall not show any significant (Note 1) change of color when tested in accordance with 7.2.

3.3 *Total Sulfates*—Calculated as SO_3, the sulfates shall not exceed 5.0 mass % of the original pigment sample when tested in accordance with 7.3.

3.4 *Water Solubility*—The total matter soluble in water shall not exceed 2.0 mass % of the original pigment sample when tested in accordance with 7.4.

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.23 on Chemical Admixtures.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.

[4] Available from American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331.

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3.5 *Atmospheric Curing Stability*—The magnitude of color differences between pigmented concrete specimens cured in dry air and those cured at high relative humidity when tested in accordance with 7.5 shall not be greater than the magnitude of the color difference between two unpigmented specimens cured under the same conditions.

3.6 *Light Resistance*—The exposed portions of the specimens shall show no significant differences (Note 1) in color from the unexposed portions when tested in accordance with 7.6. While a pigment that fails this test shall not be considered light resistant, a pigment that passes this test may still be subject to fading when exposed to natural weathering conditions.

NOTE 1—A significant difference is defined as one that is readily perceptible by visual observation without close examination. Lighting and viewing conditions as described in Practice D 1535, 6.1, may be used.

3.7 *Effects on Concrete*:

3.7.1 When compared with the control mixture, the concrete that is pigmented at the maximum prescribed dosage rate shall have a 28-day compressive strength of not less than 90 % and a water-cement ratio of not greater than 110 % of that of the control mixture when prepared and tested in accordance with 7.7 (Note 2).

3.7.2 The pigment, when added to a concrete mixture at the maximum prescribed dosage rate, shall neither accelerate the initial or final set by more than 1 h nor retard the initial or final set by more than 1½ h, as compared to the uncolored concrete control mixture when tested in accordance with 7.7 (Note 2).

3.7.3 Using the same quantity of air-entraining admixture, the pigments, when added to a concrete mixture at the maximum prescribed dosage rate, shall not change the air content by more than 1.0 %, as compared to the uncolored control mixture when tested in accordance with 7.7.

NOTE 2—These values include allowance for normal variations in test results. The object of the 90 % compressive-strength requirement is to require a level of performance of the pigmented concrete comparable to that of the reference concrete when tested in accordance with 7.7.

3.8 *Color Match of Shipment*—The color produced by the shipment of pigment shall not be significantly different (Note 1) from the color produced by the standard supplied by the pigment manufacturer when samples of both the shipment and the standard are tested in accordance with 7.8. New concrete specimens containing the standard sample of the particular pigment must be prepared whenever a new shipment is evaluated. This is necessary to eliminate color variations caused by any of the other mortar ingredients, specimen preparation, or curing.

4. Rejection

4.1 The purchaser has the right to reject material that does not conform to the requirements of this specification. Rejection shall be reported to the producer or supplier in writing.

4.2 Individual packages or containers varying more than 5 % from the stated mass may be rejected. If the average weight of 50 packages taken at random is less than that stated, the entire shipment may be rejected.

5. Packaging

5.1 Packages or containers shall be clearly marked as to color designation and the net mass.

5.2 The package or container for the pigment, only when so designated by the manufacturer, shall be added to the concrete batch, provided that it is composed of disintegrating paper or soluble material which, when tested as a unit (pigment and packaging), conforms to all requirements of this specification.

6. Materials for Tests

6.1 *Cement*—For the atmospheric curing stability and the light resistance tests, using white cement is suggested. The cement used in all other tests shall be either a Type I or Type II cement conforming to Specification C 150 or the cement proposed for specific work.

6.2 *Aggregates*—The aggregates used in all tests shall conform to Specification C 33 or shall be the aggregates proposed for specific work. For the atmospheric curing stability and the light resistance tests, clean silica sand shall be used. For both the reference and the pigmented mixtures, the aggregate grading shall be controlled by determining the mass of separate fractions.

6.3 *Admixtures*—If any of the test mixtures contain any admixtures in addition to pigment other than an air-entraining admixture complying with Specification C 260, the pigment shall be considered to comply with this specification only when used in conjunction with such other admixture(s).

7. Test Methods

7.1 *Water Wettability*—Add 10.0 g of the pigment to 150 mL of deionized water in a 250-mL beaker. If the pigment does not readily mix with the water when stirred with a spatula, but instead a substantial portion of the pigment floats on the surface of the water, the pigment is repellent and not water wettable.

7.2 *Alkali Resistance*—Add two 10.0 g-portions of the pigment to separate 250-mL beakers, each containing 150 mL of deionized water. Stir until thoroughly mixed. Add 10 mL of 10 mass % sodium hydroxide solution to one beaker, and stir thoroughly once more. Let the slurries stand 1 h, then remix and filter on separate Buchner funnels. Wash the filter cake with three replacement washes of hot deionized water. Dry the cake on the filter paper in an oven at 110 ± 3 °C (230 ± 5 °F) for 4 ± 0.5 h. Remove from the oven, cool, and crush the pigment into a fine powder in a mortar. Make two small adjacent piles of the pigment powders and press them flat with a spatula. Compare the color of the control and treated pigment powders.

7.3 *Percentage of* SO_3—Perform the sulfates soluble in hydrochloric acid test and determine the percentage in accordance with Test Methods D 50.

7.4 *Water Solubility*—Perform the matter soluble in water test in accordance with Test Methods D 1208.

7.5 *Atmospheric Curing Stability*—The composition and method of preparation of the test specimens shall be in accordance with Annex A1. Pigments shall be tested at both ½ % and 6 % levels (based on the cement mass). Two sets of specimens (designated as control specimens and test specimens) shall be prepared at the same time under identical

conditions except for curing. Each set shall consist of two pigmented mortar specimens, one at each of the two levels of pigmentation, and one unpigmented specimen. If, for a particular pigment being tested, the specimens that contain the pigment at a dosage rate of ½ % of the cement mass do not provide a significant difference (Note 1) in color when compared to the corresponding unpigmented specimen, the pigment dosage rate shall be increased until but not beyond the rate at which the difference in color becomes significant. In addition, tests using the higher dosage rate of 6 % of the cement mass shall continue to be performed as specified. Compare for color the specimens that were cured under different conditions. For evaluating the color stability of the pigment tested, also compare the uncolored mortar specimens for color variations. Differences in the curing conditions or efflorescence, or both, can affect the color shade of any finished mortar or concrete, either colored or uncolored.

7.6 *Light Resistance*—The test shall be conducted in a Type E or EH exposure apparatus as described in Practice G 23. Type EH apparatus shall be operated without automatic humidity control. The exposure apparatus shall be operated in accordance with Practice G 23, except that no water spray or dark cycles shall be employed. The black panel temperature shall be 54± 3 °C (130 ± 5 °F). The composition and method of preparation of the test specimens shall be in accordance with Annex I. Pigments shall be tested at both ½ % (7.5) and 6 % levels (based on the cement mass). Half of each specimen shall be masked from light exposure by an aluminum foil covering. The other half of each specimen shall be exposed to light for 500 h after which time its color shall be compared to the unexposed half (3.6).

7.7 *Effects on Concrete*:

7.7.1 *Preparation of Mixtures*—Prepare concrete mixtures both with and without the pigment under test. Refer herein to the concrete mixture without the pigment as the reference or control mixture. The control mixture and the pigmented mixture shall be of the same composition and batched in the same proportions except that the pigmented mixture shall include the pigment addition at the maximum prescribed dosage rate (1.4), and the water content of each mixture shall be adjusted to produce a slump of 100 ± 13 mm (4 ± ½ in.), as determined by Test Method C 143/C 143M. Add the pigment to the first increment of coarse aggregate and water. The mixture shall be proportioned using ACI Practice 211.1. The cement content shall be either the cement content for specific work or 307 ± 3 kg/m^3(517 ± 5 lb/yd^3). If an air-entraining admixture complying with Specification C 260 is used, its dosage rate shall be the same for both the pigmented and the control mixtures.

7.7.2 *Making and Curing*—Specimens made from concrete with and without the pigment under test shall be molded and cured in accordance with Method C 192/C 192M. Three or more compression specimens shall be prepared for each mixture.

7.7.3 *Time of Setting*—Test Method C 403/C 403M shall be used. The temperature of each of the ingredients of the concrete mixtures, just prior to mixing, and the temperature at which the time of setting specimens are stored during the test period shall be 23.0± 2 °C (73 ± 3 °F).

7.7.4 *Air Content*—Test Methods C 173 or C 231 shall be used.

7.7.5 *Compressive Strength*—Test Method C 39 shall be used. Specimens shall be tested at 28 days and optionally also at 7 days. The 28-day compressive strength of the concrete containing the pigment under test shall be calculated as a percentage of the 28-day compressive strength of the reference concrete as follows: The average 28-day compressive strength of the specimens made from the concrete containing the pigment under test shall be divided by the average 28-day compressive strength of the specimens made from the reference concrete at the same age, and the quotient shall be multiplied by 100.

7.8 *Color Match of Shipment*—Samples of both the shipment of pigment and the standard supplied by the pigment manufacturer shall be prepared in concrete at both the ½ % (7.5) and 6 % levels (based on the cement mass) or at another dosage rate(s) agreed upon between the purchaser and seller. The composition and methods of preparation and color comparison of the specimens should be agreed upon between the purchaser and seller. A suggested method of specimen preparation is given in Annex I. Compare the colors of the concrete specimens. Do not compare the colors of the pigment powders as a test for color control.

8. Report

8.1 The report shall include the following:

8.1.1 The manufacturer, designation, and type of pigment,

8.1.2 Maximum prescribed dosage rate of pigment,

8.1.3 Description of additional admixtures that must be used in the concrete,

8.1.4 Water wettability of pigment,

8.1.5 Resistance to color change when treated with sodium hydroxide,

8.1.6 Percent total sulfates calculated as SO_3,

8.1.7 Percent total water-soluble matter contained in pigment,

8.1.8 Resistance to color change when concrete is cured in a high-relative-humidity atmosphere,

8.1.9 Light resistance of pigment,

8.1.10 Cement content of pigmented and control mixtures,

8.1.11 Water-cement ratios of pigmented and control mixtures and the relative percentage change due to the use of pigment,

8.1.12 Compressive strength (28-day) of pigmented concrete and control and the relative percentage change resulting from the use of pigment,

8.1.13 Initial and final setting times of pigmented and control mixtures and the changes resulting from the use of pigment,

8.1.14 Air contents of pigmented and control mixtures and the change resulting from the use of pigment, and

8.1.15 When individual shipments are tested, a color comparison of each shipment and control.

9. Keywords

9.1 color match; integrally colored concrete; light resistance; pigment

ANNEX

(Mandatory Information)

A1. METHOD FOR PREPARING MORTAR TEST SPECIMENS

A1.1 *Apparatus*:

A1.1.1 *Wooden Mold*, to form specimens approximately 230 mm (9 in.) by 76 mm (3 in.) by 13 mm (½ in.) (Note A1.1). The mold shall be coated with a non-staining coating to prevent water absorption. The mold should be held together with C-clamps for easy removal.

NOTE A1.1—The dimensions may be modified, as long as finished specimen strength is maintained, to suit the individual weatherometer used for the light resistance test.

A1.1.2 *Wooden Tamping Block*, with a working surface area of approximately 50 mm (2 in.) by 100 mm (4 in.)

A1.1.3 *Metal or Ceramic Mixing Vessel*.

A1.1.4 *Stirring Device*, such as a large spoon or spatula.

A1.1.5 *Heated Drying Cabinet*.

A1.2 *Material*:

A1.2.1 *Clean Silica Sand*,

A1.2.2 *White Cement* (Note A1.2), and

A1.2.3 *Pigment to be Tested*.

NOTE A1.2—White cement is suggested to give maximum color discrimination in judging the pigment, but other cement may be used that is representative of the intended use.

A1.3 *Formulation*:

A1.3.1 Prepare the mortar mixtures at both ½ % (7.5) and 6 % pigment levels (based on the cement mass) in accordance with formulas below:

	Control[A]	½ %	6 %
Silica sand	480.0 g	480.0 g	480.0 g
White cement	160.0 g	159.2 g	151.0 g
Pigment	0.0 g	0.8 g	9.0 g
Water[B]	72 mL	72 mL	72 mL

[A]Control specimens are required for the atmospheric curing stability test but not for the light resistance test.

[B]In order to eliminate fluctuations in the moisture content (water/cement ratio) of the fresh and cured mortar specimens, it is advisable to dry the sand at 105 ± 3 °C (221 ± 5 °F) in an oven to constant weight. The amount of water should be adjusted such that a fairly dry, non-bleeding, mortar mix is obtained. However, the water content for all batches of the same mortar mix shall be identical.

A1.4 *Procedure*:

A1.4.1 In sequence, add the sand, cement, and pigment to the mixing vessel and mix thoroughly with the stirring device until the blend is uniform. Add the water and continue to mix until all the ingredients are thoroughly wetted.

A1.4.2 Place the mold on a glass slab, a steel plate, or any other flat, waterproof surface. Slightly overfill the mold with the mortar mixture. Using the wooden block, tamp the mixture firmly and evenly and with a screed, level it to the top of the mold.

A1.4.3 As soon as the mortar has set, loosen the C-clamps and carefully remove the sides of the mold.

A1.4.4 Place the mortar specimen on a table using spacers to permit ambient air to circulate around it, and let it dry in the air at room temperature for 12–24 h.

A1.4.5 Continue the curing process as follows: Transfer each specimen for the light resistance test and each control specimen for the atmospheric curing test to the heated cabinet, and finish curing at 49 ± 3 °C (120 ± 5 °F) for 24 h at 20 ± 10 % relative humidity. Transfer each test specimen for the atmospheric curing stability test to a 100 % relative humidity atmosphere at room temperature (Note A1.3) for at least 20 days, and then dry in the heated cabinet at 49 ± 3 °C (120 ± 5 °F) for 24 h at 20 ± 10 % relative humidity.

NOTE A1.3—A sealed plastic bag can be used for this purpose. Small amounts of water may be injected periodically into the bag to maintain a saturated atmosphere.

APPENDIX

(Nonmandatory Information)

X1. TYPICAL PIGMENT TYPES MANUFACTURED FOR COLORING CONCRETE

X1.1 Typical pigment types manufactured for coloring concrete are as follows:

X1.1.1 Synthetic iron oxides, yellows, red, browns, and black,

X1.1.2 Some natural iron oxides,

X1.1.3 Chromium oxide,

X1.1.4 Cobalt blue,

X1.1.5 Titanium dioxide, and

X1.1.6 Carbon black (concrete grade).

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Designation: C 1116 – 03

Standard Specification for Fiber-Reinforced Concrete and Shotcrete[1]

This standard is issued under the fixed designation C 1116; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification covers all forms of fiber-reinforced concrete that are delivered to a purchaser with the ingredients uniformly mixed, and that can be sampled and tested at the point of delivery. It does not cover the placement, consolidation, curing, or protection of the fiber-reinforced concrete after delivery to the purchaser.

1.2 Certain sections of this specification are also applicable to fiber-reinforced concrete intended for shotcreting by the dry-mix process when sampling and testing of concrete is possible only at the point of placement. In this case, the sections dealing with batching plant, mixing equipment, mixing and delivery, and measurement of workability and air content, are not applicable.

1.3 This specification does not cover thin-section glass fiber-reinforced concrete manufactured by the spray-up process that is under the jurisdiction of ASTM Subcommittee C27.40.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 The following precautionary statement pertains only to the test method portion, Sections 15 and 18, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 820 Specification for Steel Fibers for Fiber-Reinforced Concrete[2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field[3]

C 33 Specification for Concrete Aggregates[3]

C 39/C 39M Test Method for Strength of Cylindrical Concrete Specimens[3]

C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[3]

C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)[3]

C 94/C 94M Specification for Ready-Mixed Concrete[3]

C 109/C 109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)[4]

C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete[3]

C 143/C 143M Test Method for Slump of Hydraulic Cement Concrete[3]

C 150 Specification for Portland Cement[4]

C 172 Practice for Sampling Freshly Mixed Concrete[3]

C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[3]

C 191 Test Method for Time of Setting of Hydraulic Cement by Vicat Needle[4]

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory[3]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[3]

C 260 Specification for Air-Entraining Admixtures for Concrete[3]

C 330 Specification for Lightweight Aggregates for Structural Concrete[3]

C 387 Specification for Packaged, Dry, Combined Materials for Mortar and Concrete[3]

C 494/C 494M Specification for Chemical Admixtures for Concrete[3]

C 567 Test Method for Determining Density of Structural Lightweight Concrete[3]

C 595 Specification for Blended Hydraulic Cements[4]

C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete[3]

C 637 Specification for Aggregates for Radiation-Shielding Concrete[3]

C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing[3]

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.42 on Fiber-Reinforced Concrete.

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[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.01.

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

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C 684 Test Method for Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens[3]
C 685/C 685M Specification for Concrete Made by Volumetric Batching and Continuous Mixing[3]
C 887 Specification for Packaged, Dry, Combined Materials for Surface Bonding Mortar[5]
C 995 Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump Cone[3]
C 1017/C 1017M Specification for Chemical Admixtures for Use in Producing Flowing Concrete[3]
C 1018 Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)[3]
C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[3]
C 1141 Specification for Admixtures for Shotcrete[3]
C 1240 Specification for Silica Fume for Use in Hydraulic-Cement Concrete, Mortar, and Grout[3]
C 1399 Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete[3]
D 512 Test Methods for Chloride Ion in Water[6]
D 516 Test Methods for Sulfate Ion in Water[6]
2.2 *ACI Standards and Reports:*
211.1 Standard Practice for Selecting Proportions for Normal and Heavyweight Concrete[7]
211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete[7]
214 Recommended Practice for Evaluation of Strength Test Results of Concrete[7]
506.1R, State-of-the-Art Report on Fiber-Reinforced Shotcrete[7]
506.2 Specification for Materials, Proportioning and Application of Shotcrete[7]
506.R, Guide for Shotcreting[7]
544.3R Guide for Specifying, Mixing, Placing and Finishing Steel Fiber-Reinforced Concrete[7]
2.3 *AASHTO Standard:*
T26 Test Method for Solids Content of Wash Water[8]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *fibers*—slender and elongated filaments in the form of bundles, networks, or strands of any natural or manufactured material that can be distributed throughout freshly mixed concrete.

3.1.2 *manufacturer*—the contractor, subcontractor, supplier, or producer who furnishes the fiber-reinforced concrete.

3.1.3 *purchaser*—the owner or representative thereof.

4. Classification

4.1 This specification classifies fiber-reinforced concrete or shotcrete by the material type of the fiber incorporated. The performance of a fiber-reinforced concrete or shotcrete depends strongly upon the susceptibility of the fibers to physical damage during the mixing or shotcreting process, their chemical compatibility with the normally alkaline environment within cement paste, and their resistance to service conditions encountered within uncracked concrete or as a consequence of cracking, involving, for example, carbon dioxide, chlorides, or sulphates in solution with water and oxygen or ultraviolet light in the atmosphere. The magnitude of improvements in the mechanical properties of the concrete or shotcrete imparted by fibers also reflects the material characteristics of the fiber type with fibers having a high modulus of elasticity and tensile strength being more effective on an equivalent volume basis than fibers of low modulus and strength.

4.1.1 *Type I Steel Fiber-Reinforced Concrete or Shotcrete*—Contains stainless steel, alloy steel, or carbon steel fibers (see Note 1).

NOTE 1—Steel fibers are not easily damaged by the mixing or shotcreting processes and uncoated steel fibers are chemically compatible with the normally alkaline environment within cement paste. Some coatings, such as aluminum, may be detrimental to concrete. Carbon steel fibers will rust under conditions that cause rusting of conventional steel, for example, in the near-surface portion of concrete subject to carbonation.

4.1.2 *Type II Glass Fiber-Reinforced Concrete or Shotcrete*—Contains alkali-resistant glass fibers (see Note 2).

NOTE 2—Glass fibers in concrete or shotcrete subjected to wetting, humid atmosphere, or contact with moist ground have the potential to react with the alkalies present in cement paste thereby weakening the fibers. They also tend to become embrittled by hydration products penetrating the fiber bundles and filling the interstitial spaces between the individual glass filaments. Both mechanisms cause reductions in strength, toughness, and impact resistance with age. The alkali-resistant (AR) types of glass fiber developed for use with cement are more resistant to alkalies than the E-glass and other types not marketed specifically for use in cement, and should be used in conjunction with established techniques for suppressing the alkali-silica reaction, for example, use of a low-alkali cement or a mineral admixture, or both. However, even the use of AR-glass fibers does not prevent deterioration in glass fiber-reinforced concrete exposed to moisture for a long period of time, but only slows the rate at which it occurs.

Glass fibers can be damaged by conventional concrete mixing processes employing coarse aggregate, but have been used in shotcrete and in other cementitious matrices such as mechanically mixed masonry mortar (see Specification C 887) and thin-section glass fiber-reinforced concrete prepared by the spray-up process (under the jurisdiction of ASTM Subcommittee C27.40).

4.1.3 *Type III Synthetic Fiber-Reinforced Concrete or Shotcrete*—Contains synthetic fibers for which documentary evidence can be produced confirming their long-term resistance to deterioration when in contact with the moisture and alkalies present in cement paste or the substances present in air-entraining and chemical admixtures (see Note 3 and 4.2).

NOTE 3—Fibers composed of some polymers may deteriorate when in contact with moisture, alkalies, or some of the ingredients of chemical admixtures. Fibers such as polyolefins (polypropylene and polyethylene), nylon, and carbon have been shown to be durable in concrete.

4.2 When the purchaser chooses to permit the use of fibers other than those complying with the classifications in 4.1, for example: natural fibers, metallic fibers other than steel, carbon

[5] *Annual Book of ASTM Standards*, Vol 04.05.
[6] *Annual Book of ASTM Standards*, Vol 11.01.
[7] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.
[8] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

fibers, and so forth, the producer shall show evidence satisfactory to the purchaser that the type of fiber proposed for use does not react adversely with the concrete or shotcrete matrix, including the constituents of any admixtures present, or with the surrounding environment in the cracked matrix, causing deterioration in mechanical properties with age under the exposure conditions anticipated in the application.

5. Basis of Purchase

5.1 The basis of purchase for conventionally mixed fiber-reinforced concrete shall be the cubic yard or cubic metre of freshly mixed and unhardened material as discharged from the mixer.

5.2 The volume of freshly mixed and unhardened material in a given batch shall be determined from the total weight of the batch divided by the unit weight in pounds per cubic foot or kilograms per cubic metre. The total weight of the batch shall be calculated either as the sum of the weights of all materials, including water, entering the batch, or as the net weight of the concrete in the batch as delivered. The unit weight shall be determined in accordance with Test Methods C 138/C 138M or C 567 from the average of at least three measurements, each on a different sample. Sampling shall be in accordance with Practice C 172.

NOTE 4—It should be understood that the volume of hardened concrete may be, or may appear to be, less than expected due to waste and spillage, over-excavation, spreading forms, some loss of entrained air, or settlement of wet mixtures, none of which are the responsibility of the manufacturer.

5.3 The basis of purchase for fiber-reinforced shotcrete shall normally be the cubic yard or cubic metre. For wet-mix shotcrete, the volume shall be calculated from the quantities delivered and the unit weight. For dry-mix shotcrete, the volume shall be calculated from the weights of constituent materials mixed and their respective specific gravities. At the option of the purchaser, where the surface to be shotcreted is plane and a uniform finished thickness of shotcrete is specified, the basis of purchase shall be the square yard or square metre.

6. Ordering Information

6.1 The purchaser shall specify the following:

6.1.1 Type of fiber-reinforced concrete or shotcrete required. See Section 4.

6.1.2 Type of cement at the purchaser's option, otherwise the cement shall be Type 1 meeting the requirements of Specification C 150;

6.1.3 Designated size, or sizes, of coarse aggregates;

6.1.4 Slump or time of flow required at the point of delivery, or when appropriate the point of placement, subject to the tolerances hereinafter specified;

6.1.4.1 Slump shall be specified when it is anticipated to be 2 in. (50 mm) or more, and time of flow shall be specified when slump is anticipated to be less than 2 in. (50 mm). Slump or time of flow shall not be specified for shotcrete placed by the dry process.

NOTE 5—The time of flow of fiber-reinforced concrete through an inverted slump cone, determined in accordance with Test Method C 995, is a better indicator than slump (Test Method C 143/C 143M) of the appropriate level of workability for fiber-reinforced concrete placed by vibration because such concrete can exhibit very low slump due to the presence of fibers and still be easily consolidated. Mixtures with a time of flow of 8 to 15 s are readily consolidated by vibration. Consolidation becomes more difficult with increase in time of flow, and is extremely difficult even when using internal vibration if the time of flow exceeds 30 s. Mixtures with a time of flow less than 8 s should be evaluated in terms of slump because the time of flow is too short to determine with satisfactory precision, or may not be determinable because the fiber-reinforced concrete flows freely through the inverted cone.

6.1.5 Air content when air-entrainment is required, based on the air content of samples taken at the point of discharge, or when appropriate the point of placement, subject to the tolerances hereinafter specified;

6.1.5.1 Air-entrainment shall not be specified for shotcrete placed by the dry process.

NOTE 6—In selecting the specified air content, the purchaser should consider the exposure conditions to which the concrete will be subjected. Air contents less than shown in Table 1 may not produce adequate resistance to freezing and thawing. Air contents higher than the levels shown may reduce strength without contributing further to freeze-thaw resistance.

6.1.6 When structural lightweight concrete is specified, the purchaser shall specify the unit weight as wet weight, air-dry weight, or oven-dry weight.

NOTE 7—The unit weight of freshly mixed lightweight concrete, that is the only unit weight determinable at the time of delivery, is always higher than the air-dry or oven-dry weight. Definitions of, and methods for determining or calculating air-dry and oven-dry weights of lightweight concrete are covered in Test Method C 567.

6.1.7 One of the following Alternatives, 1, 2, or 3, shall be used as the basis for determining the proportions of the fiber-reinforced concrete or fiber-reinforced shotcrete of the quality required.

6.2 *Alternative Number 1*:

6.2.1 When the purchaser assumes responsibility for mixture proportioning, the following parameters shall also be specified by the purchaser:

6.2.1.1 The cement content in pounds per cubic yard (or kilograms per cubic metre),

TABLE 1 Recommended Total Air Content for Air-Entrained Concrete[A,B]

Exposure Condition[C]	Total Air Content, %						
	Nominal Maximum Sizes of Aggregate, in. (mm)						
	⅜ (9.5)	½ (12.5)	¾ (19.0)	1 (25.0)	1½ (37.5)	2 (50.0)	3 (75.0)
Mild	4.5	4.0	3.5	3.0	2.5	2.0	1.5
Moderate	6.0	5.5	5.0	4.5	4.5	4.0	3.5
Severe	7.5	7.0	6.0	6.0	5.5	5.0	4.5

[A] For air-entrained concrete, when specified.

[B] Unless exposure conditions dictate otherwise, air contents recommended above may be reduced by up to 1 % for concretes with specified compressive strength, f_c, of 5000 psi (34.5 MPa) or above.

[C] For description of exposure conditions, refer to ACI 211.1, Table number 5.3.3 with attention to accompanying footnotes.

6.2.1.2 If mineral admixtures are required, the type, and amounts to be used in pounds per cubic yard (or kilograms per cubic metre), or in percentages by weight of cement,

6.2.1.3 The maximum allowable amount of mixing water in gallons per cubic yard or litres per cubic metre, including surface moisture on the aggregates, but excluding water absorbed by the aggregate,

6.2.1.4 If air-entraining admixtures are required, the type, name, and dosage range to be used to achieve the specified air content, (see 6.1.4),

6.2.1.5 If chemical admixtures are required, the type, name, and dosage range to be used, and:

6.2.1.6 The type of fibers to be used and the amount in pounds per cubic yard (or kilograms per cubic metre), (see Classification Section 4).

NOTE 8—The dosage of air-entraining, water-reducing (including high-range), accelerating, and retarding admixtures needed to satisfy the material performance requirements varies. Therefore, dosage ranges should be specified to ensure that the material performance requirements can be met.

NOTE 9—The purchaser, in selecting requirements for which he assumes responsibility should give consideration to requirements for workability, placeability, durability, surface texture, and density. The purchaser is referred to ACI Practices 211.1 and 211.2 for selecting proportions that will result in concrete suitable for various types of structures and conditions of exposure, and to ACI Report 544.3R for selecting concrete and fiber parameters suitable for fiber-reinforced concrete. For guidance on selecting proportions for fiber-reinforced shotcrete, the purchaser is referred to ACI Reports 506.1R and 506.R and ACI Specification 506.2.

6.2.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of concrete, furnish a statement to the purchaser giving the sources, specific gravities, sieve analyses, and saturated surface-dry weights of fine and coarse aggregates, and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser.

6.3 *Alternative Number 2*:

6.3.1 When the purchaser requires the manufacturer to assume full responsibility for mixture proportioning (see Note 9), the purchaser shall also specify the following:

6.3.1.1 Requirements for flexural toughness parameters, or first-crack strength, or both, determined in accordance with Test Method C 1018, or requirements for average residual-strength determined in accordance with Test Method C 1399, or, at the option of the purchaser, for flexural strength determined in accordance with Test Method C 78, using samples obtained at the point of discharge, or when appropriate at the point of placement. At the option of the purchaser, compressive strength (Test Method C 39/C 39M) shall be specified when the flexural requirements are considered inadequate for ensuring the quality of the matrix of the fiber-reinforced concrete. Unless accelerated curing and testing in accordance with the warm water or boiling water procedures of Test Method C 684 is specified, tests shall be performed after standard moist curing in accordance with Practices C 31/C 31M or C 192/C 192M at 28 days, or such other ages as are specified by the purchaser.

NOTE 10—While first-crack strength is affected by the type and amount of fibers, it is more dependent on the characteristics of the mortar or concrete matrix, so it is recommended that the purchaser, when specifying first-crack strength, consider factors known to influence the strength of normal concrete such as, water-cement ratio, aggregate maximum size, and the presence of chemical or mineral admixtures.

6.3.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of concrete, furnish a statement to the purchaser giving the sources, specific gravities, sieve analyses, and saturated surface-dry weights of fine and coarse aggregates, the dry weights of cement and mineral admixtures, the type, dimensions, and weight of fibers, the quantities, types and names of chemical and air-entraining admixtures (if any), and the amount of mixing water per cubic yard or cubic metre that will be used in the manufacture of each class of concrete ordered by the purchaser. The manufacturer shall also furnish evidence satisfactory to the purchaser that the materials to be used and the proportions selected will produce fiber-reinforced concrete or shotcrete of the quality specified.

6.4 *Alternative Number 3*:

6.4.1 When the purchaser requires the manufacturer to assume responsibility for mixture proportioning with the minimum allowable cement content specified (see Note 9), the purchaser shall also specify the following:

6.4.1.1 Requirements for flexural toughness, parameters, or first-crack strength, or both, determined in accordance with Test Method C 1018, or requirements for average residual-strength determined in accordance with Test Method C 1399 , or, at the option of the purchaser, for flexural strength determined in accordance with Test Method C 78, using samples obtained at the point of discharge, or when appropriate the point of placement. At the option of the purchaser, compressive strength (Test Method C 39/C 39M) shall be specified when the flexural requirements are considered inadequate for ensuring the quality of the matrix of the fiber-reinforced concrete. Unless accelerated curing and testing in accordance with the warm water or boiling water procedures of Test Method C 684 is specified, tests shall be performed after standard moist curing in accordance with Practices C 31/C 31M or C 192/C 192M at 28 days, or such other ages as are specified by the purchaser (see Note 10).

6.4.1.2 Minimum cement content in pounds per cubic yard (or kilograms per cubic metre).

6.4.1.3 If admixtures are required, the type, name, and dosage to be used. The cement content shall not be reduced when admixtures are used.

NOTE 11—Alternative Number 3 can be distinctive and useful only if the designated minimum cement content is at about the same level that would ordinarily be required for the mechanical properties, aggregate size, and workability specified. It must be an amount that will be sufficient to ensure durability under expected service conditions, as well as satisfactory surface texture and density. For additional information refer to ACI Practices 211.1 and 211.2.

6.4.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser giving the sources, specific gravities, sieve analyses and saturated surface-dry weights of fine and coarse aggregates, the dry weights of cement and mineral admixtures, the type, dimensions, and weight of fibers, the quantities, types and names of chemical and air-entraining admixtures (if any), and the amount of mixing water per cubic yard or cubic metre

that will be used in the manufacture of each class of concrete ordered by the purchaser. The manufacturer shall also furnish evidence satisfactory to the purchaser that the materials to be used and the proportions selected will produce fiber-reinforced concrete or shotcrete of the quality specified.

6.5 The proportions arrived at by Alternatives 1, 2, or 3 for each class of fiber-reinforced concrete or shotcrete approved for use in a project shall be assigned a designation to facilitate identification of each mixture delivered to the project. A certified copy of the proportions of all mixtures as established in Alternatives 1, 2, and 3 shall be kept on file by the manufacturer.

7. Materials and Manufacture

7.1 In the absence of designated applicable specifications covering requirements for quality of materials, the following specifications shall govern:

7.1.1 *Cement*—Cement shall conform to Specification C 150 or C 595.

7.1.2 *Aggregates*—Aggregates shall conform to Specifications C 33, C 330, or C 637 consistent with the type of concrete required.

7.1.3 *Water*:

7.1.3.1 The mixing water shall be clear and apparently clean. If it contains quantities of substances that discolor it or make it smell or taste unusual or objectionable or cause suspicion, it shall not be used unless service records of concrete made with it or other information indicates that it is not injurious to the quality of the concrete. Water of questionable quality shall be subject to the acceptance criteria of Table 2.

7.1.3.2 Wash water from mixer washout operations may be used as mixing water provided tests of wash water comply with the physical tests of Table 2. Wash water shall be tested at a weekly interval for approximately 4 weeks, and thereafter at a monthly interval provided that no single test exceeds the applicable limit. Optional chemical requirements in accordance with Table 3 may be specified by the purchaser when appropriate for the construction. The testing frequency for chemical limits shall be as given above unless otherwise specified by the purchaser.

NOTE 12—When recycled wash water is used, attention should be given to effects on the dosage rate and batching sequence of air-entraining and other chemical admixtures, and a uniform amount should be used in consecutive batches.

7.1.4 *Admixtures*—Admixtures for conventionally mixed fiber-reinforced concrete shall conform to Specifications C 260, C 618, C 494/C 494M, C 1017/C 1017M, C 1141, or C 1240, whichever is applicable.

TABLE 2 Acceptance Criteria for Questionable Water Suppliers

	Limits	Test Method
Compressive strength, min % control at 7 days	90	C 109/C 109M[A]
Time of set, deviation from control, h: min	from 1.00 early to 1.30 later	C 191[A]

[A] Comparisons shall be based on fixed proportions and the same volume of test water compared to control mix using city water or distilled water.

TABLE 3 Chemical Limitations for Wash Water Used as Mixing Water

	Limits	Test Method[A]
Chemical requirements, maximum concentration in mixing water, ppm[B]		
Chloride as Cl ppm:		D 512
Prestressed concrete or in bridge decks	500[C]	
Other reinforced concrete in most environments or containing aluminum embedments or dissimilar metals or with stay-in-place galvanized metal forms	1000[C]	
Sulfate as SO_4, ppm	3000	D 516
Alkalies as (Na_2O + 0.658 K_2O), ppm	600	
Total solids, ppm	50 000	AASHTO T26

[A] Other test methods that have been demonstrated to yield comparable results may be used.

[B] Wash water reused as mixing water in concrete may exceed the listed concentrations of chloride and sulfate if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregates and other sources, does not exceed the stated limits.

[C] For conditions allowing use of $CaCl_2$ accelerator as an admixture, the chloride limitation may be waived by the purchaser.

7.1.5 *Fibers*—Fibers shall be capable of producing fiber-reinforced concrete meeting the requirements of this specification. Steel fibers shall conform to Specification A 820.

8. Measuring Materials

8.1 Except as otherwise specifically permitted by the purchaser, cement, pozzolans, fine and coarse aggregates, mixing water, and admixtures shall be measured in accordance with the applicable requirements of Specification C 94/C 94M or C 685/C 685M.

8.2 Fibers shall be measured by weight. When approved by the purchaser, fibers may be measured in bags, boxes, or like containers. Such bags, boxes, or containers shall be sealed by the fiber manufacturer and shall have the weight contained therein clearly marked. No fraction of an unsealed bag, box or like container delivered unsealed, or left over from previous work, shall be used unless weighed.

8.3 Prepackaged, dry, combined materials, including fibers, shall comply with the packaging and marking requirements of Specification C 387 and shall be accepted for use provided that after addition of water, the resulting fiber-reinforced concrete or shotcrete meets the performance requirements of this specification.

9. Batching Plant

9.1 Batching plant used for the preparation of batch-mixed fiber-reinforced concrete shall comply with the applicable requirements of Specification C 94/C 94M.

NOTE 13—A vibrating screen or other device for separating fibers may be required to avoid clumping of some types of fibers prior to mixing with concrete.

10. Mixing Equipment

10.1 Mixers or agitators for batch-mixed fiber-reinforced concrete shall comply with the applicable requirements of Specification C 94/C 94M.

10.2 Mixers for continuously mixed fiber-reinforced concrete shall comply with the applicable provisions of Specification C 685/C 685M.

11. Mixing and Delivery

11.1 Batch-mixed fiber-reinforced concrete, whether prepared on site or at a location remote from the site, shall be mixed and delivered to the point designated by the purchaser in accordance with the applicable requirements of Specification C 94/C 94M.

11.2 Continuously mixed fiber-reinforced concrete, whether prepared on site or at a location remote from the site, shall be mixed and delivered to the point designated by the purchaser in accordance with the applicable requirements of Specification C 685/C 685M.

11.3 Fiber-reinforced concrete shall be free of fiber balls when delivered.

12. Batch Ticket Information

12.1 The manufacturer of the fiber-reinforced concrete shall furnish to the purchaser a delivery ticket or statement of particulars on which is printed, stamped, or written, information in one of the following two alternative formats:

12.1.1 *Batch-Mixing Format*—The details identified in the applicable requirements of Specification C 94/C 94M, and details of the type, brand, and amount of fibers used.

12.1.2 *Continuous Mixing Format*—The details identified in the applicable requirements of Specification C 685/C 685M, and details of the type, brand, and amount of fibers used.

13. Inspection of Materials, Production, and Delivery

13.1 The manufacturer shall afford the inspector all reasonable access, without charge, for making necessary checks of the production facilities and for securing necessary samples to determine if the materials used in the fiber-reinforced concrete or shotcrete comply with the requirements of this specification. Inspection, sampling, and testing shall not interfere unnecessarily with the manufacturing and delivery operations.

14. Sampling

14.1 The contractor shall afford the inspector all reasonable access, without charge, for the procurement of samples of freshly mixed fiber-reinforced concrete or shotcrete at the time of placement to determine compliance with the requirements of this specification.

14.2 Samples of batch-mixed fiber-reinforced concrete shall be obtained in accordance with Practice C 172, except that wet-sieving shall not be permitted. Sampling for uniformity tests shall be in accordance with Specification C 94/C 94M.

14.3 Samples of continuously mixed fiber-reinforced concrete shall be obtained in accordance with the applicable requirements of Specification C 685/C 685M, except that wet-sieving shall not be permitted. Sampling for uniformity tests shall be in accordance with Specification C 685/C 685M.

15. Workability and Air Content Tests

15.1 Make tests for workability and air content at the time of placement at the option of the inspector as often as necessary for control checks and acceptance purposes, and always when specimens for tests on hardened concrete are made. When water is added in accordance with the requirements of this specification (see Tolerances in Workability Section16), repeat all tests, and use the results of the second set of tests to establish whether or not the requirements of this specification are met.

15.2 If the measured slump, time of flow, or air content fall outside the limits permitted by this specification, make a check test immediately on another portion of the same sample. If the results again fall outside the permitted limits, the material represented by the sample fails to meet the requirements of this specification.

16. Tolerances in Workability

16.1 Unless other tolerances are included in the project specifications, the following shall apply to all forms of fiber-reinforced concrete except dry-mix shotcrete.

16.1.1 When the project specifications for slump are written as a "maximum" or "not to exceed" requirement:

	Specified Slump	
	If 3 in. (75 mm) or less	If more than 3 in. (75 mm)
Plus Tolerance	0	0
Minus Tolerance	1½ in. (40 mm)	2½ in. (65 mm)

When the project specifications for time of flow are written as a "minimum" or "not less than" requirement:

	Specified Time of Flow	
	If 15 s or less	If more than 15 s
Plus Tolerance	5 s	10 s
Minus Tolerance	0 s	0 s

These tolerances apply only if one addition of water is permitted on the job provided such addition does not increase the water-cement ratio above the maximum permitted by the project specifications.

NOTE 14—The slump of a fiber-reinforced concrete is less than the slump of an otherwise identical concrete without fibers. The magnitude of the difference depends strongly on the amount and type of fibers, so it is recommended that trial mixtures representing the amount and type of fibers to be used in the work be prepared and tested to ensure that the specified slump requirements are met. This recommendation is also appropriate when workability is specified in terms of time of flow.

16.1.2 When the project specifications for slump are not written as a "maximum" or "not to exceed" requirement:

Tolerances for Nominal Slumps

For Specified Slump of	Tolerance
2 in. (50 mm) and less	±½ in. (15 mm)
2 to 4 in. (50 to 100 mm)	±1 in. (25 mm)
more than 4 in. (100 mm)	±1½ in. (40 mm)

When the project specifications for time of flow are not written as a "minimum" or "not less than" requirement:

Tolerances for Time of Flow

For Specified Time of Flow of	Tolerance
8 to 15 s	±3 s
more than 15 s	±5 s

16.2 Fiber-reinforced concrete shall be available within the permissible range of slump or time of flow for a period of 30 min starting either on arrival at the job site or after the permitted slump adjustment, whichever is later. The first and last ¼ yd^3 or ¼ m^3 discharged a re exempt from this requirement. If the user is unprepared for discharge of the

material at the job site, the manufacturer shall not be responsible for failure to meet slump or time of flow requirements after 30 min have elapsed beyond either the actual arrival time at the job site or the requested delivery time, whichever is later.

17. Tolerance in Air Content

17.1 When air-entrainment is specified, the total air content measured using Test Method C 173/C 173M or Test Method C 231 shall be within a tolerance of ±1.5 of the specified value in percent.

18. Acceptance Testing of Hardened Fiber-Reinforced Concrete or Shotcrete

18.1 Obtain material for the preparation of test specimens in accordance with the sampling section of this specification.

18.2 When flexural toughness parameters, or first-crack strength, or both, or average residual-strength, are used as the basis for acceptance of fiber-reinforced concrete or shotcrete, make, condition, and test sets of test specimens in accordance with Test Method C 1018 or Test Method C 1399 as appropriate.

18.3 When flexural strength is used as the basis for acceptance, make sets of at least three test specimens in accordance with the requirements for sampling and conditioning given in Test Method C 1018, and test in accordance with the applicable requirements of Test Methods C 42/C 42M or C 78. Test specimens representing thin sections, as defined in Test Method C 1018, or specimens representing fiber-reinforced shotcrete of any thickness, shall be tested as cast or placed without being turned on their sides before placement on the support system. Acceptance shall not be based on flexural strength alone when toughness is important.

NOTE 15—Test Method C 1018 provides for the determination of flexural strength when required by the purchaser. For many type-amount fiber combinations, the flexural strength is not significantly greater than the first-crack strength.

18.4 When compressive strength is used as part of the basis for acceptance of fiber-reinforced concrete, make sets of at least two test specimens in accordance with the applicable requirements of Practices C 31/C 31M and C 192/C 192M and condition and test in accordance with Test Methods C 39/C 39M or C 42/C 42M. Acceptance shall not be based on compressive strength alone.

18.5 The testing laboratory performing acceptance tests shall comply with the requirements of Practice C 1077.

19. Frequency of Tests

19.1 The frequency of tests on hardened fiber-reinforced concrete or shotcrete shall be in accordance with the following requirements:

19.1.1 *Batch-Mixing*—Tests shall be made with a frequency of not less than one test for each 150 yd^3 (115 m^3). Each test shall be made from a separate batch. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

19.1.2 *Continuous Mixing*—Tests shall be made for each 25 yd^3 (19 m^3) or fraction thereof, or whenever significant changes have been made in the proportioning controls. On each day fiber-reinforced concrete is mixed, at least one test shall be made for each class of material.

19.1.3 *Shotcrete*—Tests shall be made for each 50 yd^3 (38 m^3) placed using specimens sawed or cored from the structure or from corresponding test panels. On each day fiber-reinforced shotcrete is prepared, at least one test shall be made for each class of material.

19.2 The representative of the purchaser shall ascertain and record the delivery-ticket number or equivalent information and the exact location in the work at which the material represented by each test is deposited.

20. Calculation of Test Results

20.1 A test result shall be based on the mean of the property values for a set of hardened concrete test specimens constituting a test unit as defined herein or in the applicable test method.

20.2 Any individual test specimen in a set constituting a test unit, as defined herein or in the applicable test method, shall be deemed defective and discarded if it shows definite evidence of improper sampling, molding, handling, curing, or testing, and the mean of the property values for the remaining test specimens shall be considered the test result. If more than one specimen in the set is deemed defective on this basis, the test result shall be rejected.

21. Performance Requirements

21.1 Unless specifically excluded by the purchaser when ordering material in accordance with Alternatives Number 2 or 3, fiber-reinforced concrete or shotcrete prepared in accordance with this specification shall meet the following requirements:

21.2 For flexural toughness parameters defined in accordance with Test Method C 1018, or for average residual-strength values defined in accordance with Test Method C 1399, the test results shall equal or exceed the specified values at the applicable test age.

NOTE 16—A toughness requirement should not be specified when fibers are used only to control plastic shrinkage cracking.

21.3 When first-crack strength, flexural strength, or compressive strength are performance requirements, the test results shall equal or exceed the specified values at the applicable test age.

21.4 When the fiber-reinforced concrete is to be exposed to cycles of freezing and thawing, and the purchaser requires evidence of satisfactory durability, such evidence shall be provided by the manufacturer. A proven record of satisfactory freeze-thaw durability for concrete with or without fibers, made using the same air content, aggregates, and mixture proportions as the fiber-reinforced concrete specified for the work, shall be considered acceptable evidence when the concrete has been in place for at least two winters. In the absence of such a record, satisfactory durability shall be demonstrated for the fiber-reinforced concrete proposed for the work by the attainment of an average durability factor of at least 80 % for a set of three specimens tested according to Procedure A of Test Method C 666.

22. Failure to Meet Requirements

22.1 When fiber-reinforced concrete or shotcrete fails to meet the requirements of this specification, the manufacturer

and the purchaser shall confer to determine whether agreement can be reached as to what adjustment, if any shall be made. If agreement on a mutually satisfactory adjustment cannot be reached by the manufacturer and the purchaser, a decision shall be made by a panel of three qualified engineers, one of whom shall be designated by the purchaser, one by the manufacturer, and the third chosen by these two members of the panel. The question of responsibility for the cost of such arbitration shall be determined by the panel. Its decision shall be binding, except as modified by a court decision.

23. Keywords

23.1 accuracy; average residual-strength; certification; fibers; fiber-reinforced concrete; materials for; scales; testing; toughness

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to the standard since the last issue (C 1116 – 02) that impact the use of this standard.

(1) Revised 6.1.3 to provide for size of coarse aggregate required.

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Designation: C 94/C 94M – 05

Standard Specification for Ready-Mixed Concrete[1]

This standard is issued under the fixed designation C 94/C 94M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers ready-mixed concrete manufactured and delivered to a purchaser in a freshly mixed and unhardened state as hereinafter specified. Requirements for quality of concrete shall be either as hereinafter specified or as specified by the purchaser. In any case where the requirements of the purchaser differ from these in this specification, the purchaser's specification shall govern. This specification does not cover the placement, consolidation, curing, or protection of the concrete after delivery to the purchaser.

1.2 The values stated in either SI units, shown in brackets, or inch-pound units are to be regarded separately as standard. The values stated in each system may not be 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 As used throughout this specification the manufacturer shall be the contractor, subcontractor, supplier, or producer who furnishes the ready-mixed concrete. The purchaser shall be the owner or representative thereof.

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field
C 33 Specification for Concrete Aggregates
C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 125 Terminology Relating to Concrete and Concrete Aggregates
C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C 143/C 143M Test Method for Slump of Hydraulic-Cement Concrete
C 150 Specification for Portland Cement
C 172 Practice for Sampling Freshly Mixed Concrete
C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C 260 Specification for Air-Entraining Admixtures for Concrete
C 330 Specification for Lightweight Aggregates for Structural Concrete
C 494/C 494M Specification for Chemical Admixtures for Concrete
C 567 Test Method for Determining Density of Structural Lightweight Concrete
C 595 Specification for Blended Hydraulic Cements
C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C 637 Specification for Aggregates for Radiation-Shielding Concrete
C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
C 1017/C 1017M Specification for Chemical Admixtures for Use in Producing Flowing Concrete
C 1064/C 1064M Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
C 1157 Performance Specification for Hydraulic Cement
C 1602/C 1602M Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

2.2 *ACI Documents:*[3]

CP-1 Technician Workbook for ACI Certification of Concrete Field Testing Technician–Grade I
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.40 on Ready-Mixed Concrete.

Current edition approved Dec. 15, 2005. Published January 2006. Originally approved in 1933. Last previous edition approved in 2004 as C 94/C 94M–04a.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331.

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211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete
301 Standard Specifications for Structural Concrete
305R Hot Weather Concreting
306R Cold Weather Concreting
318 Building Code Requirements for Structural Concrete and Commentary

2.3 *Other Documents:*

Bureau of Reclamation Concrete Manual [4]

3. Terminology

3.1 *Definitions*:

The terms used in this specification are defined in Terminology C 125.

4. Basis of Purchase

4.1 The basis of purchase shall be the cubic yard or cubic metre of freshly mixed and unhardened concrete as discharged from the transportation unit.

4.2 The volume of freshly mixed and unhardened concrete in a given batch shall be determined from the total mass of the batch divided by the density of the concrete. The total mass of the batch shall be determined as the net mass of the concrete in the batch as delivered, including the total mixing water as defined in 9.3. The density shall be determined in accordance with Test Method C 138/C 138M. The yield shall be determined as the average of at least three measurements, one from each of three different transportation units sampled in accordance with Practice C 172.

NOTE 1—It should be understood that the volume of hardened concrete may be, or appear to be, less than expected due to waste and spillage, over-excavation, spreading forms, some loss of entrained air, or settlement of wet mixtures, none of which are the responsibility of the producer.

5. Ordering Information

5.1 In the absence of designated applicable general specifications, the purchaser shall specify the following:

5.1.1 Designated size, or sizes, of coarse aggregate,

5.1.2 Slump, or slumps, desired at the point of delivery (see Section 7 for acceptable tolerances),

5.1.3 When air-entrained concrete is specified, the air content of the samples taken at the point of discharge from the transportation unit (see Section 8 and Table 1 for the total air content and tolerances) (Note 2),

5.1.4 Which of Options A, B, or C shall be used as a basis for determining the proportions of the concrete to produce the required quality,

5.1.5 When structural lightweight concrete is specified, the mass per unit volume as wet mass, air-dry mass, or oven-dry mass (Note 3), and

5.1.6 If desired, any of the optional requirements of Table 2 in Specification C 1602.

NOTE 2—In selecting the specified air content, the purchaser should consider the exposure conditions to which the concrete will be subjected. Air contents less than shown in Table 1 may not give the required resistance to freezing and thawing, which is the primary purpose of air-entrained concrete. Air contents higher than the levels shown may reduce strength without contributing any further improvement of durability.

NOTE 3—The mass per unit volume of fresh concrete, which is the only unit mass determinable at the time of delivery, is always higher than the air-dry or oven-dry mass. Definitions of, and methods for determining or calculating air-dry and oven-dry masses, are covered by Test Method C 567.

5.2 *Option A*:

5.2.1 When the purchaser requires the manufacturer to assume full responsibility for the selection of the proportions for the concrete mixture (Note 4), the purchaser shall also specify the following:

5.2.1.1 Requirements for compressive strength as determined on samples taken from the transportation unit at the point of discharge evaluated in accordance with Section 18. The purchaser shall specify the requirements in terms of the compressive strength of standard specimens cured under standard laboratory conditions for moist curing (see Section 18). Unless otherwise specified the age at test shall be 28 days.

NOTE 4—The purchaser, in selecting requirements for which he assumes responsibility should give consideration to requirements for workability, placeability, durability, surface texture, and density, in addition to those for structural design. The purchaser is referred to Standard Practice ACI 211.1 and Standard Practice ACI 211.2 for the selection of proportions that will result in concrete suitable for various types of structures and conditions of exposure. The water-cement ratio of most structural lightweight concretes cannot be determined with sufficient accuracy for use as a specification basis.

5.2.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser, giving the dry masses of cement and saturated surface-dry-masses of fine and coarse aggregate and quantities, type, and name of admixtures (if any) and of water per cubic yard or cubic metre of concrete that will be used in the manufacture of each class of concrete ordered by the purchaser. He shall also furnish evidence satisfactory to the purchaser that the materials to be used and proportions selected will produce concrete of the quality specified.

5.3 *Option B*:

5.3.1 When the purchaser assumes responsibility for the proportioning of the concrete mixture, he shall also specify the following:

5.3.1.1 Cement content in bags or pounds per cubic yard [kilograms per cubic metre] of concrete,

5.3.1.2 Maximum allowable water content in gallons per cubic yard [litres per cubic metre] of concrete, including surface moisture on the aggregates, but excluding water of absorption (Note 4), and

5.3.1.3 If admixtures are required, the type, name, and dosage to be used. The cement content shall not be reduced when admixtures are used under this option without the written approval of the purchaser.

5.3.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser giving the sources, densities, and sieve analyses of the aggregates and the dry masses of cement and saturated-surface-dry masses of fine and coarse aggregate and quantities, type and name of admixture (if any) and of water

[4] Available from Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402.

per cubic yard or cubic metre of concrete that will be used in the manufacture of each class of concrete ordered by the purchaser.

5.4 *Option C*:

5.4.1 When the purchaser requires the manufacturer to assume responsibility for the selection of the proportions for the concrete mixture with the minimum allowable cement content specified (Note 5), the purchaser shall also specify the following:

5.4.1.1 Required compressive strength as determined on samples taken from the transportation unit at the point of discharge evaluated in accordance with Section 18. The purchaser shall specify the requirements for strength in terms of tests of standard specimens cured under standard laboratory conditions for moist curing (see Section 18). Unless otherwise specified the age at test shall be 28 days.

5.4.1.2 Minimum cement content in bags or pounds per cubic yard [kilograms per cubic metre] of concrete.

5.4.1.3 If admixtures are required, the type, name, and dosage to be used. The cement content shall not be reduced when admixtures are used.

NOTE 5—Option C can be distinctive and useful only if the designated minimum cement content is at about the same level that would ordinarily be required for the strength, aggregate size, and slump specified. At the same time, it must be an amount that will be sufficient to ensure durability under expected service conditions, as well as satisfactory surface texture and density, in the event specified strength is attained with it. For additional information refer to Standard Practice ACI 211.1 and Standard Practice 211.2 referred to in Note 4.

5.4.2 At the request of the purchaser, the manufacturer shall, prior to the actual delivery of the concrete, furnish a statement to the purchaser, giving the dry masses of cement and saturated surface-dry masses of fine and coarse aggregate and quantities, type, and name of admixture (if any) and of water per cubic yard or cubic metre of concrete that will be used in the manufacture of each class of concrete ordered by the purchaser. He shall also furnish evidence satisfactory to the purchaser that the materials to be used and proportions selected will produce concrete of the quality specified. Whatever strengths are attained the quantity of cement used shall not be less than the minimum specified.

5.5 The proportions arrived at by Options A, B, or C for each class of concrete and approved for use in a project shall be assigned a designation to facilitate identification of each concrete mixture delivered to the project. This is the designation required in 14.1.7 and supplies information on concrete proportions when they are not given separately on each delivery ticket as outlined in 14.2. A certified copy of all proportions as established in Options A, B, or C shall be on file at the batch plant.

5.6 The purchaser shall ensure that the manufacturer is provided copies of all reports of tests performed on concrete samples taken to determine compliance with specification requirements. Reports shall be provided on a timely basis.

6. Materials

6.1 In the absence of designated applicable specifications covering requirements for quality of materials, the following specifications shall govern:

6.1.1 *Cement*—Cement shall conform to Specification C 150, Specification C 595, or Specification C 1157 (see Note 6). The purchaser shall specify the type or types required, but if no type is specified, the requirements of Type I as prescribed in Specification C 150 shall apply.

NOTE 6—These different cements will produce concretes of different properties and should not be used interchangeably.

6.1.2 *Aggregates*—Normal weight aggregates shall conform to Specification C 33. Lightweight aggregates shall conform to Specification C 330 and heavyweight aggregates shall conform to Specification C 637.

6.1.3 *Water*—Water shall conform to Specification C 1602.

6.1.4 *Mineral Admixtures*—Coal fly ash and raw or calcined natural pozzolan shall conform to Specification C 618 as applicable.

6.1.5 *Ground Granulated Blast-Furnace Slag*—Ground granulated blast- furnace slag shall conform to Specification C 989.

6.1.6 *Air-Entraining Admixtures*—Air-entraining admixtures shall conform to Specification C 260 (Note 7).

6.1.7 *Chemical Admixtures*—Chemical admixtures shall conform to either Specification C 494/C 494M or C 1017/C 1017M as applicable (Note 7).

NOTE 7—In any given instance, the required dosage of air-entraining, accelerating, and retarding admixtures may vary. Therefore, a range of dosages should be allowed which will permit obtaining the desired effect.

7. Tolerances in Slump

7.1 Unless other tolerances are included in the project specifications, the following shall apply.

7.1.1 When the project specifications for slump are written as a "maximum" or "not to exceed" requirement:

	Specified slump:	
	If 3 in. [75 mm] or less	If more than 3 in. [75 mm]
Plus tolerance:	0	0
Minus tolerance:	1½ in. [40 mm]	2½ in. [65 mm]

This option is to be used only if one addition of water is permitted on the job provided such addition does not increase the water-cement ratio above the maximum permitted by the specifications.

TABLE 1 Recommended Total Air Content for Air-Entrained Concrete[A,B]

Exposure Condition[C]	Total Air Content, %						
	Nominal Maximum Sizes of Aggregate, in. [mm]						
	⅜ [9.5]	½ [12.5]	¾ [19.0]	1 [25.0]	1½ [37.5]	2 [50.0]	3 [75.0]
Mild	4.5	4.0	3.5	3.0	2.5	2.0	1.5
Moderate	6.0	5.5	5.0	4.5	4.5	4.0	3.5
Severe	7.5	7.0	6.0	6.0	5.5	5.0	4.5

[A] For air-entrained concrete, when specified.
[B] Unless exposure conditions dictate otherwise, it is permissible to reduce air contents recommended above by up to 1 % for concretes with specified compressive strength, f'_c, of 5000 psi [35 MPa] or above.
[C] For description of exposure conditions, refer to Standard Practice ACI 211.1, Section 6.3.3, with attention to accompanying footnotes.

7.1.2 When the project specifications for slump are *not* written as a "maximum" or "not to exceed" requirement:

Tolerances for Nominal Slumps

For Specified Slump of:	Tolerance
2 in. [50 mm] and less	±½ in. [15 mm]
More than 2 through 4 in. [50 to 100 mm]	±1 in. [25 mm]
More than 4 in. [100 mm]	±1½ in. [40 mm]

7.2 Concrete shall be available within the permissible range of slump for a period of 30 min starting either on arrival at the job site or after the initial slump adjustment permitted in 12.7, whichever is later. The first and last ¼ yd^3 or ¼ m^3 discharged are exempt from this requirement. If the user is unprepared for discharge of the concrete from the vehicle, the producer shall not be responsible for the limitation of minimum slump after 30 min have elapsed starting either on arrival of the vehicle at the prescribed destination or at the requested delivery time, whichever is later.

8. Air-Entrained Concrete

8.1 When air-entrained concrete is desired the purchaser shall specify the total air content of the concrete. See Table 1 for recommended total air contents (Note 7).

8.2 The air content of air-entrained concrete when sampled from the transportation unit at the point of discharge shall be within a tolerance of ± 1.5 of the specified value.

8.3 When a preliminary sample taken within the time limits of 12.7 and prior to discharge for placement shows an air content below the specified level by more than the allowable tolerance in accordance with 8.2, the manufacturer may use additional air entraining admixture to achieve the desired air content level, followed by a minimum of 30 revolutions at mixing speed, so long as the revolution limit of 12.7 is not exceeded (see Note 8).

NOTE 8—Acceptance sampling and testing in accordance with Practice C 172 is not obviated by this provision.

9. Measuring Materials

9.1 Except as otherwise specifically permitted, cement shall be measured by mass. When mineral admixtures (including ground granulated blast-furnace slag, coal fly ash, silica fume, or other pozzolans) are specified in the concrete proportions, the cumulative mass is permitted to be measured with cement, but in a batch hopper and on a scale which is separate and distinct from those used for other materials. The mass of the cement shall be measured before mineral admixtures. When the quantity of cement exceeds 30 % of the full capacity of the scale, the quantity of the cement shall be within ± 1 % of the required mass, and the cumulative quantity of cement plus mineral admixtures shall also be within ± 1 % of the required mass. For smaller batches to a minimum of 1 yd^3 [1 m^3], the quantity of the cement and the cumulative quantity of cement plus mineral admixture used shall be not less than the required amount nor more than 4 % in excess. Under special circumstances approved by the purchaser, cement is permitted to be measured in bags of standard mass (Note 9). No fraction of a bag of cement shall be used unless its mass has been determined.

NOTE 9—In the United States the standard mass of a bag of portland cement is 94 lb [42.6 kg] ± 3 %.

9.2 Aggregate shall be measured by mass. Batch mass measurements shall be based on dry materials and shall be the required masses of dry materials plus the total mass of moisture (both absorbed and surface) contained in the aggregate. The quantity of aggregate used in any batch of concrete as indicated by the scale shall be within ±2 % of the required mass when the mass is measured in individual aggregate weigh batchers. In a cumulative aggregate weigh batcher, the cumulative weight after each successive weighing shall be within ±1 % of the required cumulative amount up to that point when the scale is used in excess of 30 % of its capacity. For cumulative weights for less than 30 % of scale capacity, the tolerance shall be ±0.3 % of scale capacity or ±3 % of the required cumulative weight, whichever is less.

9.3 Mixing water shall consist of water added to the batch, ice added to the batch, water occurring as surface moisture on the aggregates, and water introduced in the form of admixtures. The added water shall be measured by weight or volume to an accuracy of 1 % of the required total mixing water. Added ice shall be measured by weight. In the case of truck mixers, any wash water retained in the drum for use in the next batch of concrete shall be accurately measured; if this proves impractical or impossible the wash water shall be discharged prior to loading the next batch of concrete. Total water (including any wash water) shall be measured or weighed to an accuracy of ±3 % of the specified total amount.

9.4 Admixtures in powdered form shall be measured by mass. Liquid admixtures shall be batched by mass or volume. Admixtures, except mineral admixtures (see 8.1), measured by either mass or volume, shall be batched with an accuracy of ±3 % of the total amount required or plus or minus the amount or dosage required for 100 lb [50 kg] of cement, whichever is greater.

NOTE 10—Admixture dispensers of the mechanical type capable of adjustment for variation of dosage, and of simple calibration, are recommended.

10. Batching Plant

10.1 Bins with adequate separate compartments shall be provided in the batching plant for fine and for each required size of coarse aggregate. Each bin compartment shall be designed and operated so as to discharge efficiently and freely, with minimum segregation, into the weighing hopper. Means of control shall be provided so that, as the quantity desired in the weighing hopper is approached, the material shall be shut off with precision. Weighing hoppers shall be constructed so as to eliminate accumulations of tare materials and to discharge fully.

10.2 Indicating devices shall be in full view and near enough to be read accurately by the operator while charging the hopper. The operator shall have convenient access to all controls.

10.3 Scales shall be considered accurate when at least one static load test within each quarter of the scale capacity can be shown to be within ±0.2 % of the total capacity of the scale.

10.4 Adequate standard test weights shall be available for checking accuracy. All exposed fulcrums, clevises, and similar working parts of scales shall be kept clean. Beam scales shall be equipped with a balance indicator sensitive enough to show movement when a weight equal to 0.1 % of the nominal capacity of the scale is placed in the batch hopper. Pointer travel shall be a minimum of 5 % of the net-rated capacity of the largest weigh beam for underweight and 4 % for overweight.

10.5 The device for the measurement of the added water shall be capable of delivering to the batch the quantity required within the accuracy required in 9.3. The device shall be so arranged that the measurements will not be affected by variable pressures in the water supply line. Measuring tanks shall be equipped with outside taps and valves to provide for checking their calibration unless other means are provided for readily and accurately determining the amount of water in the tank.

NOTE 11—The scale accuracy limitations of the National Ready Mixed Concrete Association Plant Certification meet the requirements of this specification.

11. Mixers and Agitators

11.1 Mixers will be stationary mixers or truck mixers. Agitators will be truck mixers or truck agitators.

11.1.1 Stationary mixers shall be equipped with a metal plate or plates on which are plainly marked the mixing speed of the drum or paddles, and the maximum capacity in terms of the volume of mixed concrete. When used for the complete mixing of concrete, stationary mixers shall be equipped with an acceptable timing device that will not permit the batch to be discharged until the specified mixing time has elapsed.

11.1.2 Each truck mixer or agitator shall have attached thereto in a prominent place a metal plate or plates on which are plainly marked the gross volume of the drum, the capacity of the drum or container in terms of the volume of mixed concrete, and the minimum and maximum mixing speeds of rotation of the drum, blades, or paddles. When the concrete is truck mixed as described in 12.5, or shrink mixed as described in 12.4, the volume of mixed concrete shall not exceed 63 % of the total volume of the drum or container. When the concrete is central mixed as described in 12.3, the volume of concrete in the truck mixer or agitator shall not exceed 80 % of the total volume of the drum or container. Truck mixers and agitators shall be equipped with means to readily verify the number of revolutions of the drum, blades, or paddles.

11.2 All stationary and truck mixers shall be capable of combining the ingredients of the concrete within the specified time or the number of revolutions specified in 11.5, into a thoroughly mixed and uniform mass and of discharging the concrete so that not less than five of the six requirements shown in Table A1.1 shall have been met.

NOTE 12—The sequence or method of charging the mixer will have an important effect on the uniformity of the concrete.

11.3 The agitator shall be capable of maintaining the mixed concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity as defined by Annex A1.

11.4 Slump tests of individual samples taken after discharge of approximately 15 % and 85 % of the load will provide a quick check of the probable degree of uniformity (Note 13). These two samples shall be obtained within an elapsed time of not more than 15 min. If these slumps differ more than that specified in Annex A1, the mixer or agitator shall not be used unless the condition is corrected, except as provided in 11.5.

NOTE 13—No samples should be taken before 10 % or after 90 % of the batch has been discharged. Due to the difficulty of determining the actual quantity of concrete discharged, the intent is to provide samples that are representative of widely separated portions, but not the beginning and end of the load.

11.5 Use of the equipment is permitted when operation with a longer mixing time, a smaller load, or a more efficient charging sequence will permit the requirements of Annex A1 to be met.

11.6 Mixers and agitators shall be examined or their mass determined as frequently as necessary to detect changes in condition due to accumulations of hardened concrete or mortar and examined to detect wear of blades. When such changes are extensive enough to affect the mixer performance, the proof-tests described in Annex A1 shall be performed to show whether the correction of deficiencies is required.

12. Mixing and Delivery

12.1 Ready-mixed concrete shall be mixed and delivered to the point designated by the purchaser by means of one of the following combinations of operations:

12.1.1 *Central-Mixed Concrete*.

12.1.2 *Shrink-Mixed Concrete*.

12.1.3 *Truck-Mixed Concrete*.

12.2 Mixers and agitators shall be operated within the limits of capacity and speed of rotation designated by the manufacturer of the equipment.

12.3 *Central-Mixed Concrete*—Concrete that is mixed completely in a stationary mixer and transported to the point of delivery either in a truck agitator, or a truck mixer operating at agitating speed, or in nonagitating equipment approved by the

purchaser and meeting the requirements of Section 13, shall conform to the following: The mixing time shall be counted from the time all the solid materials are in the drum. The batch shall be so charged into the mixer that some water will enter in advance of the cement and aggregate, and all water shall be in the drum by the end of the first one fourth of the specified mixing time.

12.3.1 Where no mixer performance tests are made, the acceptable mixing time for mixers having capacities of 1 yd^3 [0.76 m^3] or less shall be not less than 1 min. For mixers of greater capacity, this minimum shall be increased 15 s for each cubic yard [cubic metre] or fraction thereof of additional capacity.

12.3.2 Where mixer performance tests have been made on given concrete mixtures in accordance with the testing program set forth in the following paragraphs, and the mixers have been charged to their rated capacity, the acceptable mixing time is permitted to be reduced for those particular circumstances to a point at which satisfactory mixing defined in 12.3.3 shall have been accomplished. When the mixing time is so reduced the maximum time of mixing shall not exceed this reduced time by more than 60 s for air-entrained concrete.

12.3.3 *Sampling for Uniformity Tests of Stationary Mixers*—Samples of concrete for comparative purposes shall be obtained immediately after arbitrarily designated mixing times, in accordance with one of the following procedures:

12.3.3.1 *Alternative Procedure 1*—The mixer shall be stopped, and the required samples removed by any suitable means from the concrete at approximately equal distances from the front and back of the drum, or

12.3.3.2 *Alternative Procedure 2*—As the mixer is being emptied, individual samples shall be taken after discharge of approximately 15 % and 85 % of the load. The method of sampling shall provide that the samples are representative of widely separated portions, but not from the very ends of the batch (Note 13).

12.3.3.3 The samples of concrete shall be tested in accordance with Section 18, and differences in test results for the two samples shall not exceed those given in Annex A1. Mixer performance tests shall be repeated whenever the appearance of the concrete or the coarse aggregate content of samples selected as outlined in this section indicates that adequate mixing has not been accomplished.

12.4 *Shrink-Mixed Concrete*—Concrete that is first partially mixed in a stationary mixer, and then mixed completely in a truck mixer, shall conform to the following: The time of partial mixing shall be minimum required to intermingle the ingredients. After transfer to a truck mixer the amount of mixing at the designated mixing speed will be that necessary to meet the requirements for uniformity of concrete as indicated in Annex A1. Tests to confirm such performance shall be made in accordance with 12.3.3 and 12.3.3.3. Additional turning of the mixer, if any, shall be at a designated agitating speed.

12.5 *Truck-Mixed Concrete*—Concrete that is completely mixed in a truck mixer, 70 to 100 revolutions at the mixing speed designated by the manufacturer to produce the uniformity of concrete indicated in Annex A1. Concrete uniformity tests shall be made in accordance with 12.5.1 and if requirements for uniformity of concrete indicated in Annex A1 are not met with 100 revolutions of mixing, after all ingredients including water, are in the drum, that mixer shall not be used until the condition is corrected, except as provided in 11.5. When satisfactory performance is found in one truck mixer, the performance of mixers of substantially the same design and condition of blades are permitted to be regarded as satisfactory. Additional revolutions of the mixer beyond the number found to produce the required uniformity of concrete shall be at a designated agitating speed.

12.5.1 *Sampling for Uniformity of Concrete Produced in Truck Mixers*—The concrete shall be discharged at the normal operating rate for the mixer being tested, with care being exercised not to obstruct or retard the discharge by an incompletely opened gate or seal. Separate samples, each consisting of approximately 2 ft^3 [0.1 m^3 approximately] shall be taken after discharge of approximately 15 % and 85 % of the load (Note 13). These samples shall be obtained within an elapsed time of not more than 15 min. The samples shall be secured in accordance with Practice C 172, but shall be kept separate to represent specific points in the batch rather than combined to form a composite sample. Between samples, where necessary to maintain slump, the mixer shall be turned in mixing direction at agitating speed. During sampling the receptacle shall receive the full discharge of the chute. Sufficient personnel must be available to perform the required tests promptly. Segregation during sampling and handling must be avoided. Each sample shall be remixed the minimum amount to ensure uniformity before specimens are molded for a particular test.

12.6 When a truck mixer or truck agitator is used for transporting concrete that has been completely mixed in a stationary mixer, any turning during transportation shall be at the speed designated by the manufacturer of the equipment as agitating speed.

12.7 When a truck mixer or agitator is approved for mixing or delivery of concrete, no water from the truck water system or elsewhere shall be added after the initial introduction of mixing water for the batch except when on arrival at the job site the slump of the concrete is less than that specified. Such additional water to bring the slump within required limits shall be injected into the mixer under such pressure and direction of flow that the requirements for uniformity specified in Annex A1 are met. The drum or blades shall be turned an additional 30 revolutions or more if necessary, at mixing speed, until the uniformity of the concrete is within these limits. Water shall not be added to the batch at any later time. Discharge of the concrete shall be completed within 1½ h, or before the drum has revolved 300 revolutions, whichever comes first, after the introduction of the mixing water to the cement and aggregates or the introduction of the cement to the aggregates. These limitations are permitted to be waived by the purchaser if the concrete is of such slump after the 1½-h time or 300-revolution limit has been reached that it can be placed, without the addition of water, to the batch. In hot weather, or under conditions contributing to quick stiffening of the concrete, a time less than 1½ h is permitted to be specified by the purchaser.

12.8 Concrete delivered in cold weather shall have the applicable minimum temperature indicated in the following table. (The purchaser shall inform the producer as to the type of construction for which the concrete is intended.)

Minimum Concrete Temperature as Placed

Section Size, in. [mm]	Temperature, min, °F [°C]
<12 [<300]	55 [13]
12–36 [300–900]	50 [10]
36–72 [900–1800]	45 [7]
>72 [>1800]	40 [5]

The maximum temperature of concrete produced with heated aggregates, heated water, or both, shall at no time during its production or transportation exceed 90 °F [32 °C].

NOTE 14—When hot water is used rapid stiffening may occur if hot water is brought in direct contact with the cement. Additional information on cold weather concreting is contained in ACI 306R.

12.9 The producer shall deliver the ready mixed concrete during hot weather at concrete temperatures as low as practicable, subject to the approval of the purchaser.

NOTE 15—In some situations difficulty may be encountered when concrete temperatures approach 90 °F [32 °C]. Additional information may be found in the Bureau of Reclamation Concrete Manual and in ACI 305R.

13. Use of Nonagitating Equipment

13.1 When the use of non-agitating transportation equipment is approved by the purchaser, the concrete shall be manufactured in a central mix plant. The proportions of the concrete shall be approved by the purchaser and the following limitations shall apply:

13.2 Bodies of nonagitating equipment shall be smooth, watertight, metal containers equipped with gates that will permit control of the discharge of the concrete. Covers shall be provided for protection against the weather when required by the purchaser.

13.3 The concrete shall be delivered to the site of the work in a thoroughly mixed and uniform mass and discharged with a satisfactory degree of uniformity as prescribed in Annex A1.

13.4 Slump tests of individual samples taken after discharge of approximately 15 % and 85 % of the load will provide for a quick check of the probable degree of uniformity (Note 13). These two samples shall be obtained within an elapsed time of not more than 15 min. If these slumps differ more than that specified in Table A1.1, the nonagitating equipment shall not be used unless the conditions are corrected as provided in 13.5.

13.5 If the requirements of Annex A1 are not met when the nonagitating equipment is operated for the maximum time of haul, and with the concrete mixed the minimum time, the equipment shall only be used when operated using shorter hauls, or longer mixing times, or combinations thereof that will result in the requirements of Annex A1 being met.

14. Batch Ticket Information

14.1 The manufacturer of the concrete shall furnish to the purchaser with each batch of concrete before unloading at the site, a delivery ticket on which is printed, stamped, or written, information concerning said concrete as follows:

14.1.1 Name of ready-mix company and batch plant, or batch plant number,

14.1.2 Serial number of ticket,

14.1.3 Date,

14.1.4 Truck number,

14.1.5 Name of purchaser,

14.1.6 Specific designation of job (name and location),

14.1.7 Specific class or designation of the concrete in conformance with that employed in job specifications,

14.1.8 Amount of concrete in cubic yards (or cubic metres),

14.1.9 Time loaded or of first mixing of cement and aggregates, and

14.1.10 Water added by receiver of concrete and his initials.

14.2 Additional information for certification purposes as designated by the purchaser and required by the job specifications shall be furnished when requested; such information as:

14.2.1 Reading of revolution counter at the first addition of water,

14.2.2 Type, brand, and amount of cement,

14.2.3 Class, brand, and amount of coal fly ash, or raw or calcined natural pozzolans,

14.2.4 Grade, brand, and amount of ground granulated blast-furnace slag,

14.2.5 Type, brand, and amount of silica fume,

14.2.6 Type, brand, and amount of admixtures

14.2.7 Type, brand, and amount of fiber reinforcement,

14.2.8 Source and amount of each metered or weighed water or recycled slurry,

14.2.9 Information necessary to calculate the total mixing water. Total mixing water includes free water on aggregates, batch water (metered or weighed) including ice batched at the plant, wash water retained in the mixing drum, and water added by the truck operator from the mixer tank,

14.2.10 Maximum size of aggregate,

14.2.11 Mass (amount) of fine and coarse aggregate,

14.2.12 Ingredients certified as being previously approved, and

14.2.13 Signature or initials of producer's representative.

15. Plant Inspection

15.1 The manufacturer shall afford the inspector all reasonable access, without charge, for making necessary checks of the production facilities and for securing necessary samples to determine if the concrete is being produced in accordance with this specification. All tests and inspection shall be so conducted as not to interfere unnecessarily with the manufacture and delivery of concrete.

16. Practices, Test Methods, and Reporting

16.1 Test ready-mixed concrete in accordance with the following methods:

16.1.1 *Compression Test Specimens*—Practice C 31/C 31M, using standard moist curing in accordance with the applicable provisions of Practice C 31/C 31M.

16.1.2 *Compression Tests*—Test Method C 39/C 39M.

16.1.3 *Yield, Mass per Cubic Foot*—Test Method C 138/C 138M.

16.1.4 *Air Content*—Test Method C 138/C 138M; Test Method C 173/C 173M or Test Method C 231.

16.1.5 *Slump*—Test Method C 143/C 143M.

16.1.6 *Sampling Fresh Concrete*—Practice C 172.

16.1.7 *Temperature*—Test Method C 1064/C 1064M.

16.2 The testing laboratory performing acceptance tests of concrete shall meet the requirements of Practice C 1077.

16.3 Laboratory reports of concrete test results used to determine compliance with this specification shall include a statement that all tests performed by the laboratory or its agents were in accordance with the applicable test methods or shall note all known deviations from the prescribed procedures (Note 16). The reports shall also list any part of the test methods not performed by the laboratory.

NOTE 16—Deviation from standard test methods may adversely affect test results.

NOTE 17—Deviation from standard moisture and temperature curing conditions is often a reason for low strength test results. Such deviations may invalidate the use of such test results as a basis for rejection of the concrete.

17. Sampling and Testing Fresh Concrete

17.1 The contractor shall afford the inspector all reasonable access and assistance, without charge, for the procurement of samples of fresh concrete at time of placement to determine conformance of it to this specification.

17.2 Tests of concrete required to determine compliance with this specification shall be made by a certified ACI Concrete Field Testing Technician, Grade I or equivalent. Equivalent personnel certification programs shall include both written and performance examinations as outlined in ACI CP-1.

17.3 Samples of concrete shall be obtained in accordance with Practice C 172, except when taken to determine uniformity of slump within any one batch or load of concrete (11.4, 12.3.3, 12.5.1, and 13.4).

17.4 Slump, air-content, density, and temperature tests shall be made at the time of placement at the option of the inspector as often as is necessary for control checks. In addition, these tests shall be made when specified and always when strength specimens are made.

17.5 Strength tests as well as slump, temperature, density, and air content tests shall generally be made with a frequency of not less than one test for each 150 yd^3 (115 m^3). Each test shall be made from a separate batch. On each day concrete is delivered, at least one strength test shall be made for each class of concrete.

17.6 If preliminary checks of slump or air content are made, a single sample shall be taken after the discharge of not less than ¼ yd^3[¼ m^3]. All other requirements of Practice C 172 shall be retained. If the preliminary measurement of slump (12.7) or air content (8.3) falls outside the specified limits, address as indicated in section 17.6.1 or 17.6.2 as appropriate.

17.6.1 If the measured slump or air content, or both is greater than the specified upper limit, a check test shall be made immediately on a new test sample. In the event the check test fails, the concrete shall be considered to have failed the requirements of the specification.

17.6.2 If the measured slump or air content, or both is less than the lower limit, permit adjustments in accordance with 12.7 or 8.3 or both, as appropriate, and obtain a new sample. If the sample of the adjusted concrete fails, a check test shall be made immediately on a new sample of the adjusted concrete. In the event the check test fails, the concrete shall be considered to have failed the requirements of the specification.

18. Strength

18.1 When strength is used as a basis for acceptance of concrete, standard specimens shall be made in accordance to Practice C 31/C 31M. The specimens shall be cured under standard moisture and temperature conditions in accordance with the applicable provisions of Practice C 31/C 31M. The technician performing the strength test shall be certified as an ACI Concrete Strength Testing Technician, Concrete Laboratory Testing Technician—Grade II or by an equivalent written and performance test program covering the relevant test methods. If acceptance is based upon compressive strength test results, the certification requirement is satisfied by certification as an ACI Concrete Laboratory Testing Technician—Grade I or by an equivalent written and performance test program.

18.2 For a strength test, at least two standard test specimens shall be made from a composite sample secured as required in Section 17. A test shall be the average of the strengths of the specimens tested at the age specified in 5.2.1.1 or 5.4.1.1 (Note 18). If a specimen shows definite evidence other than low strength, of improper sampling, molding, handling, curing, or testing, it shall be discarded and the strength of the remaining cylinder shall then be considered the test result.

NOTE 18—Additional tests may be made at other ages to obtain information for determining form removal time or when a structure may be put in service. Specimens for such tests are cured according to the section on Field Curing in Practice C 31/C 31M.

18.3 The representative of the purchaser shall ascertain and record the delivery-ticket number for the concrete and the exact location in the work at which each load represented by a strength test is deposited.

18.4 To conform to the requirements of this specification, strength tests representing each class of concrete must meet the following two requirements (Note 19):

18.4.1 The average of any three consecutive strength tests shall be equal to, or greater than, the specified strength, f'_c, and

18.4.2 When the specified strength is 5000 psi [35 MPa] or less, no individual strength test (average of two cylinder tests) shall be more than 500 psi [3.5 MPa] below the specified strength, f'_c.

NOTE 19—Due to variations in materials, operations, and testing, the average strength necessary to meet these requirements will be substantially higher than the specified strength. The amount higher depends upon the standard deviation of the test results and the accuracy with which that value can be estimated from prior data as explained in ACI 318 and ACI 301. Pertinent data are given in Appendix X1.

18.4.3 When the specified strength is greater than 5000 psi [35 MPa], no individual strength test (average of two cylinder tests) shall be less than 0.90 f'_c.

19. Failure to Meet Strength Requirements

19.1 In the event that concrete tested in accordance with the requirements of Section 18 fails to meet the strength requirements of this specification, the manufacturer of the ready-mixed concrete and the purchaser shall confer to determine

whether agreement can be reached as to what adjustment, if any, shall be made. If an agreement on a mutually satisfactory adjustment cannot be reached by the manufacturer and the purchaser, a decision shall be made by a panel of three qualified engineers, one of whom shall be designated by the purchaser, one by the manufacturer, and the third chosen by these two members of the panel. The question of responsibility for the cost of such arbitration shall be determined by the panel. Its decision shall be binding, except as modified by a court decision.

20. Keywords

20.1 accuracy; blended hydraulic cement; certification; ready-mixed concrete; scales; testing

ANNEX

(Mandatory Information)

A1. CONCRETE UNIFORMITY REQUIREMENTS

A1.1 The variation within a batch as provided in Table A1.1 shall be determined for each property listed as the difference between the highest value and the lowest value obtained from the different portions of the same batch. For this specification the comparison will be between two samples, representing the first and last portions of the batch being tested. Test results conforming to the limits of five of the six tests listed in Table A1.1 shall indicate uniform concrete within the limits of this specification.

A1.2 *Coarse Aggregate Content,* using the washout test, shall be computed from the following relations:

$$P = (c/b) \times 100 \tag{A1.1}$$

where:

P = mass % of coarse aggregate in concrete,
c = saturated-surface-dry mass in lb [kg] of aggregate retained on the No. 4 [4.75-mm] sieve, resulting from washing all material finer than this sieve from the fresh concrete, and
b = mass of sample of fresh concrete in mass per unit volume container, lb [kg].

A1.3 *Mass per Unit Volume of Air Free Mortar* shall be calculated as follows:

Inch-pound units:

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{G}\right)} \tag{A1.2}$$

SI units:

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{G}\right)} \tag{A1.3}$$

where:

M = mass per unit volume of air-free mortar, lb/ft^3 [kg/m^3],
b = mass of concrete sample in mass container, lb [kg],
c = saturated-surface-dry mass of aggregate retained on No. 4 [4.75-mm] sieve, lb [kg],
V = volume of mass per unit volume container, ft^3 [m^3],
A = air content of concrete, %, measured in accordance with 16.1.4 on the sample being tested, and
G = density of coarse aggregate (SSD).

TABLE A1.1 Requirements for Uniformity of Concrete

Test	Requirement, Expressed as Maximum Permissible Difference in Results of Tests of Samples Taken from Two Locations in the Concrete Batch
Mass per cubic foot [mass per cubic meter] calculated to an air-free basis, lb/ft^3[kg/m^3]	1.0 [16]
Air content, volume % of concrete	1.0
Slump:	
If average slump is 4 in. [100 mm] or less, in. [mm]	1.0 [25]
If average slump is 4 to 6 in. [100 to 150 mm], in. [mm]	1.5 [40]
Coarse aggregate content, portion by mass of each sample retained on No. 4 [4.75-mm] sieve, %	6.0
Mass per unit volume of air-free mortar[A] based on average for all comparative samples tested, %.	1.6
Average compressive strength at 7 days for each sample,[B] based on average strength of all comparative test specimens, %	7.5[C]

[A] "Test for Variability of Constituents in Concrete," Designation 26, *Bureau of Reclamation Concrete Manual,* 7th Edition.[4]
[B] Not less than 3 cylinders will be molded and tested from each of the samples.
[C] Approval of the mixer shall be tentative, pending results of the 7-day compressive strength tests.

APPENDIX

(Nonmandatory Information)

X1. Calculation of the Average Compressive Strength (f'_{cr}), Necessary to Meet the Strength Requirements of Sections 18.4.1, 18.4.2, and 18.4.3

X1.1 Section 18.4 of this specification contains the same strength requirements as those contained in ACI 318 and ACI 301, except it does not require the submittal of the data and calculation of the average strength, f'_{cr} necessary to meet those ACI Code and Specifications. This Appendix does not include all of the detailed requirements of the ACI Code and Specification that will govern a submittal for their respective purposes. The following material is intended to guide users of this specification when no formal submittal is required.

X1.1.1 Table X1.1 provides the statistical formulas that can be used to calculate the required average strength f'_{cr} when historical statistical data are available. The formula to achieve a satisfactory average of three consecutive strength tests as required in 18.4.1 is (Eq. X1.1) of Table X1.1. The formulas for the minimum strength of an individual strength test result as required in 18.4.2 and 18.4.3 are (Eq. X1.2) and (Eq. X1.3) in Table X1.1. Since the average strength, f'_{cr}, must be high enough to conform to both averages of three consecutive tests and the requirements on minimum strength of a test, the one which requires highest average strength (f'_{cr}) governs.

X1.1.2 The first step in the process of calculating the over-design above f'_c or the required average strength is to determine if a record of 30 consecutive tests is available for the proposed mixture or similar mixture with a design strength within 1000 psi [6.6 MPa] of the specified compressive strength proposed for use. If it is a new mixture or strength level and no standard deviation data is available then Table X1.2 provides default levels of over-design equal to 1000, 1200 or ($1.10f'_c$ +700) psi.

X1.1.3 Table X1.3 provides calculated values of over-design and required average strength for selected standard deviations and specified strength levels. Because of the large ranges of strength and standard deviations, the gray shaded areas are considered unusual or not likely to be encountered.

TABLE X1.1 Required Average Compressive Strength when Data are Available to Establish a Standard Deviation

Inch-pound System			SI System		
Specified Strength f'_c, psi	Required Average Strength f'_{cr}, psi		Specified Strength f'_c, MPa	Required Average Strength f'_{cr}, MPa	
f'_c equal to or less than 5000	Use the larger from Eq X1.1 and X1.2		f'_c equal to or less than 35	Use the larger from Eq X1.1 and X1.2m	
	$f'_{cr} = f'_c + 1.34s$	(X1.1)		$f'_{cr} = f'_c + 1.34s$	(X1.1)
	$f'_{cr} = f'_c + 2.33s - 500$	(X1.2)		$f'_{cr} = f'_c + 2.33s - 3.45$	(X1.2m)
greater than 5000	Use the larger from Eq X1.1 and X1.3		greater than 35	Use the larger from Eq X1.1 and X1.3	
	$f'_{cr} = f'_c + 1.34s$	(X1.1)		$f'_{cr} = f'_c + 1.34s$	(X1.1)
	$f'_{cr} = 0.90f'_c + 2.33s$	(X1.3)		$f'_{cr} = 0.90f'_c + 2.33s$	(X1.3)

where:
f'_c = the specified compressive strength
f'_{cr} = the required average compressive strength
s = the standard deviation

TABLE X1.2 Required Average Compressive Strength When Data Are Not Available to Establish a Standard Deviation

Inch-pound System		SI System	
Specified Strength f'_c, psi	Required Average Strength f'_{cr}, psi	Specified Strength f'_c, MPa	Required Average Strength f'_{cr}, MPa
Less than 3000	$f'_c + 1000$	Less than 21	$f'_c + 7.0$
3000 to 5000	$f'_c + 1200$	21 to 35	$f'_c + 8.5$
greater than 5000	$1.10f'_c + 700$	greater than 35	$1.10f'_c + 5.0$

where:
f'_c = the specified compressive strength
f'_{cr} = the required average compressive strength
s = the standard deviation

TABLE X1.3 Overdesign Necessary to Conform to Specified Compressive Strength

Required Overdesign

Inch - Pound units

f'c, psi Specified Strength	Standard Deviation from field data: 300	500	700	900	1,100	no SD data: unknown
	Overdesign above f'c					
less than 3000						f'c+1000
3,000	402	670	1,131	1,597	2,063	1,200
5,000	402	670	1,131	1,597	2,063	1,200
7,000	402	670	938	1,397	1,863	1,400
9,000	402	670	938	1,206	1,663	1,600
11,000	402	670	938	1,206	1,474	1,800
13,000	402	670	938	1,206	1,474	2,000
15,000	402	670	938	1,206	1,474	2,200
17,000	402	670	938	1,206	1,474	2,400

SI metric units

f'c, MPa Specified Strength	Standard Deviation from field data: 2.0	3.5	5.0	6.0	7.5	no SD data: unknown
	Overdesign above f'c					
less than 21						f'c+7.0
21	3.0	5.0	8.5	10.8	14.3	8.5
35	2.7	4.7	8.2	10.5	14.0	8.5
50	2.7	4.7	6.7	9.0	12.5	10.0
60	2.7	4.7	6.7	8.0	11.5	11.0
75	2.7	4.7	6.7	8.0	10.1	12.5
90	2.7	4.7	6.7	8.0	10.1	14.0
100	2.7	4.7	6.7	8.0	10.1	15.0
120	2.7	4.7	6.7	8.0	10.1	17.0

Required Average Strength

f'c, psi Specified Strength	Standard Deviation from field data, psi: 300	500	700	900	1,100	no SD data: unknown
	f'cr, required Average Strength, psi					
less than 3000						f'c+1000
3,000	3,402	3,670	4,131	4,597	5,063	4,200
5,000	5,402	5,670	6,131	6,597	7,063	6,200
7,000	7,402	7,670	7,938	8,397	8,863	8,400
9,000	9,402	9,670	9,938	10,206	10,663	10,600
11,000	11,402	11,670	11,938	12,206	12,474	12,800
13,000	13,402	13,670	13,938	14,206	14,474	15,000
15,000	15,402	15,670	15,938	16,206	16,474	17,200
17,000	17,402	17,670	17,938	18,206	18,474	19,400

f'c, MPa Specified Strength	Standard Deviation, Mpa from field data: 2.0	3.5	5.0	6.0	7.5	No data: unknown
	f'cr, required Average Strength, MPa					
less than 21						f'c+7.0
21.0	24	26	29	32	35	29.5
35.0	38	40	43	46	49	43.5
50.0	53	55	57	59	62	60.0
60.0	63	65	67	68	71	71.0
75.0	78	80	82	83	85	87.5
90.0	93	95	97	98	100	104.0
100.0	103	105	107	108	110	115.0
120.0	123	125	127	128	130	137.0

Shaded Areas identify levels of specified strength where the standard deviations should be considered unusual or inappropiate.

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ACI 305.1-06

Specification for Hot Weather Concreting

An ACI Standard

Reported by ACI Committee 305

American Concrete Institute®

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American Concrete Institute®
Advancing concrete knowledge

Specification for Hot Weather Concreting

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Specification for Hot Weather Concreting

An ACI Standard

Reported by ACI Committee 305

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This specification provides requirements for hot weather concreting that the Architect/ Engineer can make applicable to any construction project by citing it in project specifications.

It is intended that the Architect/Engineer use the checklists included in this specification to customize the project specification.

The document includes hot weather requirements for production preparations, delivery, placement, finishing, bleed-water evaporation, curing, and protection of concrete. Provisions governing a preplacement conference, concrete mixture proportions, maximum allowable concrete temperature, measurement of the rate of surface evaporation, evaporation control measures, and acceptance of a concrete mixture from past field experience or preconstruction testing are included.

Keywords: bleeding; concrete, curing; finishing; hot weather concreting; mixture proportioning; plastic shrinkage cracking; protection period; trial batch.

NOTE TO SPECIFIER

This specification is incorporated by reference in the Project Specification using the wording in P3 of the Preface and including information from the Optional Requirements and Submittals checklists following the Specification.

PREFACE

P1. ACI Specification 305.1 is intended to be used by reference or incorporation in its entirety in the Project Specification. Do not copy individual Parts, Sections, Articles, or Paragraphs into the Project Specification, because taking them out of context may change their meaning.

P2. If Sections or Parts of ACI Specification 305.1 are copied into the Project Specification or any other document, do not refer to them as an ACI Specification, because the specification has been altered.

P3. A statement such as the following will serve to make ACI Specification 305.1 a part of the Project Specification:

> Work on (Project Title) shall conform to all requirements of ACI 305.1-06, Specification for Hot Weather Concreting, published by the American Concrete Institute, Farmington Hills, Michigan, except as modified by these Contract Documents.

P4. Each technical Section of ACI Specification 305.1 is written in the three-part Section format of the Construction Specifications Institute, as adapted for ACI requirements. The language is imperative and terse.

P5. The Specification is written to the Contractor. When a provision of this Specification requires action by the Contractor, the verb "shall" is used. If the Contractor is allowed to exercise an option when limited alternatives are available, the phrasing "either...or..." is used. Statements provided in the Specification as information to the Contractor use the verbs "may" or "will." Informational statements typically identify activities or options that "will be taken" or "may be taken" by the Owner or Architect/Engineer.

ACI 305.1-06 was adopted November 7, 2006 and published March 2007.
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SECTION 1—GENERAL

1.1—Scope

This Specification covers requirements for hot weather concrete construction. Provisions of this Specification shall govern, except where other provisions are specified in Contract Documents. This Specification shall not be used in conjunction with ACI 301 or ACI 530.1.

1.2—Referenced standards

1.2.1 Standards of ACI and ASTM referred to in this Specification are listed with serial designation, including year of adoption or revision, and are part of this Specification.

1.2.2 *ACI Standards*

308.1-98 Standard Specification for Curing Concrete

1.2.3 *ASTM Standards*

C 31/C31 M-03a	Practice for Making and Curing Concrete Test Specimens in the Field
C 39/C 39M-05	Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 78-02	Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C 94/C 94M-05	Specification for Ready-Mixed Concrete
C 138/C 138M-01a	Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C 143/C 143M-05a	Test Method for Slump of Hydraulic-Cement Concrete
C 171-03	Specification for Sheet Materials for Curing Concrete
C 173/C 173M- 01$^{\varepsilon 1}$	Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C 192/C 192M-05	Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 231-04	Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C 293-02	Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading)
C 1064/C 1064M-05	Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete

1.2.4 Abbreviations for and complete names and addresses of organizations issuing documents referred to in this Specification are listed:

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1.3—Definitions

day—a period of 24 consecutive hours.

evaporation retardant—a material that generates a continuous thin film when spread over water on the surface of fresh concrete and thus retards the evaporation of bleed water.

hot weather—job-site conditions that accelerate the rate of moisture loss or rate of cement hydration of freshly mixed concrete, including an ambient temperature of 27 °C (80 °F) or higher, and an evaporation rate that exceeds 1 kg/m^2/h, or as revised by the Architect/Engineer.

hot weather concreting—operations concerning the preparation, production, delivery, placement, finishing, protection, and curing of concrete during hot weather.

moist—slightly damp but not quite dry to the touch; "wet" implies visible free water, "damp" implies less wetness than "wet," and "moist" implies not quite dry.

protection period—the required time during which the concrete is protected against thermal cracking due to rapid temperature drops.

temperature of fresh concrete—the temperature measured during the discharge and placement in accordance with ASTM C 1064/C 1064M.

temperature of hardened concrete—the temperature measured at the concrete surface.

units—values stated in either U.S. Customary or SI units shall be regarded separately as standard. Values stated in each system might not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

1.4—Submittal of procedures

1.4.1 Before hot weather concreting and the preplacement conference, submit to Architect/Engineer for review and comment detailed procedures, including production, placement, finishing, curing and protection of concrete during hot weather concreting.

1.5—Preplacement conference

1.5.1 At least 15 days before the start of the concrete construction schedule, hold a preplacement conference for the purpose of reviewing hot weather concreting requirements and mix designs.

1.5.2 Send a preplacement conference agenda on hot weather operations and procedures to representatives of concerned parties not less than 10 days before the scheduled date of the conference.

1.5.3 Preplacement conference shall include, but is not limited to, representation of Contractor, Concrete Subcontractor, Testing Agency, Pumping Contractor, and Ready-Mixed Concrete Producer.

1.5.4 Distribute the minutes of the preplacement conference to representatives of concerned parties within 5 days after the preplacement conference.

1.6—Documents required on site

1.6.1 Copies of ACI 305R, ACI 305.1, and ACI 308.1 must be available at the project site during concrete construction.

SECTION 2—PRODUCTS

2.1—General

2.1.1 Store all materials and equipment required for curing and protection at or near the project site before hot weather concreting commences.

2.1.2 *Initial site curing of strength test specimens for acceptance*—Provide facilities that ensure compliance with the initial curing requirements of ASTM C 31/C 31M.

2.2—Concrete mixture proportions

2.2.1 Submit concrete mixture proportions to Architect/Engineer for review. Include specific materials, manufacturer, and type for hot weather concreting.

SECTION 3—EXECUTION

3.1—General

3.1.1 Do not place concrete against surfaces of absorbent materials that are dry. Do not place concrete against surfaces that have free water.

3.1.2 Prepare all materials required for accepted evaporation control measures and have them available on site so that specified measures can be executed as necessary.

3.1.3 Initiate accepted evaporation control measures when concrete and air temperatures, relative humidity of the air, and the wind velocity have the capacity to evaporate water from a free water surface at a rate that is equal to or greater than 1.0 kg/m^2/h (0.2 lb/ft^2/h), unless otherwise specified. Determine the evaporation rate of surface moisture by use of the Menzel Formula:

$$W = 0.315(e_o - e_a)(0.253 + 0.060V) \text{ [SI units]}$$

$$W = 0.44(e_o - e_a)(0.253 + 0.096V) \text{ [U.S. Customary units]}$$

where

W = mass of water evaporated in kg (lb) per m^2 (ft^2) of water-covered surface per hour;

e_o = saturation water vapor pressure in kPa (psi) in the air immediately over the evaporating surface, at the temperature of the evaporating surface. Obtain this value from Table 3.1(a) or (b). The temperature of the evaporating surface shall be taken as the concrete temperature;

e_a = water vapor pressure in kPa (psi) in the air surrounding the concrete. Multiply the saturation vapor pressure at the temperature of the air surrounding the concrete by the relative humidity of the air. Air temperature and relative humidity are to be measured at a level approximately 1.2 to 1.8 m (4 to 6 ft) above the evaporating surface on the windward side and shielded from the sun's rays; and

V = average wind speed in km/h (mph), measured at 0.5 m (20 in.) above the evaporating surface.

3.1.3.1 Monitor site conditions (air temperature, humidity, wind speed) to assess the need for evaporation control measures beginning no later than 1 hour before the start of concrete placing operations. Continue to monitor site conditions at intervals of 30 minutes or less until specified curing procedures have been applied.

3.1.3.2 For measuring the rate of evaporation of surface moisture, use equipment or instruments that are certified by the manufacturer as accurate to within 1 °C (2 °F), 5% relative humidity, and 1.6 km/h (1 mph) wind speed. Use equipment in accordance with the product manufacturer recommendations.

3.2—Maximum allowable concrete temperature

3.2.1 Limit the maximum allowable fresh concrete temperature to 35 °C (95 °F), unless otherwise specified, or unless a higher allowable temperature is accepted by Architect/Engineer, based upon past field experience or preconstruction testing using a concrete mixture similar to one known to have been successfully used at a higher concrete temperature.

Table 3.1(a)—Saturation water vapor pressure (kPa) over water (SI units)

Air and concrete temperature, °C	Saturation pressure, kPa	Air and concrete temperature, °C	Saturation pressure, kPa
4	0.813	28	3.78
5	0.872	29	4.01
6	0.934	30	4.24
7	1.00	31	4.49
8	1.07	32	4.75
9	1.15	33	5.03
10	1.23	34	5.32
11	1.31	35	5.62
12	1.40	36	5.94
13	1.50	37	6.28
14	1.60	38	6.63
15	1.70	39	6.99
16	1.82	40	7.38
17	1.94	41	7.78
18	2.06	42	8.20
19	2.20	43	8.64
20	2.34	44	9.10
21	2.49	45	9.58
22	2.64	46	10.1
23	2.81	47	10.6
24	2.98	48	11.2
25	3.17	49	11.7
26	3.36	50	12.3
27	3.56		

Data source: *CRC Handbook of Chemistry and Physics*, 68th Edition, 1987, mathematically converted into kPa.

3.2.2 Measure the fresh concrete temperature at the point and time of discharge in accordance with ASTM C 1064/C 1064M. Frequency of temperature determination shall be in accordance with ASTM C 94/C 94M and at the option of the inspector.

3.3—Qualification of concrete mixture proportions

3.3.1 Approval of concrete mixture and proposed maximum allowable fresh concrete temperature, supported by past field experience of Section 3.2.1, shall be based, on similar climate and production conditions, materials, mixture proportions and temperatures, placing and finishing methods, and concrete delivery time.

3.3.2 Approval of concrete mixture and proposed maximum allowable fresh concrete temperature, supported by preconstruction testing of Section 3.2.1, shall require materials similar to those proposed for use in the project.

3.3.3 *Laboratory trial batch*—Batch the laboratory concrete trial mixture within 2 °C (3 °F) of the proposed maximum allowable concrete temperature and mix in accordance with ASTM C 192/C 192M, except as modified herein. If necessary, move the laboratory mixer into an enclosed, heated and ventilated space, or use heated mixing water, or both, to achieve and maintain the proposed maximum allowable concrete temperature. For drum-type mixers, the concrete mixture shall remain in the mixer for 47 minutes after completion of the 3-minute initial mixing period unless specified otherwise. During the 50-minute period, cover the mixer opening with a non-absorbent material, such as plastic, to prevent moisture loss, and rotate the mixer continuously at an agitation speed of 6 to 8 rpm. For laboratory mixers without speed adjustments, simulate agitation by rotating the mixer continuously at a drum angle between 45 and 75 degrees from horizontal. At the end of 50 minutes, mix the concrete mixture at full mixing speed designated by the manufacturer (8 to 20 rpm) for 2 minutes.

For pan-type mixers, the concrete mixture shall remain in the mixer for 41 minutes after completion of the initial 3-minute

Table 3.1(b)—Saturation water vapor pressure (psi) over water (U.S. Customary units)

Air and concrete temperature, °F	Saturation pressure, psi	Air and concrete temperature, °F	Saturation pressure, psi
40	0.121	81	0.523
41	0.127	82	0.542
42	0.132	83	0.559
43	0.137	84	0.577
44	0.143	85	0.595
45	0.147	86	0.615
46	0.153	87	0.637
47	0.159	88	0.658
48	0.166	89	0.679
49	0.171	90	0.698
50	0.178	91	0.722
51	0.185	92	0.746
52	0.192	93	0.769
53	0.199	94	0.789
54	0.206	95	0.816
55	0.214	96	0.843
56	0.222	97	0.870
57	0.231	98	0.896
58	0.238	99	0.920
59	0.247	100	0.951
60	0.257	101	0.981
61	0.267	102	1.01
62	0.277	103	1.04
63	0.285	104	1.07
64	0.296	105	1.10
65	0.308	106	1.13
66	0.319	107	1.17
67	0.327	108	1.20
68	0.339	109	1.24
69	0.352	110	1.27
70	0.366	111	1.31
71	0.378	112	1.35
72	0.388	113	1.39
73	0.403	114	1.43
74	0.418	115	1.47
75	0.433	116	1.52
76	0.443	117	1.56
77	0.459	118	1.60
78	0.476	119	1.65
79	0.494	120	1.70
80	0.510		

Data source: *CRC Handbook of Chemistry and Physics*, 68th Edition, 1987, mathematically converted into °F and psi.

mixing period. During the 44-minute period, the mixer shall cycle through periods of rest for 5 minutes, and then mixing for 1 minute. During the rest period, cover the mixer opening with a non-absorbent material, such as plastic, to prevent moisture loss. At the end of 44 minutes, mix the concrete mixture at full mixing speed designated by the manufacturer (8 to 20 rpm) for 2 minutes.

During mixing and agitation periods for both drum-type and pan-type mixers, the addition of water, chemical admixture, or both, to adjust slump is permitted provided that the specified concrete mixture *w/cm* is not exceeded. As needed, check and adjust the slump of the concrete mixture during the middle 1/3 of the 50- or 44-minute laboratory trial mixing period.

3.3.3.1 The proposed concrete mixture shall meet the specified slump range at the end of the laboratory mixing period and meet the required strength at the specified test age.

3.3.4 *Field trial batch*—Batch the field concrete trial mixture within 2 °C (3 °F) of the proposed maximum allowable concrete temperature in a truck-mixer with a minimum batch size of 3 m^3 (4 yd^3). If necessary, move the truck mixer into an enclosed, heated, and ventilated space to achieve a concrete temperature within the specified tolerance of the proposed maximum allowable concrete temperature.

The concrete mixture shall be held in the mixer for 90 minutes, unless otherwise specified by the Architect/Engineer. During the entire 90-minute period, agitate the mixer at 1 to 6 rpm. At the end of 90 minutes, mix the concrete mixture at full mixing speed designated by the manufacturer (6 to 18 rpm) for 2 minutes. During mixing and agitation periods, the addition of water, chemical admixture, or both, to adjust slump is permitted provided that the specified concrete mixture *w/cm* is not exceeded. As needed, check and adjust the slump of the concrete mixture during the middle 1/3 of the 90-minute mixing period.

3.3.4.1 The proposed concrete mixture shall be within the specified slump range at the end of the 90-minute field mixing period and meet the required strength at the specified test age.

3.3.5 Test values obtained in accordance with the appropriate ASTM Standard shall include compressive strength (C 192/C 192M or C 31/C 31M, and C 39/C 39M), flexural strength (C 192/C 192M and either C 78 or C 293; C 31/C 31M and either C 78 or C 293), or both; slump (C 143/C 143M); air content (C 231, C 173/C 173M, or C 138/C 138M); concrete density (unit weight) (C 138/ C 138M); and concrete temperature (C 1064/C 1064M). Slump, air content, and concrete and air temperature measurements shall be performed after initial mixing, intermediately as needed or as desired, and at the conclusion of the mixing period along with the other specified tests.

3.3.6 *Acceptance of concrete mixture proportions*—Submit to the Architect/Engineer for acceptance a request for a specific higher maximum allowable concrete temperature. Include the constituent materials and proportions of the proposed concrete mixture and all values obtained from past field experience or preconstruction testing. Test results shall be within the Project Specification ranges and tolerances.

3.4—Concrete production and delivery

3.4.1 Concrete shall be produced at a temperature such that its maximum temperature at discharge will not exceed the specified maximum allowable concrete temperature. Acceptable production methods to reduce the temperature of the concrete include: shading aggregate stockpiles, sprinkling water on coarse aggregate stockpiles; using chilled water for concrete production; substituting chipped or shaved iced for portions of the mixing water; and cooling concrete materials using liquid nitrogen. The submittals for hot weather concreting shall indicate which methods will be used and in what order they will be initiated when multiple methods are to be used. The substitution of other cooling methods will be considered by the Architect/Engineer when requested in the submittal and accompanied by satisfactory supporting data.

3.4.2 Unless otherwise specified, deliver concrete in accordance with ASTM C 94/C 94M, which requires the concrete to be discharged within 1-1/2 hours or before the truck-mixer drum has revolved 300 revolutions, whichever comes first.

3.5—Concrete placement and finishing

3.5.1 Concrete placement and finishing operations shall proceed as quickly as conditions will permit.

3.6—Concrete bleed-water evaporation

3.6.1 Control concrete surface bleed-water evaporation with application of evaporation reducers, plastic sheeting, fog spray, or wind breaks. Use these materials and methods in accordance with ACI 308.1.

3.7—Concrete curing

3.7.1 *Concrete curing*—Cure concrete in accordance with ACI 308.1.

3.8—Concrete protection

3.8.1 *Protection period*—Protect the concrete against thermal shrinkage cracking due to rapid drops in concrete temperature greater than 22 °C (40 °F) during the first 24 hours unless otherwise specified.

3.8.2 *Protection materials*—Acceptable protection materials to prevent excessive temperature drops are insulating blankets, batt insulation with moisture-proof covering, layers of dry porous material such as straw, hay, or multiple layers of impervious paper meeting ASTM C 171. These protection materials shall not be applied until the concrete surface temperature has become steady or is beginning to decline.

FOREWORD TO CHECKLISTS

F1. This Foreword is included for explanatory purposes only; it does not form a part of Specification ACI 305.1.

F2. ACI Specification 305.1 may be referenced by the Specifier in the Project Specification for any building project, together with supplementary requirements for the specific project. Responsibilities for project participants must be defined in the Project Specification. The ACI Specification cannot and does not address responsibilities for any project participant other than the Contractor.

F3. Checklists do not form a part of ACI Specification 305.1. Checklists assist the Specifier in selecting and specifying project requirements in the Project Specification.

F4. The Specifier shall make adjustments to the needs of a particular project by reviewing each of the items in the checklists and including the items the Specifier selects as mandatory requirements in the Project Specification.

F5. The Optional Requirements Checklist identifies Specifier choices and alternatives. The checklists identify the Sections, Parts, and Articles of the reference specification and the action required or available to the Specifier.

F6. The Submittals Checklist identifies Specifier choices for information or data to be provided by the Contractor before, during, or after construction.

F7. *Recommended references*—Documents and publications that are referenced in the Checklists of ACI Specification 305.1 are listed. These references provide guidance to the Specifier and are not considered to be part of ACI Specification 305.1.

American Concrete Institute

305R	Hot Weather Concreting
308R	Guide to Curing Concrete

OPTIONAL REQUIREMENTS CHECKLIST

Section/Part/Article	Notes to Architect/Engineer
1.2	Review applicability of cited references and make exceptions if required.
3.1.3	The 1.0 kg/m^2/h (0.2 lb/ft^2/h) default value may be revised by the Architect/Engineer. Concrete mixtures containing conventional or ultra-fine pozzolan or other cementitious materials may require lower allowable evaporation rates. Further guidance is available in Sections 2.1.4 through 2.1.6 of ACI 305R.
3.2.1	A change in the maximum allowable concrete temperature may be appropriate. A maximum concrete temperature at the time of discharge is often used in an effort to control strength, durability, plastic shrinkage cracking, thermal cracking, and drying shrinkage. Generally, if concrete strengths are satisfactory and curing practices are sufficient to avoid undesirable drying of surfaces, durability of hot weather concrete will not differ significantly from similar concrete placed at normal temperatures. A higher allowable maximum concrete temperature may be specified by the Architect/Engineer based on previous field experience, similar conditions, and concrete materials.
3.3.3	ACI 305R presents two additional trial batch procedures available for laboratory use. These procedures (A and B of 305R, Section 2.9.4) produce slump loss similar to that expected for 30- to 40-minute delivery times. The laboratory trial batch procedure in Section 3.3.3 is based on delivery time plus holding times approaching 1-1/2 hours. Specify a shorter duration laboratory batch trial if applicable.
3.3.4	The default time of 90 minutes corresponds with the normal default time provided in ASTM C 94/C 94M. If a different maximum field mixing time is to be permitted or required, the field trial batch time should be altered to match the specification.
3.4.2	In hot weather, a time of less than 1-1/2 hours, such as 1 hour, may be specified. The limitations of ASTM C 94/C 94M, Paragraph 11.7, are permitted to be waived by the purchaser if the concrete is of such slump that it can be placed without the addition of water. With extended set control admixtures, concrete slump can be maintained without the addition of water for up to 10 hours with no detrimental effect to the concrete in place.
3.8.1	Rapid temperature drops of the concrete can lead to thermal cracking. Concrete exposed to rapid cooling has a lower tensile strain capacity and is more susceptible to cracking than concrete cooled slowly.

SUBMITTALS CHECKLIST

NOTE: The items listed will be submitted by the Contractor and reviewed by the Architect/Engineer.

Notify the Contractor of acceptance or rejection after review of submittals. All submittals and responses should be retained in files for future reference during the Work. Some submittal requirements shown will apply only when optional requirements are selected and written into the Project Specifications. Once optional requirements have been selected, review the Section/Part/Article indicated for the submittal item to see if it applies.

Section/Part/Article	Submittal items and notes to Architect/Engineer
2.2.1 3.4.1	The submittal shall include concrete mixture adjustment parameters and methods to be implemented during changes in weather conditions. These may include partial cement substitution with fly ash, pozzolans, or ground-granulated blast-furnace slag; use of chemical admixtures, ice or chilled water, or liquid nitrogen; or cooling of aggregates.
3.3.6	These submittals are a result of the preconstruction testing to verify a proposed concrete mixture will function satisfactorily at a concrete temperature greater than 35 °C (95 °F). Full-size field batches are preferred over laboratory batches. Submittals should include all test results.
3.6.1	Submit for approval the desired method to be used when concreting during periods with evaporation rates higher than permitted.

APPENDIX A—THE MENZEL FORMULA AND ESTIMATED SURFACE EVAPORATION RATES

The modified NRMCA Nomograph for Estimated Surface Evaporation Rates is intended as a graphical guide to determine an approximate solution of the Menzel Formula described in Section 3.1.3. The nomograph and this appendix are not a part of ACI Specification 305.1. They are intended only to assist in field estimations of surface evaporation rates and do not replace the Menzel Formula for meeting the requirements of Section 3.1.3.

EXAMPLE OF MENZEL FORMULA (SI UNITS)

Air temperature	40 °C
Relative humidity	45%
Concrete temperature	35 °C
Wind speed V	16 km/h

From Table 3.1(a) for saturation pressure:
Concrete temperature of 35 °C: $e_o = 5.623$ kPa
Saturated water vapor pressure of air at 40 °C = 7.374 kPa
$e_a = 7.374 \times 0.45 = 3.3$ kPa (*limited to two significant figures by relative humidity value*)

Calculations: $W = 0.315(e_o - e_a)(0.253 + 0.060V)$

$W = 0.315(5.623 - (7.374 \times 0.45))(0.253 + (0.060 \times 16))$
(*precision on wind speed is two significant figures*)
(*precision on subtraction of vapor pressures limited to two significant figures*)

$W = 0.315(5.623 - 3.318)(0.253 + 0.96)$
(*precision on addition of 0.253 + 0.96 limited to two decimal places*)

$W = 0.315(2.3)(1.21)$
(*precision limited to two significant figures by 2.3*)

$W = 0.88$ kg/m^2/h

In this example, 0.88 kg/m^2/h is less than the specified evaporation rate of free surface water of 1.0 kg/m^2/h, as listed in Section 3.1.3. This example would indicate that, although the evaporation rate is approaching the specified limit, measures to reduce the evaporation rate would not be required by specification. For some mixtures, however, this evaporation rate could result in plastic shrinkage cracking, which is why the Architect/Engineer may select a lower specified value, for example 0.75 kg/m^2/h, in accordance with the Optional Requirements Checklist.

EXAMPLE OF MENZEL FORMULA (U.S. CUSTOMARY UNITS)

Air temperature	104 °F
Relative humidity	45%
Concrete temperature	95 °F
Wind speed V	10 mph

From Table 3.1(b) for saturation pressure:
Concrete temperature of 95 °F: $e_o = 0.816$ psi
Saturated water vapor pressure of air at 104 °F = 1.070 psi
$e_a = 1.070 \times 0.45 = 0.48$ psi (*limited to two significant figures by relative humidity value*)

Calculations: $W = 0.44(e_o - e_a)(0.253 + 0.096V)$

$W = 0.44(0.816 - (1.070 \times 0.45))(0.253 + (0.096 \times 10))$
(*precision on wind speed is two significant figures*)
(*precision on subtraction of vapor pressures limited to two decimal places*)

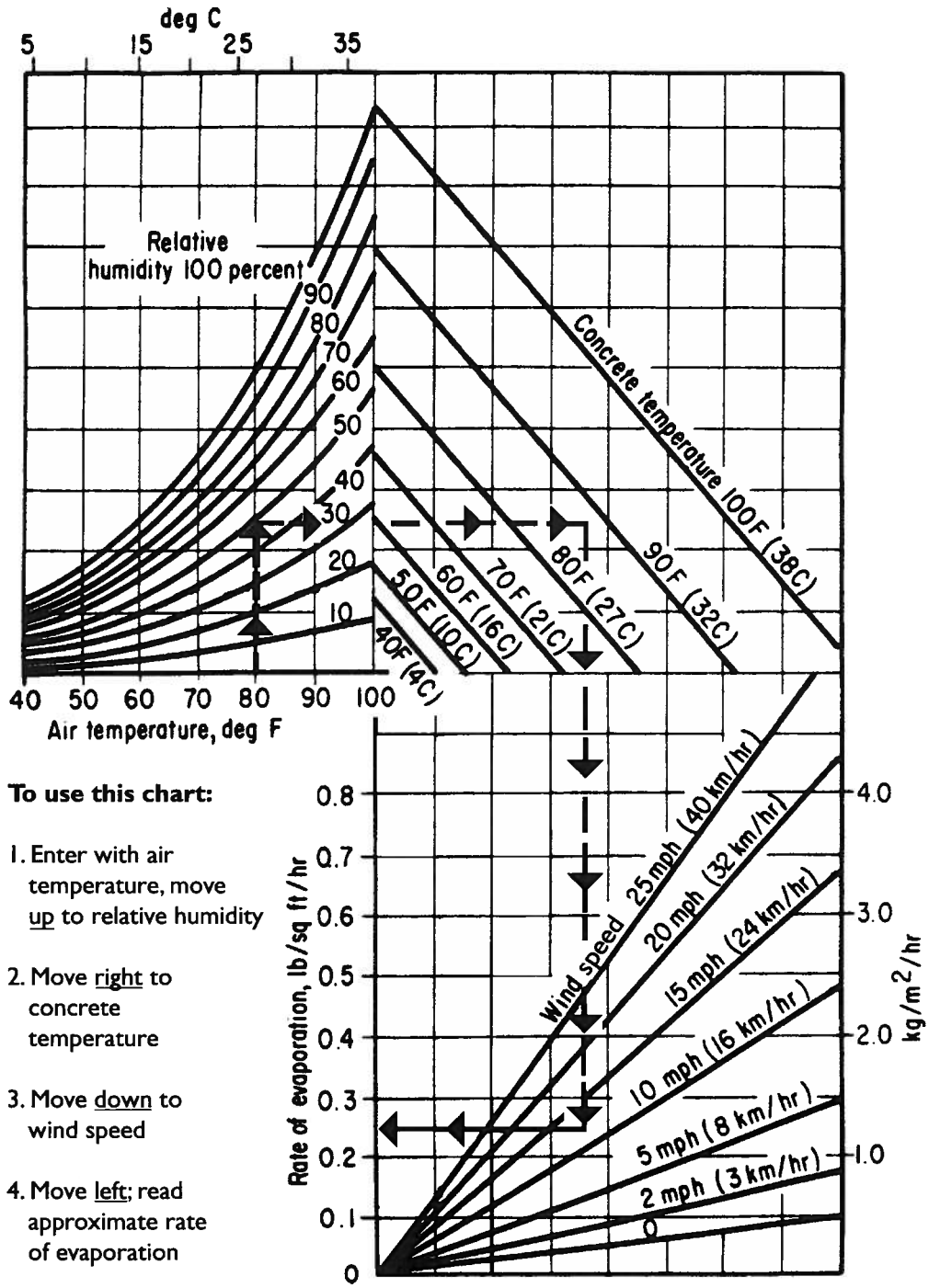
$W = 0.44(0.82 - 0.48)(0.253 + 0.96)$
(*precision on addition of 0.253 + 0.96 limited to two decimal places*)

$W = 0.44(0.34)(1.21)$
(*precision limited to two significant figures by 0.34 and by empirical constant 0.44*)

$W = 0.18$ lb/ft^2/h

In this example, 0.18 lb/ft^2/h is less than the value (0.2 lb/ft^2/h, specified in Section 3.1.3. This example would indicate that, although the evaporation rate is approaching the specified limit, measures to reduce the evaporation rate would not be required by specification. For some mixtures, however, this evaporation rate could result in plastic shrinkage cracking, which is why the Architect/Engineer may select a lower specified value, for example 0.15 lb/ft^2/h, in accordance with the Optional Requirements Checklist.

NRMCA NOMOGRAPH FOR ESTIMATING EVAPORATION RATE ON THE BASIS OF MENZEL FORMULA



To use this chart:

1. Enter with air temperature, move up to relative humidity
2. Move right to concrete temperature
3. Move down to wind speed
4. Move left; read approximate rate of evaporation

*Effect of concrete and air temperatures, relative humidity, and wind speed on the rate of evaporation of surface moisture from concrete. This chart provides a graphic method of estimating the loss of surface moisture for various weather conditions. To use this chart, follow the four steps outlined above. If the rate of evaporation approaches 1 kg/m^2/h (0.2 lb/ft^2/h), precautions against plastic-shrinkage cracking are necessary (Lerch 1957). Wind speed is the average horizontal air or wind speed in km/h (mph) and should be measured at a level approximately 510 mm (20 in.) higher than the evaporating surface. Air temperature and relative humidity should be measured at a level approximately 1.2 to 1.8 m (4 to 6 ft) higher than the evaporating surface on its windward side shielded from the sun's rays (*PCA Journal *1957).*

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Specification for Hot Weather Concreting

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ACI 306R-88

(Reapproved 2002)

Cold Weather Concreting

Reported by ACI Committee 306

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The general requirements for producing satisfactory concrete during cold weather are discussed, and methods for satisfying these requirements are described. One of the objectives of cold weather concreting practice is to provide protection of the concrete at early ages to prevent damage from freezing. For many structural concretes, protection considerably in excess of that required to prevent damage by early freezing is needed to assure development of adequate strength.

The following items are discussed in the report: recommended temperature of concrete, temperature records, temperature of materials, preparations prior to placement, duration of protection period, methods for determining in-place strength, form removal, protective insulating covers, heated enclosures, curing methods, and accelerating admixtures. References are included that provide supplementary data on the effects of curing temperature on concrete strength.

Keywords: accelerating admixtures; age; aggregates; calcium chloride; cold weather; compressive strength; concrete construction; concretes; curing; durability; form removal; formwork (construction); freeze-thaw durability; heating; in-place testing; insulation; materials handling; protection; subgrade preparation; temperature.

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ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in designing, planning, executing, or inspecting construction and in preparing specifications. Reference to these documents shall not be made in the Project Documents. If items found in these documents are desired to be part of the Project Documents they should be phrased in mandatory language and incorporated into the Project Documents.

*Task force member.

This report supercedes ACI 306R-78 (Revised 1983).

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CHAPTER 1 - INTRODUCTION

1.1 - Definition of cold weather

This report describes construction procedures which, if properly followed, can result in concrete placed in cold weather of sufficient strength and durability to satisfy intended service requirements. Concrete placed during cold weather will develop these qualities only if it is properly produced, placed, and protected. The necessary degree of protection increases as the ambient temperature decreases.

Cold weather is defined as a period when, for more than 3 consecutive days, the following conditions exist: 1) the average daily air temperature is less than 40 F (5 C) and 2) the air temperature is not greater than 50 F (10 C) for more than one-half of any 24-hr period.* The average daily air temperature is the average of the highest and the lowest temperatures occurring during the period from midnight to midnight. Cold weather, as defined in this report, usually starts during fall and usually continues until spring.

1.2 - Standard specification

If requirements for cold weather concreting are needed in specification form, ACI 306.1 should be referenced; if necessary, appropriate modifications should be added to the contract documents after consulting the specification checklist.

1.3 - Objectives

The objectives of cold weather concreting practices are to:

1.3.1 - prevent damage to concrete due to freezing at early ages. When no external water is available, the degree of saturation of newly placed concrete decreases as the concrete gains maturity and the mixing water combines with cement during hydration. Under such conditions, the degree of saturation falls below the critical level (the degree of water saturation where a single cycle of freezing would cause damage) at approximately the time that the concrete attains a compressive strength of 500 psi (3.5 MPa) (Powers 1962). At 50 F (10 C), most well-proportioned concrete mixtures reach this strength during the second day.

1.3.2 - assure that the concrete develops the required strength for safe removal of forms, for safe removal of shores and reshores, and for safe loading of the structure during and after construction.

1.3.3 - maintain curing conditions that foster normal strength development without using excessive heat and without causing critical saturation of the concrete at the end of the protection period.

1.3.4 - limit rapid temperature changes, particularly before the concrete has developed sufficient strength to withstand induced thermal stresses. Rapid cooling of concrete surfaces or large temperature differences between exterior and interior members of the structure can cause cracking, which can be detrimental to strength and durability. At the end of the required period, insulation or other means of protection should be removed gradually so that the surface temperature decreases gradually during the subsequent 24-hr period (see Section 5.5).

1.3.5 - provide protection consistent with the intended serviceability of the structure. Concrete structures are intended for a useful life of many years. The attainment of satisfactory strength for 28-day, standard-cured cylinders is irrelevant if the structure has corners damaged by freezing; dehydrated areas; and cracking from overheating because of inadequate protection, improper curing, or careless workmanship. Similarly, early concrete strength achieved by indiscriminate use of excessive calcium chloride is of no avail if the concrete becomes excessively cracked in later years because of the likelihood of disruptive internal expansion due to alkali-aggregate reaction or of possible corrosion of reinforcement (see Section 9.2). Short-term construction economy should not be obtained at the expense of long-term durability.

1.4 - Principles

This report presents recommendations to achieve the objectives listed in Section 1.3 (Schnarr and Young 1934a and 1934b). The practices and procedures described in this report stem from the following principles concerning cold weather concreting:

1.4.1 - Concrete that is protected from freezing until it has attained a compressive strength of at least 500 psi (3.5 MPa) will not be damaged by exposure to a single freezing cycle (Powers 1962).

1.4.2 - Concrete that is protected as in Section 1.4.1 will mature to its potential strength despite subsequent exposure to cold weather (Malhotra and Berwanger 1973). No further protection is necessary unless a certain strength must be attained in less time.

*The values in SI units are direct conversions of the in.-lb values. They do nor necessarily represent common metric ranges or sizes. For practical application. The user should adjust them to conform with local practice.

Table 3.1 - Recommended concrete temperatures

Line	Air temperature	Section size, minimum dimension, in. (mm)			
		< 12 in. (300 mm)	12-36 in. (300-900 mm)	36-72 in. (900-1800 mm)	> 72 in. (1800 mm)
Minimum concrete temperature as placed and maintained					
1	-	55 F (13 C)	50 F (10 C)	45 F (7 C)	40 F (5 C)
Minimum concrete temperature as mixed for indicated air temperature*					
2	Above 30 F (- 1 C)	60 F (16 C)	55 F (13 C)	50 F (10 C)	45 F (7 C)
3	0 to 30 F (-18 to -1 C)	65 F (18 C)	60 F (16 C)	55 F (13 C)	50 F (10 C)
4	Below 0 F (- 18 C)	70 F (21 C)	65 F (18 C)	60 F (16 C)	55 F (13 C)
Maximum allowable gradual temperature drop in first 24 hr after end of protection					
5	-	50 F (28 C)	40 F (22 C)	30 F (17 C)	20 F (11 C)

*For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

1.4.3 - Where a specified concrete strength must be attained in a few days or weeks, protection at temperatures above 50 F (10 C) is required. See Chapters 5 and 6.

1.4.4 - Except within heated protective enclosures, little or no external supply of moisture is required for curing during cold weather. See Chapter 8.

1.4.5 - Under certain conditions, calcium chloride should not be used to accelerate setting and hardening because of the increased chances of corrosion of metals embedded in concrete or other adverse effects. See Chapter 9.

Times and temperatures given in this report are not exact values for all situations and they should not be used as such. The user should keep in mind the primary intent of these recommendations and should use discretion in deciding what is adequate for each particular circumstance.

1.5 - Economy

Experience has shown that the overall costs of adequate protection for cold weather concreting are not excessive, considering what is required and the resulting benefits. The owner must decide whether the extra costs involved in cold weather concreting operations are a profitable investment or if it is more cost effective to wait for mild weather. Neglect of protection against early freezing can cause immediate destruction or permanently weakened concrete. Therefore, if cold weather concreting is performed, adequate protection from low temperatures and proper curing are essential.

CHAPTER 2 - GENERAL REQUIREMENTS

2.1 - Planning

It is recommended that the concrete contractor, concrete supplier, and owner (or architect/engineer) meet in a preconstruction conference to define in clear terms how cold weather concreting methods will be used. This report provides a basis for the contractor to select specific methods to satisfy the minimum requirements during cold weather concreting,

Plans to protect fresh concrete from freezing and to maintain temperatures above the recommended minimum values should be made well before freezing temperatures are expected to occur. Necessary equipment and materials should be at the work site before cold weather is likely to occur, not after concrete has been placed and its temperature begins to approach the freezing point.

2.2 - Protection during fall and spring

During periods not defined as cold weather, such as in fall or spring, but when heavy frost or freezing is forecast at the job site,* all concrete surfaces should be protected from freezing for at least the first 24 hr after placement. Concrete protected in this manner will be safe from damage by freezing at an early age. If the concrete is air entrained and properly cured, the ultimate strength and durability of the concrete will be unimpaired. Protection from freezing during the first 24 hr does not assure a satisfactory rate of strength development, particularly when followed by considerably colder weather. Protection and curing should continue long enough - and at a temperature sufficiently above freezing - to produce the strength required for form removal or structural safety (see Chapters 5 and 6).

2.3 - Concrete temperature

During cold weather, the concrete temperature at the time of placement should not be lower than the values given in Chapter 3. In action, to prevent freezing at early ages, the concrete temperature should be maintained at not less than the recommended placement temperature for the length of time given in Chapter 5. This length of time depends on the type and amount of cement, whether an accelerating admixture is used, and the service category.

The recommended minimum placement temperatures given in Table 3.1 in Chapter 3 apply to normal weight

*Charts showing mean dates of freezing weather in the United States may be obtained from the National Climatic Center, Federal Building, Ashville, NC 28801

concrete. Experience indicates that freshly mixed lightweight concrete loses heat more slowly than freshly mixed normal-weight concrete. Lighter weight insulating concretes lose heat even more slowly. However, when exposed to freezing temperatures, such concretes are more susceptible to damage from surface freezing.

The temperature of concrete at the time of placement should always be near the minimum temperatures given in Chapter 3, Table 3.1. Placement temperatures should not be higher than these minimum values by more than 20 F (11 C). One should take advantage of the opportunity provided by cold weather to place low-temperature concrete. Concrete that is placed at low temperatures [40 to 55 F (5 to 13 C)] is protected against freezing and receives long-time curing, thus developing a higher ultimate strength (Klieger 1958) and greater durability. It is, therefore, less subject to thermal cracking than similar concrete placed at higher temperatures. Placement at higher temperatures may expedite finishing in cold weather, but it will impair long-term concrete properties.

2.4 - Temperature records

The actual temperature at the concrete surface determines the effectiveness of protection, regardless of air temperature. Therefore, it is desirable to monitor and record the concrete temperature. Temperature recording and monitoring must consider the following:

2.4.1 - The corners and edges of concrete are more vulnerable to freezing and usually are more difficult to maintain at the required temperature, therefore, their temperature should be monitored to evaluate and verify the effectiveness of the protection provided.

2.4.2 - Inspection personnel should keep a record of the date, time, outside air temperature, temperature of concrete as placed, and weather conditions (calm, windy, clear, cloudy, etc.). Temperatures of concrete and the outdoor air should be recorded at regular time intervals but not less than twice per 24-hr period. The record should include temperatures at several points within the enclosure and on the concrete surface, corners, and edges. There should be a sufficient number of temperature measurement locations to show the range of concrete temperatures. Temperature measuring devices embedded in the concrete surface are ideal, but satisfactory accuracy and greater flexibility of observation can be obtained by placing thermometers against the concrete under temporary covers of heavy insulating material until constant temperatures are indicated.

2.4.3 - Maximum and minimum temperature readings in each 24-hr period should be recorded. Data recorded should clearly show the temperature history of each section of concrete cast. A copy of the temperature readings should be included in the permanent job records. It is preferable to measure the temperature of concrete at more than one location in the section cast and use the lowest reading to represent the temperature of that section. Internal temperature of concrete should be monitored to insure that excessive heating does not occur (see Section 7.4). For this, expendable thermistors or thermocouples cast in the concrete may be used.

2.5 - Heated enclosures

Heated enclosures must be strong enough to be windproof and weatherproof. Otherwise, proper temperatures at corners, edges, and in thin sections may not be maintained despite high energy consumption. Combustion heaters should be vented and they should not be permitted to heat or to dry the concrete locally. Fresh concrete surfaces exposed to carbon dioxide, resulting from the use of salamanders or other combustion heaters that exhaust flue gases into an enclosed area, may be damaged by carbonation of the concrete. Carbonation may result in soft surfaces or surface crazing depending on the concentration of carbon dioxide, the concrete temperature, and the relative humidity (see Section 7.4). Carbon monoxide, which can result from partial combustion, and high levels of carbon dioxide are potential hazards to workers.

In addition, strict fire prevention measures should be enforced. Fire can destroy the protective enclosures as well as damage the concrete. Concrete can be damaged by fire at any age. However, at a very early age additional damage can occur by subsequent freezing of the concrete before new protective enclosures are provided.

2.6 - Exposure to freezing and thawing

If, during construction, it is likely that the concrete will be exposed to cycles of freezing and thawing while it is in a saturated condition, it should be properly air entrained even though it will not be exposed to freezing and thawing in service. The water-cement ratio should not exceed the limits recommended in ACI 201.2R, and the concrete should not be allowed to freeze and thaw in a saturated condition before developing a compressive strength of 3500 psi (24 MPa). Therefore, new sidewalks and other flatwork exposed to melting snow during daytime and freezing during nighttime should be air entrained and protected from freezing until a strength of at least 3500 psi (24 MPa) has been attained.

2.7 - Concrete slump

Concrete with a slump lower than normal [less than 4 in. (100 mm)] is particularly desirable in cold weather for flatwork; bleeding of water is minimized and setting occurs earlier. During cold weather, bleed water may remain on the surface for such a long period that it interferes with proper finishing. If the bleed water is mixed into the concrete during trowelling, the resulting surface will have a lower strength and may be prone to dusting and subsequent freeze-thaw damage if exposed. Thus, during cold weather, the concrete mixture should be proportioned so that bleeding is minimized as much as practicable. If bleedwater is present on flatwork, it should be skimmed off prior to trowelling by using a rope or hose.

CHAPTER 3 - TEMPERATURE OF CONCRETE AS MIXED AND PLACED AND HEATING OF MATERIALS

3.1 - Placement temperature

During cold weather, the concrete mixing temperature should be controlled as described in Section 3.2 so that when the concrete is placed its temperature is not below the values shown in Line 1 of Table 3.1. The placement temperature of concrete should be determined according to ASTM C 1064. The more massive the concrete section, the less rapidly it loses heat; therefore, lower minimum placement temperatures are recommended as concrete sections become larger. For massive structures, it is especially beneficial to have low placement temperatures (see ACI 207.1R). Concrete temperatures that are much higher than the values in Line 1 do not result in a proportionally longer protection against freezing because the rate of heat loss is greater for larger temperature differentials.

In addition, higher temperatures require more mixing water, increase the rate of slump loss, may cause quick setting, and increase thermal contraction. Rapid moisture loss from exposed surfaces of flatwork may cause plastic shrinkage cracks. Rapid moisture loss can occur from surfaces exposed to cold weather because the warm concrete heats the surrounding cold air and reduces its relative humidity (see AC1 302.1R). Therefore, the temperature of concrete as placed should be kept as close to the recommended minimum value as is practicable. Placement temperatures should not be higher than these minimum values by more than 20 F (11 C).

3.2 - Mixing temperature

The recommended minimum temperature of concrete at the time of mixing is shown in Lines 2, 3, and 4 of Table 3.1. As the ambient air temperature decreases, the concrete temperature during mixing should be increased to offset the heat lost in the interval between mixing and placing. The mixing temperature should not be more than 15 F (8 C) above the recommended values in Lines 2, 3, and 4. While it is difficult to heat aggregates uniformly to a predetermined temperature, the mixing water temperature can be adjusted easily by blending hot and cold water to obtain a concrete temperature within 10 F (5 C) of the required temperature.

3.3 - Heating mixing water

Mixing water should be available at a consistent, regulated temperature, and in sufficient quantity to avoid appreciable fluctuations in temperature of the concrete from batch to batch. Since the temperature of concrete affects the rate of slump loss and may affect the performance of admixtures, temperature fluctuations can result in variable behavior of individual batches.

Premature contact of very hot water and concentrated quantities of cement has been reported to cause flash set and cement balls in truck mixers. When water above 140 F (80 C) is used, it may be necessary to adjust the order in which ingredients are blended. It may be helpful to add the hot water and coarse aggregate ahead of the cement and to stop or slow down the addition of water while the cement and aggregate are loaded.

If the cement is batched separately from the aggregate, mixing may be more difficult. To facilitate mixing, about three-fourths of the added hot water should be placed in the drum either ahead of the aggregates or with them. To prevent packing at the end of the mixer, coarse aggregate should be added first. The cement should be added after the aggregates. As the final ingredient, the remaining one-fourth of the mixing water should be placed into the drum at a moderate rate.

Water with a temperature as high as the boiling point may be used provided that resulting concrete temperatures are within the limits discussed in Section 3.2 and no flash setting occurs. If loss of effectiveness of the air-entraining admixture is noted due to an initial contact with hot water, the admixture must be added to the batch after the water temperature has been reduced by contact with the cooler solid materials.

3.4 - Heating aggregates

When aggregates are free of ice and frozen lumps, the desired temperature of the concrete during mixing can usually be obtained by heating only the mixing water, but when air temperatures are consistently below 25 F (- 4 C), it is usually necessary to also heat the aggregates. Heating aggregates to temperatures higher than 60 F (15 C) is rarely necessary if the mixing water is heated to 140 F (60 C). If the coarse aggregate is dry and free of frost, ice, and frozen lumps, adequate temperatures of freshly mixed concrete can be obtained by increasing the temperature of only the sand, which seldom has to be above about 105 F (40 C), if mixing water is heated to 140 F (60 C). Seasonal variations must be considered, as average aggregate temperatures can be substantially higher than air temperature during autumn, while the reverse may occur during spring.

3.5 - Steam heating of aggregates

Circulating steam in pipes is recommended for heating aggregates. For small jobs, aggregates may be thawed by heating them carefully over culvert pipes in which fires are maintained. When aggregates are thawed or heated by circulating steam in pipes, exposed surfaces of aggregate should be covered with tarpaulins as much as is practicable to maintain a uniform distribution of heat and to prevent formation of ice crusts. Steam jets liberated in aggregate may cause troublesome moisture variation, but this method is the most thermally efficient procedure to heat aggregate. If steam is confined in a pipe-heating system, difficulties from variable moisture in aggregates are avoided, but the likelihood of localized hot, dry spots is increased. Wear and corrosion of steam pipes in aggregates will eventually cause leaks, which may lead to the same moisture variation problem caused by steam jets. Peri-

odic inspection of the pipes and replacement as necessary are recommended.

When conditions require thawing of substantial quantities of extremely low temperature aggregates, steam jets may be the only practicable means of providing the necessary heat. In such a case, thawing must be done as far in advance of batching as is possible to achieve substantial equilibrium in both moisture content and temperature. After thawing is completed, the steam supply can be reduced to the minimum that will prevent further freezing, thereby reducing to some extent the problems arising from variable moisture content. Nevertheless, under such conditions, mixing water control must be largely on an individual batch adjustment basis. Dry hot air instead of steam has been used to keep aggregates ice free.

3.6 - Overheating of aggregates

Aggregates should be heated sufficiently to eliminate ice, snow, and frozen lumps of aggregate. Often 3-in. (76-mm) frozen lumps will survive mixing and remain in the concrete after placing. Overheating should be avoided so that spot temperatures do not exceed 212 F (100 C) and the average temperature does not exceed 150 F (65 C) when the aggregates are added to the batch. Either of these temperatures is considerably higher than is necessary for obtaining desirable temperatures of freshly mixed concrete. Materials should be heated uniformly since considerable variation in their temperature will significantly vary the water requirement, air entrainment, rate of setting, and slump of the concrete.

Extra care is required when batching the first few loads of concrete following a prolonged period of steaming the aggregates in storage bins. Many concrete producers recycle the first few tons of very hot aggregates. This material is normally discharged and recycled by placing it on top of the aggregates in the storage bins.

3.7 - Calculation of mixture temperature

If the weights and temperatures of all constituents and the moisture content of the aggregates are known, the final temperature of the concrete mixture may be estimated from the formula

$$T = \frac{[0.22(T_s W_s + T_a W_a + T_c W_c) + T_w W_w + T_s W_{ws} + T_a W_w]}{[0.22\ (W_s + W_a + W_c) + W_w + W_{wa} + W_{ws}]} \quad (3\text{-}1)$$

where

T = final temperature of concrete mixture (deg F or C)
T_c = temperature of cement (deg F or C)
T_s = temperature of fine aggregate (deg F or C)
T_a = temperature of coarse aggregate (deg F or C)
T_w = temperature of added mixing water (deg F or C)
W_c = weight of cement (lb or kg)
W_s = saturated surface-dry weight of fine aggregate (lb or kg)
W_a = saturated surface-dry weight of coarse aggregate (lb or kg)
W_w = weight of mixing water (lb or kg)
W_{ws} = weight of free water on fine aggregate (lb or kg)
W_{wa} = weight of free water on coarse aggregate (lb or kg)

Eq. (3-l) is derived by considering the equilibrium heat balance of the materials before and after mixing and by assuming that the specific heats of the cement and aggregates are equal to 0.22 Btu/(lb F) [0.22 kcal/(kg C)].

If the temperature of one or both of the aggregates is below 32 F (0 C), the free water will be frozen, and Eq. (3-1) must be modified to take into account the heat required to raise the temperature of the ice to 32 F (0 C), to change the ice into water, and to raise the temperature of the free water to the final mixture temperature. The specific heat of ice is 0.5 Btu/(lb F) [0.5 kcal/(kg C)] and the heat of fusion of ice is 144 Btu/lb (80 kcal/kg). Thus Eq. (3-1) is modified by substituting the following expressions for $T_s W_{ws}$ or $T_a W_{wa}$, or both, depending on whether the fine aggregate or coarse aggregate, or both, are below 32 F (0 C).

For in.-lb units

$$\text{for } T_s W_{ws} \text{ substitute } W_{ws}\,(0.50 T_s - 128) \quad (3\text{-}2)$$

$$\text{for } T_a W_{wa} \text{ substitute } W_{wa}\,(0.50 T_a - 128) \quad (3\text{-}3)$$

For SI units

$$\text{for } T_s W_{ws} \text{ substitute } W_{ws}\,(0.50 T_s - 80) \quad (3\text{-}4)$$

$$\text{for } T_a W_{wa} \text{ substitute } W_{wa}(0.50 T_s - 80) \quad (3\text{-}5)$$

In these equations, the numbers 128 and 80 are obtained from the heat of fusion needed to melt the ice, the specific heat of the ice, and the melting temperature of ice.

3.8 - Temperature loss during delivery

The Swedish Cement and Concrete Research Institute (Petersons 1966) performed tests to determine the expected decrease in concrete temperature during delivery in cold weather. Their studies included revolving drum mixers, covered-dump bodies, and open-dump bodies. Approximate temperature drop for a delivery time of 1 hr can be computed using Eq. (3-6)-(3-8). For revolving drum mixers

$$T = 0.25\ (t_r - t_a) \quad (3\text{-}6)$$

For covered-dump body

$$T = 0.10\ (t_r - t_a) \quad (3\text{-}7)$$

For open-dump body

$$T = 0.20\ (t_r - t_a) \quad (3\text{-}8)$$

where

T = temperature drop to be expected during a 1-hr delivery time, deg F or C. (This value must be added to t_r to determine the required temperature of concrete at the plant.)

t_r = concrete temperature required at the job, deg F or C.

t_a = ambient air temperature, deg F or C.

The values from these equations are proportionally adjusted for delivery times greater than or less than one hour.

3.9.1 - The following examples illustrate the application of these approximate equations:

1. Concrete is to be continuously agitated in a revolving drum mixer during a 1-hr delivery period. The air temperature is 20 F and the concrete at delivery must be at least 50 F. From Eq. (3-6)

$$T = 0.25\ (50 - 20) = 7.5\ \text{F}$$

Therefore, allowance must be made for a 7.5-deg temperature drop, and the concrete at the plant must have a temperature of at least (50 + 7.5 F), or about 58 F.

2. For the same temperature conditions given in Example 1, the concrete will be delivered within 1 hr and the drum will not be revolved except for initial mixing and again briefly at the time of discharge. Assuming that Eq. (3-7) represents this situation best, the temperature drop is

$$T = 0.10\ (50 - 20) = 3\ \text{F}$$

Thus provisions must be made for a concrete temperature of (50 + 3 F), or 53 F, at the plant.

The advantage of covered dump bodies over revolving drums suggests that temperature losses can be minimized by not revolving the drum more than is absolutely necessary during delivery.

CHAPTER 4 - PREPARATION BEFORE CONCRETING

4.1 - Temperature of surfaces in contact with fresh concrete

Preparation for concreting, other than mentioned in Section 2.1, consists primarily of insuring that all surfaces that will be in contact with newly placed concrete are at temperatures that cannot cause early freezing or seriously prolong setting of the concrete. Ordinarily, the temperatures of these contact surfaces, including subgrade materials, need not be higher than a few degrees above freezing, say 35 F (2 C), and preferably not more than 10 F (5 C) higher than the minimum placement temperatures given in Line 1 of Table 3.1.

4.2 - Metallic embedments

The placement of concrete around massive metallic embedments that are at temperatures below the freezing point of the water in concrete may result in local freezing of the concrete at the interface. If the interface remains frozen beyond the time of final vibration, there will be a permanent decrease in the interfacial bond strength. Whether freezing will occur, the volume of frozen water, and the duration of the frozen period depend primarily upon the placement temperature of concrete, the relative volumes of the concrete and the embedment, and the temperature of the embedment. An analytical study, using the finite element method to solve the heat flow problem, has been reported (Suprenant and Basham 1985). Two cases were investigated: a No. 9 bar in a slab and a square steel tube filled with concrete. Based on that limited study, it was suggested that steel embedments having a cross-sectional area greater than 1 in.^{2} (650 mm^2) should have a temperature of at least 10 F (- 12 C) immediately before being surrounded by fresh concrete at a temperature of at least 55 F (13 C). Additional study is required before definitive recommendations can be formulated. The engineer/architect should determine whether the structure contains large embedments that pose potential problems. If heating is required, the heating process should not alter the mechanical or metallurgical properties of the metal. The contractor should submit the plan for heating to the engineer for approval.

4.3 - Removal of snow and ice

All snow, ice, and frost must be removed so that it does not occupy space intended to be filled with concrete. Hot-air jets can be used to remove frost, snow, and ice from forms, reinforcement, and other embedments. Unless the work area is housed, this work should be done immediately prior to concrete placement to prevent refreezing.

4.4 - Condition of subgrade

Concrete should not be placed on frozen subgrade material. The subgrade sometimes can be thawed acceptably by covering it with insulating material for a few days before the concrete placement, but in most cases external heat must be applied. Experimenting at the site will show what combinations of insulation and time causes subsurface heat to thaw the subgrade material. If necessary, the thawed material should be recompacted.

CHAPTER 5 - PROTECTION AGAINST FREEZING AND PROTECTION FOR CONCRETE NOT REQUIRING CONSTRUCTION SUPPORTS

5.1 - Protection to prevent early-age freezing

To prevent early-age freezing, protection must be provided immediately after concrete placement. Arrangements for covering, insulating, housing, or heating newly placed concrete should be made before placement. The protection that is provided should be adequate to achieve, in all sections of the concrete cast, the temperature and moisture conditions recommended in this report. In cold weather, the temperature of the newly placed concrete should be kept close to the val-

Table 5.1 - Length of protection period required to prevent damage from early-age freezing of air-entrained concrete

Line	Exposure	Protection period at temperature indicated in Line 1 of Table 3.1, days*	
		Type I or II cement	Type III cement, or accelerating admixture, or 100 lb/yd³ (60 kg/m³) of additional cement
1	Not exposed	2	1
2	Exposed	3	2

*A day is a 24-hr period.

ues shown in Line 1 of Table 3.1 for the lengths of time indicated in Table 5.1 for protection against early-age freezing. The length of the protection period may be reduced by: (1) using Type III cement; (2) using an accelerating admixture; or (3) using 100 lb/yd³ (60 kg/m³) of cement in excess of the design cement content. Line 1 of Table 5.1 refers to concrete that will be exposed to little or no freezing and thawing in service or during construction, such as in foundations and substructures. Line 2 refers to concrete that will be exposed to the weather in service or during construction.

It has been shown that when there is no external source of curing water, concrete that has attained a strength of 500 psi will not be damaged by one cycle of freezing and thawing (Powers 1962; Hoff and Buck 1983). The protection periods given in Table 5.1 may be reduced if it is verified that the concrete, including corners and edges, has attained in in-place compressive strength of at least 500 psi (3.5 MPa), and will not be expected to be exposed to more than one cycle of freezing and thawing before being buried or backfilled. Techniques for estimating the in-place strength are discussed in Chapter 6. To protect massive concrete against thermal cracking, a longer protection period than given in Table 5.1 is required. For concrete with a low cement content, a longer protection period may be needed to reach a strength of 500 psi (3.5 MPa).

5.2 - Need for additional protection

The comparatively short periods of protection shown in Table 5.1 are for air-entrained concrete having the air content recommended in ACI 211.1. These are the minimum protection requirements to prevent damage from one early cycle of freezing and thawing* and thereby assure that there is no impairment to the ultimate durability of the concrete. These short periods are permissible only when: (1) there is sufficient subsequent curing (see Chapter 8) and protection to develop the required safe strength for the specific service category (see Section 5.3); and (2) the concrete is not subject to freezing in a critically saturated condition. When there are early-age strength requirements, it is necessary to extend the protection period beyond the minimum duration given in Table 5.1.

*Since non-air-entrained concrete should not be used where freezing and thawing occur, this concrete is not covered in the recommendations. However, the limited durability potential of non-air-entrained concrete is best achieved by using a protection period that is at least twice that indicated in Table 5.1.

Table 5.3 - Length of protection period for concrete placed during cold weather

Line	Service category	Protection period at temperature indicated in Line 1 of Table 3.1, days*	
		Type I or II cement	Type III cement, or accelerating admixture, or 100 lb/yd³ (60 kg/m³) of additional cement
1	1 - no load, not exposed	2	1
2	2 - no load, exposed	3	2
3	3 - partial load, exposed	6	4
4	4 - full load	See Chapter 6	

*A day is a 24-hr period.

5.3 - Length of protection period

The length of the required protection period depends on the type and amount of cement, whether an accelerating admixture is used, and the service category (Sturrup and Clendening 1962). Table 5.3 gives the minimum length of the protection period at the temperatures given in Line 1 of Table 3.1. These minimum protection periods are recommended unless the in-place strength of the concrete has attained a previously established value. The service categories are as follows:

5.3.1 *Category 1: No load, not exposed* - This category includes foundations and substructures that are not subject to early load, and, because they are buried deep within the ground or are backfilled, will undergo little or no freezing and thawing in service. For concrete in this service category, conditions are favorable for continued natural curing. This concrete requires only the protection time recommended for Category 1 (Line 1) in Table 5.3. It is seen that for Category 1, the length of the protection period in Table 5.3 is the same as the requirement for protection against early-age freezing given in Line 1 of Table 5.1. Thus, for this service category, only protection against early-age freezing is necessary.

5.3.2 *Category 2: No load exposed* - This category includes massive piers and dams that have surfaces exposed to freezing and weathering in service but have no early strength requirements. Interior portions of these structures are self-curing. Exterior surfaces will continue to cure when natural conditions are favorable. To provide initial curing and insure durability of surfaces and edges, the concrete should receive at least the length of protection recommended for Category 2 (Line 2) in Table 5.3. It is seen that for Category 2, the length of the protection period in Table 5.3 is the same as the requirement for protection against early-age freezing given in Line 2 of Table 5.1. Thus, for this service category, only protection against early-age freezing is necessary.

5.3.3 *Category 3: Partial load, exposed* - The third category includes structures exposed to the weather that may be subjected to small, early-age loads compared

Table 5.5 - Maximum allowable temperature drop during first 24 hr after end of protection period

Section size, minimum dimensions, in. (mm)			
< 12 in. (< 300 mm)	12 to 36 in. (300 to 900 mm)	36 to 72 in. (900 to 1800 mm)	> 72 in. (> 1800 mm)
50 F (28 C)	40 F (22 C)	30 F (17 C)	20 F (11 C)

with their design strengths and will have an opportunity for additional strength development prior to the application of design loads. In such cases, the concrete should have at least the length of protection recommended for Category 3 in Table 5.3.

5.3.4 *Category 4: Full load* - This category includes structural concrete requiring temporary construction supports to safely resist construction loads. Protection requirements for this category are discussed in Chapter 6.

5.4 - Stripping of forms

During cold weather, protection afforded by forms, except those made of steel, is often of great significance. In heated enclosures, forms serve to evenly distribute the heat. In many cases, if suitable insulation or insulated forms are used, the forms, including those made of steel, would provide adequate protection without supplemental heating. Thus it is often advantageous to keep forms in place for at least the required minimum period of protection. However, an economical construction schedule often dictates their removal at the earliest practicable time. In such cases, forms can be removed at the earliest age that will not cause damage or danger to the concrete. Refer to Chapter 6 and ACI 347 for additional information on form removal.

If wedges are used to separate forms from young concrete, they should be made of wood. Usually, if the concrete is sufficiently strong, corners and edges will not be damaged during stripping. The minimum time before stripping can best be determined by experience, since it is influenced by several job factors, including type and amount of cement and other aspects of the concrete mixture, curing temperature, type of structure, design of forms, and skill of workers. After removal of forms, concrete should be covered with insulating-blankets or protected by heated enclosures for the time recommended in Table 5.3. If internal heating by embedded electrical coils is used, concrete should be covered with an impervious sheet and heating continued for the recommended time.

In the case of retaining walls, basement walls, or other structures where one side could be subjected to hydrostatic pressure, hasty removal of forms while the concrete is still relatively young may dislodge the form ties and create channels through which water can flow.

5.5 - Temperature drop after removal of protection

At the end of the protection period, concrete should be cooled gradually to reduce crack-inducing differential strains between the interior and exterior of the structure. The temperature drop of concrete surfaces should not exceed the rates indicated in Table 5.5. This can be accomplished by slowly reducing sources of heat, or by allowing insulation to remain until the concrete has essentially reached equilibrium with the mean ambient temperatures. Insulated forms, however, can present some difficulties in lowering the surface temperatures. Initial loosening of forms away from the concrete and covering with polyethylene sheets to allow some air circulation can alleviate the problem. As shown in Table 5.5, the maximum allowable cooling rates for surfaces of mass concrete are lower than for thinner members.

5.6 - Allowable temperature differential

Although concrete should be cooled to ambient temperatures to avoid thermal cracking, a temperature differential may be permitted when protection is discontinued. For example, Fig. 5.6 can be used to determine the maximum allowable difference between the concrete temperature in a wall and the ambient air temperature (winds not exceeding 15 mph [24 km/h]). These curves compensate for the thickness of the wall and its shape restraint factor, which is governed by the ratio of wall length to wall height.

CHAPTER 6 - PROTECTION FOR STRUCTURAL CONCRETE REQUIRING CONSTRUCTION SUPPORTS

6.1 - Introduction

For structural concrete, where a considerable level of design strength must be attained before safe removal of forms and shores is permitted, additional protection time must be provided beyond the minimums given in Table 5.1, since these minimum times are not sufficient to allow adequate strength gain. The criteria for removal of forms and shores from structural concrete should be based on the in-place strength of the concrete rather than on an arbitrary time duration. The recommendations in this chapter are based on job conditions meeting the requirements listed in Section 6.10.

6.2 - Tests of field-cured specimens

One method used to verify attainment of sufficient in-place strength before support is reduced, changed, or removed, and before curing and protection are discontinued, is to cast at least six field-cured test specimens from the last 100 yd^3 (75 m^3) of concrete. However, at least three specimens should be cast for each 2 hr of the entire placing time, or for each 100 yd^3 (75 m^3) of concrete, whichever provides the greater number of specimens. The specimens should be made in accordance with ASTM C 31, following the procedures given for "Curing Cylinders for Determining Form Removal Time or When a Structure May be Put into Service." The specimens should be protected immediately from the cold weather until they can be placed under the same protection provided for the parts of the structure they represent. After demolding, the cylinders should

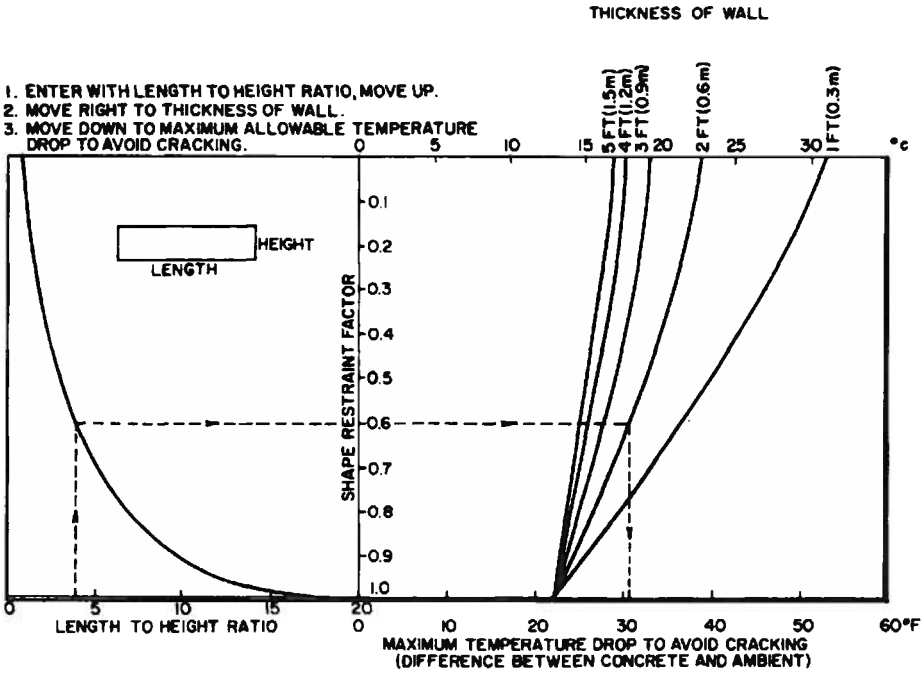

Fig. 5.6 - Graphical determination of safe differential temperature for walls (Mustard and Ghosh 1979)

be capped and tested in accordance with the applicable sections of ASTM C 31 and ASTM C 39.

For flatwork, field-cured test specimens can be obtained by using special cylindrical molds that are positioned in the formwork and filled during the placement of concrete in the structure (ASTM C 873). Since the test specimens are cured in the structure, they experience the same temperature history as the structure. When a strength determination is required, the molds are extracted from the structure and the cylinder is prepared for testing according to ASTM C 39. The holes remaining in the structure would be filled with concrete.

6.3 - In-place testing

In-place and nondestructive concrete strength testing (Malhotra 1976), when correlated with field-cured and standard-cured (ASTM C 192) cylinder test results, is another method that can be used to verify attainment of strength. These tests are performed on the concrete in the structure using portable, hand-held instruments, and they offer advantages compared with testing field-cured specimens. For example, in-place testing eliminates the difficulty of trying to prepare test specimens that truly experience the same temperature history as the concrete in the structure. Hence, they are usually preferable to testing field-cured specimens prepared according to ASTM C 31. Applicable in-place test methods include the probe penetration method (ASTM C 803) and the pullout test method (ASTM C 900). The architect/engineer should review and accept the proposed method, including appropriate correlation data, for estimating in-place strength.

6.4 - Maturity method

Since strength gain of concrete is a function of time and temperature, estimation of strength development of concrete in a structure also can be made by relating the time-temperature history of field concrete to the strength of cylinders of the same concrete mixture cured under standard conditions in a laboratory. This relationship has been established (Bergstrom 1953) by use of a maturity factor M expressed as

$$M = \Sigma\ (T - T_o)\ \Delta\ t \qquad (6\text{-}1)$$

where
M = maturity factor, deg-hr
T = temperature of concrete, deg F (C)
T_o = datum temperature, deg F (C)
$\Delta\ t$ = duration of curing period at temperature T, hr

When concrete temperature is constant, as in laboratory curing methods, the summation sign in Eq. (6-1) is not necessary. The appropriate value for the datum temperature T_o depends on the type of cement, the type and quantity of admixture, and the range of the curing temperature. A value of 23 F (-5 C) is suggested (Carino 1984) for concrete made with Type I cement and cured within the range of 32 to 70 F (0 to 20 C). This value may not be applicable to other types of cements or to Type I cement in combination with liquid or mineral admixtures. A procedure for experimental determination of the datum temperature is given in ASTM C 1074.

6.4.1 - The principle of the maturity method is that the strength of a given concrete mixture can be related

Table 6.4.4 Calculation of maturity factor and estimated in-place strength

1	2	3	4	5	6	7	8	9	10
Date	Elapsed time *h*, hr	Temperature in structure, F	Average temperature in structure F	Average temperature in structure C	Col. 5 + 5 C, C	Time interval *h*, hr	Col. 6x Col. 7 C hr	Maturity factor Σ Col. 8, C hr	Corresponding compressive strength psi
Sept. 1	0	50							
	12	50	50	10	15	12	180	180	-
2	24	50	50	10	15	12	180	360	-
	30	46	48	8.9	13.9	6	83	443	400
3	48	48	47	8.3	13.3	18	240	683	1080
	60	46	47	8.3	13.3	12	160	843	1400
4	72	44	45	7.2	12.2	12	146	989	1600
8	168	42	43	6.1	11.1	96	1065	2054	2600
11	240	42	42	5.6	10.6	72	763	2817	3100
14	312	42	42	5.6	10.6	72	763	3580	3400

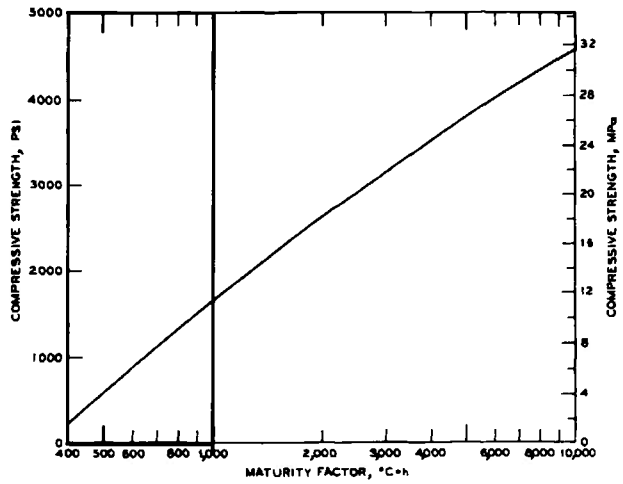

Fig. 6.4.4 - Example of a strength-maturity factor relationship for laboratory-cured cylinders (22.8 C)

to the value of the maturity factor. To use this technique, a strength versus maturity factor curve is established by performing compressive strength tests at various ages on a series of cylinders made with concrete similar to that which will be used in construction. The specimens are usually cured at room temperature and the temperature history of the concrete is recorded to compute the maturity factor at the time of testing. The average cylinder strengths and corresponding maturity factors at each test age are plotted, and a smooth curve is fitted to the data.

6.4.2 - The in-place strength of properly cured concrete at a particular location and at a particular time is predicted by determining the maturity factor at that time and reading the corresponding strength on the strength-maturity factor curve. The in-place maturity factor at a particular location is determined by measuring the temperature of the concrete at closely spaced time intervals and using Eq. (6-l) to sum the successive products of the time intervals and the corresponding average concrete temperature above the datum temperature.

Temperatures can be measured with expendable thermistors or thermocouples cast in the concrete. The temperature sensors should be embedded in the structure at critical locations in terms of severity of exposure and loading conditions. Electronic instruments known as maturity meters are available that permit direct and continuous determination of the maturity factor at a particular location in the structure. These instruments use a probe inserted into a tube embedded in the concrete to measure the temperature, and they automatically compute and display the maturity factor in degree-hours.

6.4.3 - Strength prediction based on the maturity factor assumes that the in-place concrete has the same strength potential as the concrete used to develop the strength-maturity factor curve. Prior to removing forms or shores, it is necessary to determine whether the in-place concrete has the assumed strength potential. This may be done by additional testing of the concrete in question, such as by testing standard-cured cylinders at early ages, by using accelerated strength tests as described in ASTM C 684, by testing field-cured cylinders for which the maturity factor has been monitored, or by using one of the in-place tests listed in 6.3.

6.4.4 *Example* - The following example illustrates the use of the maturity factor method:

In anticipation of cold weather, a contractor installed thermocouples at critical locations in a concrete wall placed at 9:00 A.M. on Sept. 1. A history of the strength gain for the particular concrete mixture to be used in the wall had been developed under laboratory conditions, and the strength-maturity factor curve, which is shown in Fig. 6.4.4, had been established. A record of the in-place concrete temperature was maintained as indicated in Columns 2 and 3 of Table 6.4.4.

After 3 days (72 hr), the contractor needed to know the in-place strength of the concrete in the wall. Using the temperature record, the contractor calculated the average temperature (Column 5) during the various time intervals and the cumulative maturity factors at different ages (Column 9). Based on the strength-maturity factor curve (Fig. 6.4.4), the predicted in-place

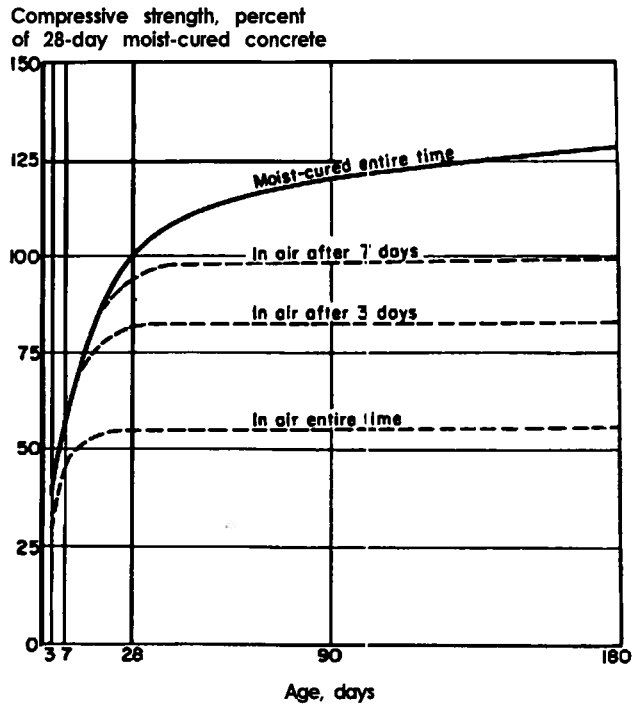

Fig. 6.5 - Compressive strength of concrete dried in laboratory air after preliminary moist curing (Price 1951)

strength (Column 10) at 72 hr is 1600 psi (11.0 MPa). By continuing the procedure, strength at later ages can be predicted.

6.5 - Attainment of design strength

Generally there is little opportunity for further curing of structural concrete beyond that provided initially. Fig. 6.5 illustrates the strength development of concrete specimens removed from moist curing at various ages and subsequently exposed to laboratory air. It is seen that as the specimens dry out, strength gain ceases. For this reason, early strengths high enough to assure later attainment of design strength must be attained before temporarily supported structural concretes can be safely released from cold weather protection and exposed to freezing weather.

6.6 - Increasing early strength

The time needed for concrete to attain the strength required for safe removal of shores is influenced by many factors. Most important among them are those that affect the rate and level of strength development, such as the initial temperature of the concrete when placed, the temperature at which the concrete is maintained after placing, the type of cement, the type and amount of accelerating admixture or other admixtures used, and the conditions of protection and curing. Economic considerations may dictate an accelerated construction schedule even though the resulting concrete may be of lesser quality in terms of reduced long-term ultimate strength or increased thermal cracking. In

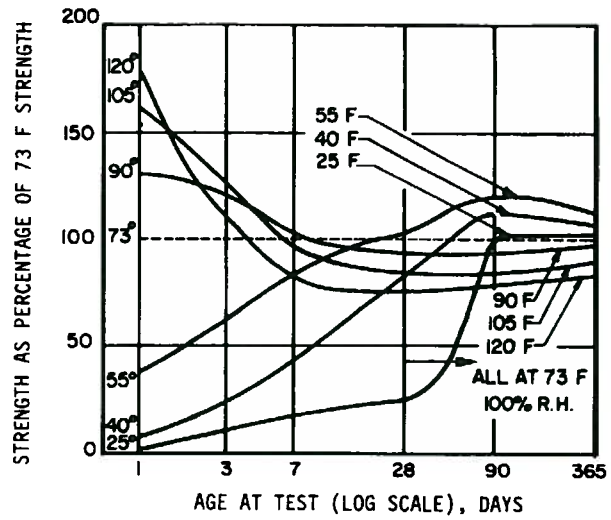

Fig. 6.6.1 - Effect of temperature conditions on the strength development of concrete (Type I cement) (Kleiger 1958)

such cases, the duration of protection may be substantially reduced by:

6.6.1 - holding the temperature during protection and curing at a higher level than that indicated in Line 1 of Table 3.1. Fig. 6.6.1 illustrates the effects of curing temperature on strength development, where strength is expressed as a percentage of the strength at the same age for curing at 73 F (23 C). Type I and III cements give somewhat higher strengths than Type II at early ages. Because of variations in the performance of any one given cement, the data in Fig. 6.6.1 should be used only as a guide.

6.6.2 - using types and compositions of cement that exhibit higher earlier strength development and by using a higher cement content with a lower water-cement ratio (see Section 9.1).

6.6.3 - using an accelerating admixture conforming to ASTM C 494, Type C (accelerating), or Type E (water-reducing and accelerating). The several items for concern mentioned in Chapter 9 should be reviewed before using calcium chloride or Type C or Type E admixtures containing calcium chloride. Due to variation in performance with different brands and types of cement, tests should be performed in advance at the anticipated curing temperature using the cement, aggregates, and admixtures proposed for use.

6.7 - Cooling of concrete

To lower the likelihood of cracking due to thermal stresses, precautions should be taken to assure gradual cooling of concrete surfaces at the termination of the protection period (see Section 5.5).

6.8 - Estimating strength development

There may be times when conservative estimates of concrete strength must be made when adequate curing and protection was provided but no actions were taken to determine the level of strength development. In such

Table 6.8 - Duration of recommended protection for percentage of standard-cured 28-day strength*

Percentage of standard-cured 28-day strength	At 50 F (10 C), days			At 70 F (21 C), days		
	Type of cement			Type of cement		
	I	II	III	I	II	III
50	6	9	3	4	6	3
65	11	14	5	8	10	14
85	21	28	16	16	18	12
95	29	35	26	23	24	20

*The data in this table were derived from concretes with strengths from 3000 to 5000 psi (20.7 to 34.4 MPa) after 28 days of curing at 70 ± 3 F (21 ± 1.7 C). The 28-day strength for each type of cement was considered as 100 percent in determining the times to reach various percentages of this strength for curing at 50 F (10 C) and 70 F (21 C). These times are only approximate, and specific values should be obtained for he concrete used on the job.

cases, Table 6.8 may be used as a guide to determine the recommended duration of curing and protection at 50 or 70 F (10 or 21 C) to achieve different percentages of the standard-cured 28-day strength.

6.9 - Removal of forms and supports

The removal of forms and supports and the placing and removal of reshores should be in accordance with the recommendations of ACI 347:

6.9.1 - The in-place strength of concrete that is required to permit removal of forms and shores should be specified by the engineer/architect.

6.9.2 - Suitable tests of field-cured concrete specimens or of concrete in place should be made (see Sections 6.2 and 6.3).

6.9.3 - Methods for evaluating the results of concrete strength tests and the minimum strength required for form and shore removal should be completely prescribed in the specifications.

6.9.4 - The results of all tests, as well as records of weather conditions and other pertinent information, should be recorded and used by the engineer/architect in deciding when to remove forms and shores.

6.9.5 - The reshoring procedure, which is one of the most critical operations in formwork, should be planned in advance and reviewed by the engineer. This operation should be performed so that large areas of new construction are not subjected to combined dead and construction loads in excess of their capacity, as determined by the in-place concrete strength at the time of form removal and reshoring.

6.10 - Requirements

The recommendations made in this chapter and in Table 6.8 are based on job conditions meeting the following requirements:

6.10.1 - The internal concrete temperature is at least 50 F (10 C) after the concrete is in place. To reduce subsequent thermal contractions, this temperature should be exceeded as little as is practicable.

6.10.2 - Facilities are available to maintain the concrete temperature throughout the structure at 50 F (10 C) or above until protection can be safely discontinued. Such facilities should incorporate, as required, the following:

a. suitable protection from wind and loss of heat

b. effective and sufficient heating equipment and personnel to maintain all parts of the concrete at the required temperature

c. necessary fire protection equipment

d. protection and heating to include the top surface of newly placed slabs or floors

e. venting and circulation to maintain an even temperature at the top and the bottom of vertical units such as walls, piers, and columns

6.10.3 - Reshores are left in place as long as is necessary to safeguard all members of the structure. The number of tiers reshored below the tier being placed and how long such reshores remain in place should be based on reliable evidence that sufficient strength exists to safely carry the applied loads.

6.10.4 - The concrete is made with Type I, II, or III portland cement.

6.10.5 - Proper curing is used, particularly to avoid drying of the concrete in heated enclosures.

6.10.6 - Inspections are performed to check compliance with the construction requirements of ACI 301, ACI 318, and other ACI standards for construction practices.

CHAPTER 7 - MATERIALS AND METHODS OF PROTECTION

7.1 - Introduction

Concrete placed during cold weather should be maintained as close as possible to the recommended temperatures in Line 1 of Table 3.1 and for the length of times recommended in Table 5.3 unless the in-place strength has reached a previously established target value. The specific protection system required to maintain the recommended temperatures depends on such factors as the ambient weather conditions, the geometry of the structure, and the concrete mixture proportions. In some cases, it may only be necessary to cover the concrete with insulating materials and use the natural heat of hydration to maintain the temperature at the recommended levels. In more extreme cases, it may be necessary to build enclosures and use heating units to maintain the desired temperatures.

7.2 - Insulating materials

Since most of the heat of hydration of the cement is generated during the first 3 days, heating from external sources may not be required to prevent freezing of the concrete if the generated heat is retained. Heat of hydration may be retained by using insulating blankets on unformed surfaces and by using insulating forms (Tuthill, et al. 1951; Wallace 1954; Mustard and Ghosh 1979). Insulation must be kept in close contact with the concrete or the form surface to be effective. Some commonly used insulating materials include:

7.2.1 *Polystyrene foam sheets* - These may be cut to shape and wedged between the studs of the forms or glued into place.

7.2.2 *Urethane foam* - This foam may be sprayed onto the surface of forms making a continuous insulating layer. A good weather-resistant enamel should be sprayed over urethane foam to reduce water absorption and protect it from the deteriorating effect of ultraviolet rays. Urethane foam should be used with caution because it generates highly noxious fumes when exposed to fire.

7.2.3 *Foamed vinyl blankets* - These materials are pliable blankets of foamed vinyl with an extruded vinyl backing. They also may have electric wires embedded in the foam to provide additional heat. Blankets without embedded wires are available in rolls of standard widths. Heated blankets must be custom ordered.

7.2.4 *Mineral wool or cellulose fibers* - Generally, mineral wool or cellulose fibers are encased in heavy polyethylene liners and formed into large mats or rolls. The plastic liners are sometimes given a rough surface finish to reduce the risk of slipping. They may be laid flat to cover slabs or they may be draped over other structural elements.

7.2.5 *Straw* - Straw is still popular although it is not as effective as blankets or mats Disadvantages of straw are its bulk, its flammability, and the need to protect it from moisture. Tarpaulins, polyethylene sheets, or waterproof paper must be used as a protective cover to inhibit wind convection and to keep the straw dry and in place.

7.2.6 *Blanket or batt insulation* - Commercial blanket or batt insulation must be adequately protected from wind, rain, snow, or other moisture by means of tough, moistureproof cover material because wetting will impair its insulating value. Closed-cell material is particularly advantageous because of its resistance to wetting.

7.3 - Selection of insulation

Concrete temperature records reveal the effectiveness of different amounts or kinds of insulation and of other methods of protection for various types of concrete work under different weather conditions. Using these temperature records, appropriate modifications can be made to the protection method or selected materials. Additional methods for estimating the temperatures that can be maintained by various insulation arrangements under given weather conditions have been published (Tuthill et al. 1951; Mustard and Ghosh 1979).

As was mentioned in Section 7.2, the heat of hydration is high during the first few days after placement and it then gradually decreases with age. Thus, to maintain a specified temperature throughout the protection period, the amount of required insulation is greater for a long protection period than for a shorter period. Conversely, for a giver insulation system, concrete that is to be protected for a short period, such as 3 days, can be exposed to a lower ambient temperature than concrete that is to be protected for a longer period, such as 7 days.

Based on the requirements of this report, Tables 7.3.1, 7.3.2, 7.3.3, and 7.3.4 and Fig. 7.3.1, 7.3.2, 7.3.3, and 7.3.4 indicate the minimum ambient air temperatures to which concrete walls or slabs of different thicknesses may be exposed for different values of thermal resistance R, for different cement contents, and for protection periods of 3 or 7 days. For protection periods less than 3 days, the tables or figures for 3 days should be used. For protection periods between 3 and 7 days, interpolation between the values in the tables or figures should be used. For these figures and tables it is assumed that the concrete temperature as placed is 50 F (10 C).

These tables and figures can also be used to determine the required thermal resistance R under different conditions. The thickness of the chosen insulating material that is needed to obtain the required thermal resistance can be calculated using the insulation values in Table 7.3.5. The thermal resistance of the various insulating materials have been calculated under the assumption that the insulation is applied to the exterior surfaces of steel forms. When 3/4-in. (20-mm) plywood forms are used, an R value of 0.94 (0.17) for the plywood form should be added to the R-value of the added insulation. The values shown in the tables and figures are based on the assumption that wind speeds are not greater than 15 mph (24 km/h). With higher wind speeds, the effectiveness of a given thickness of insulation diminishes. However, at a wind speed of 30 mph (48 km/h), the decrease in the effective thermal resistance amounts to less than an R - value of 0.1. Thus, for all practical purposes, the effects of wind speed may be neglected in determining the required thickness of added insulation.

Corners and edges are particularly vulnerable during cold weather. Therefore, the thickness of insulation for these parts should be about three times the thickness that is required for walls or slabs. In addition, the tables and figures are for cement having a heat of hydration similar to Type I portland cement. For Type II cement and blended hydraulic cements with moderate heat of hydration, the insulation requirements given in the tables and figures should be increased by about 30 percent. Where other types of cements or blends of cement and other cementitious materials are used,* similar proportional adjustments should be made to the amount of insulation (Tuthill et al. 1951; Mustard and Ghosh 1979). Insulation beyond the required amount should not be used because it may raise the internal temperature of the concrete above recommended levels, which will lengthen the gradual cooling period, increase thermal shrinkage, and increase the risk of cracking due to thermal shock.

7.3.1 *Example* - The following example illustrates how to determine the required thickness of insulation for a given condition.

*Typical heat of hydration curves for various cements can be found in "Concrete for Massive Structures," *Bulletin No. IS128T*, Portland Cement Association, Skokie, IL.

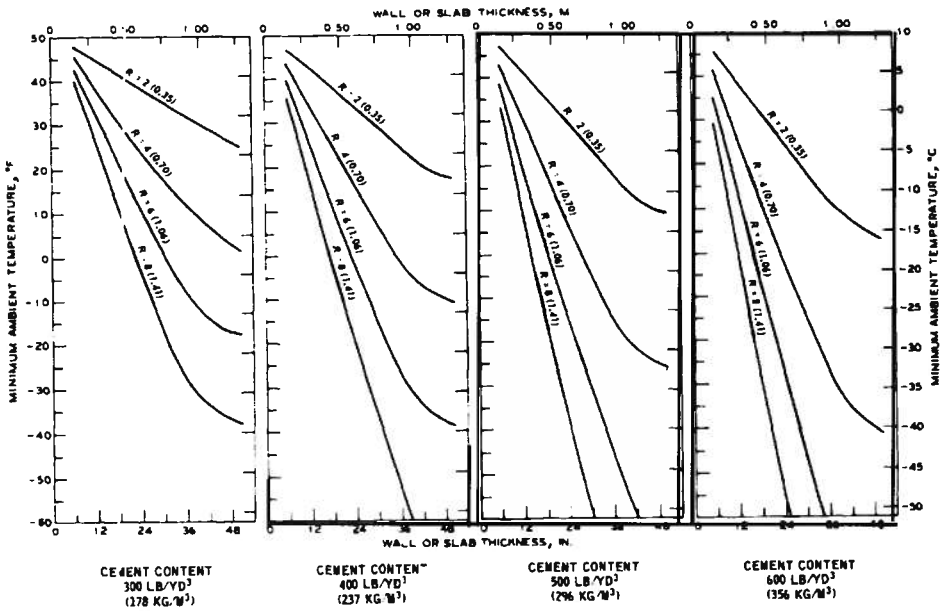

Fig. 7.3.1- Minimum exposure temperatures for concrete slabs above ground and walls as a function of member thickness, R-value, and cement content. Concrete placed and surface temperature maintained at 50 F (10 C) for 7 days

Table 7.3.1 - Minimum exposure temperatures for concrete slabs above ground and walls for concrete placed and surface temperature maintained at 50 F (10 C) for 7 days

Wall or slab thickness, in. (mm)	Minimum ambient air temperature, deg F (C) allowable when insulation having these values of thermal resistance *R*, hr•ft²•F/Btu (m²•K/W), is used			
	R = 2 (0.35)	*R* = 4 (0.70)	*R* = 6 (1.06)	*R* = 8 (1.41)
	Cement content = 300 lb/yd³ (178 kg/m³)			
6 (0.15)	48 (9)	46 (8)	43 (6)	40 (4)
12 (0.30)	45 (7)	39 (4)	32 (0)	25 (-4)
18 (0.46)	41 (5)	31 (- 1)	21 (-6)	11 (-12)
24 (0.61)	38 (3)	24 (-4)	10 (- 12)	- 2 (-19)
36 (0.91)	32 (0)	12 (-11)	- 8 (-22)	-28 (-33)
48 (1.2)	26 (- 3)	3 (-16)	-17 (-27)	-37 (-38)
60 (1.5)	26 (-3)	3 (-16)	-17 (-27)	-37 (-38)
	Cement content = 400 lb/yd³ (237 kg/m³)			
6 (0.15)	47 (8)	44 (7)	40 (4)	36 (2)
12 (0.30)	43 (6)	35 (2)	26 (-3)	17 (-8)
18 (0.46)	39 (4)	25 (-4)	11 (-12)	- 2 (-19)
24 (0.61)	34 (1)	16 (-8)	- 2 (-19)	-20 (-29)
36 (0.91)	25 (-4)	- 1 (-18)	-27 (-31)	-53 (-47)
48 (1.2)	18 (-8)	-10 (-23)	-38 (-39)	*
60 (1.5)	18 (-8)	-10 (-23)	-38 (-39)	*
	Cement content = 500 lb/yd³ (296 kg/m³)			
6 (0.15)	47 (8)	43 (6)	38 (3)	33 (1)
12 (0.30)	42 (6)	31 (- 1)	20 (-7)	9 (-13)
18 (0.46)	36 (2)	19 (-7)	2 (-17)	-15 (-26)
24 (0.61)	30 (- 1)	7 (-14)	-16 (-27)	-39 (-39)
36 (0.91)	18 (-8)	-15 (-26)	-46 (-43)	-79 (-62)
48 (1.2)	10 (-12)	-25 (-32)	-60 (-51)	*
60 (1.5)	10 (-12)	-25 (-32)	*	*
	Cement content = 600 lb/yd³ (356 kg/m³)			
6 (0.15)	46 (8)	41 (5)	35 (2)	29 (-2)
12 (0.30)	40 (4)	28 (-2)	14 (- 10)	0 (-18)
18 (0.46)	33 (1)	13 (-11)	- 7 (-22)	-29 (-34)
24 (0.61)	26 (- 3)	-1 (-18)	-28 (-33)	-55 (-48)
36 (0.91)	12 (-11)	-27 (-31)	-66 (-54)	*
48 (1.2)	4 (-16)	-40 (-40)	*	*
60 (1.5)	4 (-16)	-40 (-40)	*	*

*<< -60 F (-51 C).

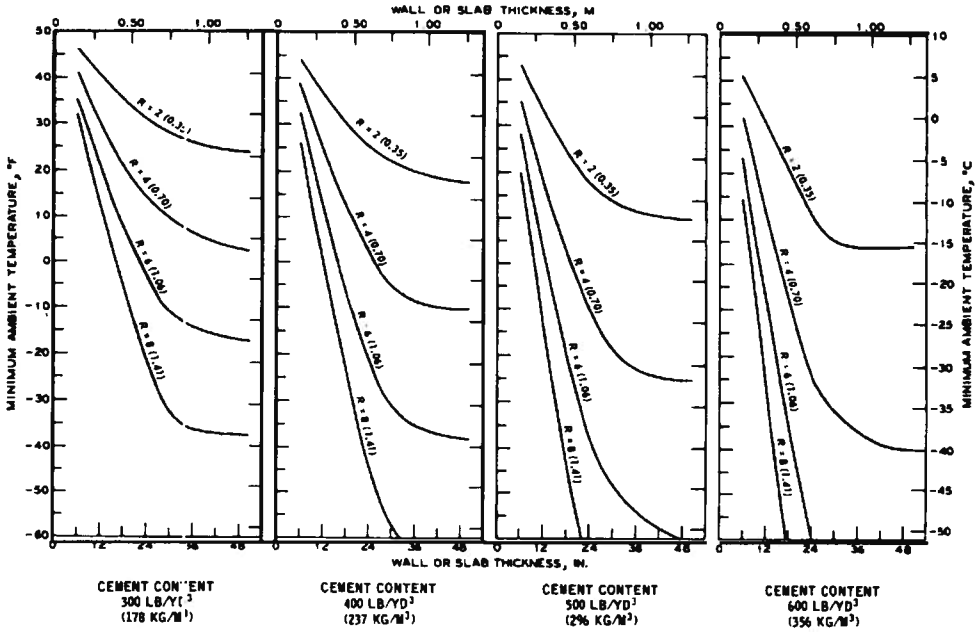

Fig. 7.3.2 - Minimum exposure temperatures for concrete slabs above ground and walls as a function of member thickness, R-value, and cement content. Concrete placed and surface temperature maintained at 50 F (10 C) for 3 days

Table 7.3.2 - Minimum exposure temperatures for concrete slabs above ground and walls for concrete placed and surface temperature maintained at 50 F (10 C) for 3 days

Wall or slab thickness, in. (mm)	Minimum ambient air temperature, deg F (C) allowable when insulation having these values of thermal resistance *R*, hr•ft²•F/Btu (m²•K/W), is used			
	R = 2 (0.35)	R = 4 (0.70)	R = 6 (1.06)	R = 8 (1.41)
	Cement content = 300 lb/yd³(178 kg/m³)			
6 (0.15)	46 (8)	41 (5)	36 (2)	32 (0)
12 (0.30)	41 (5)	31 (-1)	21 (-6)	11 (-12)
18 (0.46)	36 (2)	21 (-6)	8 (-13)	-5 (-21)
24 (0.61)	31 (-1)	14 (-10)	-3 (-19)	-21 (-29)
36 (0.91)	26 (-3)	8 (-13)	-14 (-26)	-36 (-38)
48 (1.2)	26 (-3)	3 (-16)	-17 (-27)	-37 (-38)
60 (1.5)	26 (-3)	3 (-16)	-17 (-27)	-37 (-38)
	Cement content = 400 lb/yd³(237 kg/m³)			
6 (0.15)	44 (7)	38 (3)	32 (0)	26 (-3)
12 (0.30)	37 (3)	24 (-4)	12 (-11)	0 (-18)
18 (0.46)	30 (-1)	12 (-11)	-6 (-21)	-24 (-31)
24 (0.61)	25 (-4)	2 (-17)	-21 (-29)	-44 (-42)
36 (0.91)	20 (-7)	-9 (-23)	-36 (-38)	-63 (-53)
48 (1.2)	18 (-8)	-10 (-23)	-38 (-39)	*
60 (1.5)	18 (-8)	-10 (-23)	-38 (-39)	*
	Cement content = 500 lb/yd³(296 kg/m³)			
6 (0.15)	43 (6)	35 (2)	28 (-2)	20 (-7)
12 (0.30)	34 (1)	18 (-8)	3 (-16)	-12 (-24)
18 (0.46)	25 (-4)	2 (-16)	-21 (-29)	-44 (-42)
24 (0.61)	18 (-8)	-10 (-23)	-38 (-39)	-68 (-56)
36 (0.91)	12 (-11)	-23 (-31)	-60 (-51)	*
48 (1.2)	13 (-12)	-25 (-32)	*	*
60 (1.5)	13 (-12)	-25 (-32)	*	*
	Cement content = 600 lb/yd³(356 kg/m³)			
6 (0.15)	41 (5)	32 (0)	23 (-5)	14 (-10)
12 (0.30)	31 (-1)	12 (-11)	-7 (-22)	-26 (-32)
18 (0.46)	21 (-6)	-7 (-22)	-35 (-37)	-63 (-53)
24 (0.61)	11 (-12)	-24 (-31)	-59 (-51)	*
36 (0.91)	1 (-16)	-36 (-38)	*	*
48 (1.2)	1 (-16)	-40 (-40)	*	*
60 (1.5)	1 (-16)	-40 (-40)	*	*

* << -60 F (-51 C).

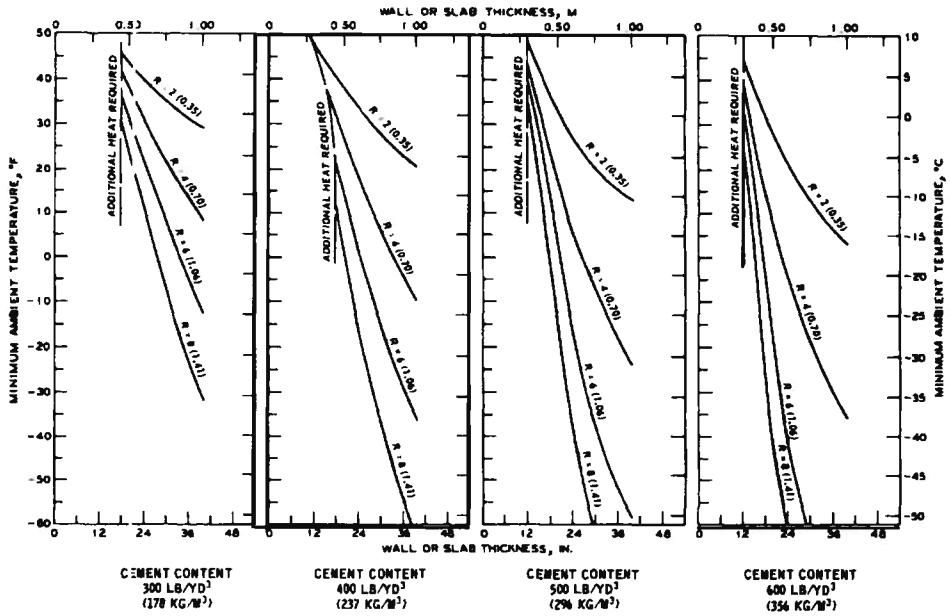

Fig. 7.3.3. - Minimum exposure temperatures for concrete flatwork placed on the ground as a function of member thickness, R-value, and cement content. Concrete placed and surface temperature maintained at 50 F (10 C) for 7 days on ground at 35 F (2 C)

Table 7.3.3 - Minimum exposure temperatures for concrete flatwork placed on the ground for concrete placed and surface temperature maintained at 50 F (10 C) for 7 days on ground at 35 F (2 C)

Wall or slab thickness, in. (mm)	Minimum ambient air temperature, deg F (C) allowable when insulation having these values of thermal resistance *R*, hr•ft²•F/Btu (m²•K/W), is used			
	R = 2 (0.35)	R = 4 (0.70)	R = 6 (1.06)	R = 8 (1.41)
	Cement content = 300 lb/yd³(178 kg/m³)			
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	*	*	*	*
18 (0.46)	46 (8)	42 (6)	36 (2)	30 (-1)
24 (0.61)	40 (4)	31 (-1)	22 (-6)	11 (-12)
30 (0.76)	35 (2)	22 (-6)	7 (-14)	-8 (-22)
36 (0.91)	31 (-1)	13 (-11)	-5 (-21)	-23 (-31)
	Cement content = 400 lb/yd³(237 kg/m³)			
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	*	*	*	50 (10)
18 (0.46)	41 (5)	32 (0)	22 (-6)	12 (-11)
24 (0.61)	35 (2)	19 (-7)	-1 (-17)	-15 (-26)
30 (0.76)	28 (-2)	8 (-13)	-14 (-26)	-36 (-38)
36 (0.91)	23 (-5)	-4 (-20)	-29 (-34)	-54 (-48)
	Cement content = 500 lb/yd³(296 kg/m³)			
4 (0.10)	*	*	*	
8 (0.20)	*	*	*	*
12 (0.31)	48 (9)	44 (7)	40 (4)	36 (2)
18 (0.46)	36 (2)	22 (-6)	8 (-13)	-6 (-21)
24 (0.61)	28 (-2)	6 (-14)	-16 (-27)	-38 (-39)
30 (0.76)	22 (-6)	-7 (-22)	-36 (-38)	-64 (-53)
36 (0.91)	16 (-9)	-18 (-28)	-50 (-46)	†
	Cement content = 600 lb/yd³(356 kg/m³)			
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	44 (7)	38 (3)	32 (0)	26 (-3)
18 (0.46)	31 (-1)	14 (-10)	-5 (-21)	-24 (-31)
24 (0.61)	22 (-6)	-5 (-21)	-32 (-36)	-61 (-52)
30 (0.76)	14 (-10)	-19 (-28)	-67 (-55)	†
36 (0.91)	7 (-14)	-30 (-34)	†	†

* > 50 F (10 C): additional heat required.
†<< -60 F (-51C).

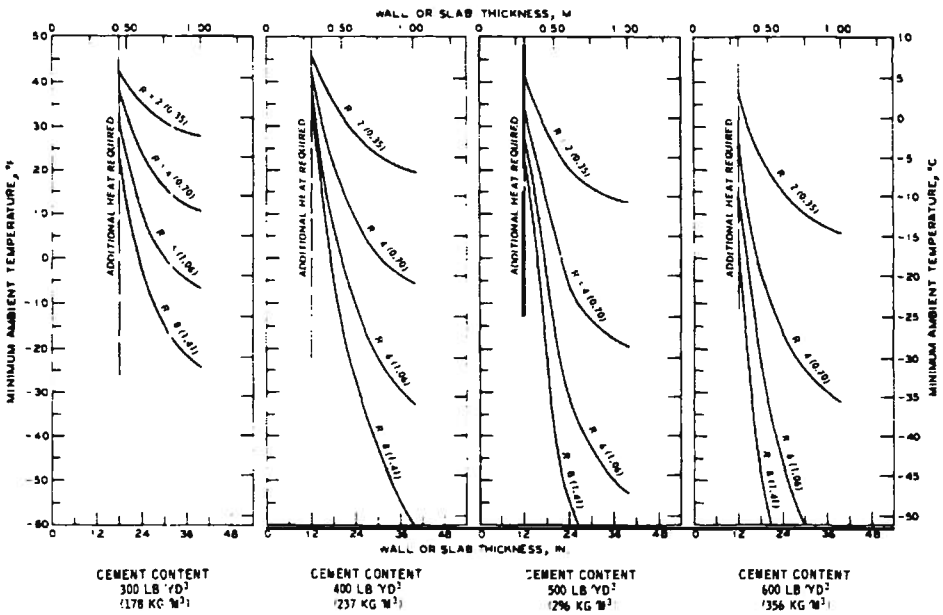

Fig. 7.3.4 - Minimum exposure temperatures for concrete flatwork placed on the ground as a function of member thickness, R-value, and cement content. Concrete placed and surface temperature maintained at 50 F (10 C) for 3 days on ground at 35 F (2 C)

Table 7.3.4 - Minimum exposure temperatures for concrete flatwork placed on the ground for concrete placed and surface temperature maintained at 50 F (10 C) for 3 days on ground at 35 F (2 C)

Slab thickness, in. (m)	Minimum ambient air temperature, deg F (C) allowable when insulation having these values of thermal resistance *R*, hr•ft²•F/Bru (m²•K/W), is used			
	R = 2 (0.35)	*R* = 4 (0.70)	*R* = 6 (1.06)	*R* = 8 (1.41)
Cement content = 300 lb/yd³ (178 kg/m³)				
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	*	*	*	*
18 (0.46)	42 (6)	38 (3)	32 (0)	26 (-3)
24 (0.61)	37 (3)	25 (-4)	11 (-12)	-3 (-19)
30 (0.76)	31 (-1)	15 (-9)	-1 (-18)	-17 (-27)
36 (0.91)	31 (-1)	12 (-11)	-5 (-21)	-22 (-30)
Cement content = 400 lb/yd³ (237 kg/m³)				
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	46 (8)	44 (7)	42 (6)	40 (4)
18 (0.46)	36 (2)	22 (-6)	8 (-13)	-6 (-21)
24 (0.61)	28 (-2)	9 (-13)	-10 (-23)	-29 (-34)
30 (0.76)	21 (-6)	0 (-18)	-21 (-29)	-42 (-41)
36 (0.91)	21 (-6)	-4 (-20)	-29 (-34)	-50 (-46)
Cement content = 500 lb/yd³ (296 kg/m³)				
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	42 (6)	36 (2)	30 (-1)	24 (-4)
18 (0.46)	30 (-1)	12 (-11)	-6 (-21)	-22 (-30)
23 (0.61)	11 (-6)	-5 (-21)	-31 (-35)	-50 (-46)
30 (0.76)	16 (-9)	-10 (-23)	-42 (-41)	-74 (-59)
36 (0.91)	16 (-9)	-18 (-28)	-50 (-46)	
Cement content = 600 lb/yd³ (356 kg/m3)				
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	38 (3)	26 (-3)	14 (- 10)	2 (-17)
18 (0.46)	24 (-1)	0 (-18)	- 24 (-31)	-48 (-44)
24 (0.61)	14 (-10)	-16 (-27)	-46 (-33)	-82 (-63)
30 (0.76)	10 (-12)	-20 (-29)	-62 (-52)	†
36 (0.91)	7 (-14)	-30 (-34)	†	†

* > 50 F (10 C): additional heat required
† << -60 F (-51 C)

Table 7.3.5 - Thermal resistance of various insulating materials

Insulating material	Thermal resistance *R* for these thicknesses of material* 1 in., hr•ft²•F/Btu	10 mm, m²•K/W
Boards and slabs		
Expanded polyurethane (*R* - 11 exp.)	6.25	0.438
Expanded polystyrene extruded (*R* - 12 exp.)	5.00	0.347
Expanded polystyrene extruded, plain	4.00	0.277
Glass fiber, organic bonded	4.00	0.277
Expanded polystyrene, molded beads	3.57	0.247
Mineral fiber with resin binder	3.45	0.239
Mineral fiber board, wet felted	2.94	0.204
Sheathing, regular density	2.63	0.182
Cellular glass	2.63	0.182
Laminated paperboard	2.00	0.139
Particle board (low density)	1.85	0.128
Plywood	1.25	0.087
Blanket		
Mineral fiber, fibrous form processed from rock, slag, cr glass	3.23	0.224
Loose fill		
Wood fiber, soft woods	3.33	0.231
Mineral fiber (rock, slag, or glass)	2.50	0.173
Perlite (expanded)	2.70	0.187
Vermiculite (exfoliated)	2.20	0.152
Sawdust or shavings	2.22	0.154

*Values from *ASHRAE Handbook of Fundamentals*, 1977, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York.

Problem - A contractor anticipates having to place an 18 in. (0.46 m) thick concrete wall when the ambient temperature will be about 0 F (- 18 C). The concrete will have a cement content of 500 lb/yd³ (296 kg/m³). There will be no early-age strength requirements for the concrete; therefore, a 3-day protection period will be used. The forms are made of 3/4-in. plywood. The contractor would like to use plain expanded polystyrene boards for insulation. What should be the thickness of the polystyrene boards?

Solution - Table 7.3.2 or Fig. 7.3.2 may be used to solve the problem. According to Table 7.3.2, an *R*-value of 4 (0.7) is sufficient for an ambient temperature of 2 F (- 16 C), which will be assumed to be close enough to the expected ambient temperature. Since the plywood forms will provide some of this insulation, the required added insulation must have an *R-value* of 4 - 0.94 = 3.06 (0.70 - 0.17 = 0.53). Referring to Table 7.3.5, it is seen that a 1 in. (25 mm) plain polystyrene board has an R-value of 4 (0.7). Therefore, 3/4-in. (19 mm) thick polystyrene boards will provide the needed additional insulation.

7.4 - Enclosures

Enclosures are probably the most effective means of protection, but they are also the most expensive. The need for enclosures is dependent on the nature of the structure and the weather conditions (wind and snow). Experience has shown that they are generally required for placing operations when the air temperature is less than - 5 F (- 20 C). Builders attempting to place concrete at such low temperatures without enclosures will encounter manpower and equipment difficulties that will result in inferior constructions.

Enclosures block the wind, keep out the cold air, and conserve heat. They can be made with any suitable material such as wood, canvas, building board, or plastic sheet. Enclosures made with flexible materials are less expensive and easier to build and remove. Enclosures built with rigid materials are more effective in blocking wind and maintaining perimeter temperatures. Enclosures should be capable of withstanding wind and snow loads and be reasonably airtight. Sufficient space should be provided between the concrete and the enclosure to permit free circulation of the warmed air. Sufficient headroom should be provided, so that workers can work efficiently.

Heat can be supplied to the enclosures by live steam, forced hot air, or combustion heaters of various types. Although live steam heating provides an ideal curing environment, it offers less than ideal working conditions and can cause icing problems around the perimeter of the enclosure. Heaters and ducts should be positioned so as not to cause areas of overheating or drying of the concrete surface. During the protection period, concrete surfaces should not be exposed to air at more than 20 F (11 C) above the minimum placement temperatures given in Line 1 of Table 3.1 unless higher values are required by an accepted curing method.

Combustion heaters should be vented to prevent reaction of the carbon dioxide in the exhaust gases with the exposed surfaces of newly placed concrete. Carbon dioxide reacts with calcium hydroxide in the concrete and forms calcium carbonate (Kauer and Freeman 1955) resulting in a weak dusty surface.

Combustion heaters called vented heaters have a heat exchanger in the firebox so that none of the products of combustion are blown into the heated area. The exhaust gases are vented from the firebox to the outside atmosphere. Even though they use energy inefficiently compared to direct firebox heaters, vented heaters must be used to maintain concrete floor finish quality and for safety. The fact that a conventional combustion heater is located outside the enclosed concreting area and hot air is blown into the enclosure through ducts does not mean that the heater is vented, since the hot air may contain carbon dioxide.

Operation of combustion heaters should be supervised continuously, and adequate fire fighting equipment should be available at the job site at all times.

7.5 - Internal electric heating

Concrete can be heated internally by using embedded coiled and insulated electrical resistors. Low voltage current is passed through the coils, which are embedded near the surfaces of the section in a predetermined pattern. Internal concrete temperature may be raised to any required level by selecting the appropriate spacing

or pitch of the coils. Gradual cooling may be controlled by intermittently interrupting the current passing through the coils. Heating usually begins after a presetting period of 4 to 5 hr depending on the setting characteristics of the concrete. Therefore, insulated forms are required only to prevent freezing of concrete during the presetting period and to minimize heat dissipation from surfaces where coils are not used. Moisture loss due to evaporation from unformed surfaces should be prevented by covering the surfaces with plastic sheets. Concrete temperatures must be monitored so that the recommended values are not exceeded.

7.6 - Covering after placement

Tarpaulins or other easily movable coverings, supported on sawhorses or on other framework, should follow closely the finishing of the concrete. The tarpaulins should be arranged so that heated air can circulate freely on both the top and, where exposed, the bottom of the slab. Layers of insulating material placed directly on the concrete are also effective in preventing freezing. This protection is pa:-titularly important in the case of lightweight structural concrete. The lower rate of heat diffusion of lightweight concrete allows more rapid freezing of surfaces to occur compared to normal weight concrete.

7.7 - Temporary removal of protection

Housing and enclosures should be left in place for the entire recommended protection period. Sections may be temporarily removed to permit placing additional forms or concrete, but scheduling of this work must insure that the previously placed concrete does not freeze. Sections that are removed should be replaced as soon as forms or concrete are in their final position. The time during which protection is temporarily removed should not be considered as part of the protection period. Time lost from the required period of protection should be made up with twice the number of lost degree-hours before protection is discontinued. For example, if protection was temporarily removed for 6 hr and the surface temperature dropped 15 F (8 C) below the minimum value given in Table 3.1, the deficiency in protection would be 90 F-hr (48 C-hr). Therefore, the protection period should be extended for 180 F-hr (96 C-hr).

7.8 - Insulated forms

When insulated forms are used in addition to heated enclosures, the interior temperature as well as the surface temperature of the concrete should be monitored to insure that the concrete is not heated more than is necessary. This recommendation applies particularly to mass concrete.

CHAPTER 8 - CURING REQUIREMENTS AND METHODS

8.1 - Introduction

Newly placed concrete must be protected from drying so that adequate hydration can occur. Normally, measures must be taken to prevent evaporation of moisture from concrete. During cold weather, when the air temperature is below 50 F (10 C), atmospheric conditions in most areas will not cause excessive drying. However, new concrete is vulnerable to freezing when it is in a critically saturated condition. Therefore, if concrete has been saturated during the protection period, it should be allowed to undergo some drying before being exposed to freezing temperatures.

8.2 - Curing during the protection period

Concrete exposed to cold weather is not likely to dry at an undesirable rate; however, this may not be true for concrete that is being protected from cold weather. As long as forms remain in place, concrete surfaces adjacent to the forms will retain adequate moisture. On the other hand, exposed horizontal surfaces, particularly finished floors, are prone to rapid drying in a heated enclosure.

When concrete that is warmer than 60 F (16 C) is exposed to air at 50 F (10 C) or higher, it is essential that measures be taken to prevent drying. The preferred technique is to use steam for both heating and preventing excessive evaporation. When dry heating is used, the concrete should be covered with an approved impervious material or a curing compound meeting the requirements of ASTM C 309, or it may be water cured. However, water curing is not recommended and is the least desirable method, since during periods of subfreezing temperatures it produces icing problems where water runs out of the enclosure or where there is a poor seal. It also increases the likelihood of the concrete freezing in a nearly saturated condition when protection is removed. If water or steam curing are used, they should be terminated 12 hr before the end of the temperature protection period, and the concrete should be permitted to dry prior to and during the period of gradual adjustment to ambient cold weather conditions, as discussed in Section 5.5.

When the air temperature within the enclosure has fallen to 50 F (10 C), the concrete can be exposed to the air provided the relative humidity is not less than 40 percent. During very cold weather, it is always necessary to add moisture to heated air to maintain this humidity. For example, if the outside temperature is 10 F (-12 C), the relative humidity of the air within the heated enclosure will be less than 20 percent if no moisture is added.

8.3 - Curing following the protection period

Following the removal of the temperature protection, it is usually not necessary to provide measures to prevent excessive drying as long as the air temperature remains below 50 F (10 C), except when concrete is placed in extremely arid regions. If a curing compound is applied during the first period of above-freezing temperature after protection is removed, the need to conduct further curing operations if the temperature should rise above 50 F (10 C) is eliminated.

The severity of drying is dependent on four factors: (1) the temperature of the concrete, (2) the temperature of the air, (3) the wind speed, and (4) the relative humidity of the air. For example, drying will be excessive if concrete at 50 F (20 C) is exposed to air having a temperature of 50 F (10 C) and a relative humidity less than 40 percent. As the air temperature decreases, the air requires a higher relative humidity to prevent excessive drying. For example, if concrete at 50 F (10 C) is exposed to air having a temperature of 40 F (5 C), the air must have a relative humidity greater than 60 percent to prevent excessive drying. However, when the concrete temperature has dropped to 40 F (5 C), an ambient air temperature of 40 F (5 C) with a relative humidity of 11 percent can be tolerated. For air temperatures above 50 F (10 C), the rate of drying increases rapidly.

If excessive drying is anticipated, concrete may be water cured when no freezing is expected. Otherwise, the use of curing compounds or an impervious cover is the preferred procedure. During cold weather periods when freezing occurs, occasional peak temperatures above 50 F (10 C) should not be a cause of concern. However, when temperatures above 50 F (10 C) occur during more than half of any 24-hr period for three consecutive days, the concrete should no longer be regarded as cold weather concrete and normal curing practice should apply (see ACI 308).

CHAPTER 9 - ACCELERATION OF SETTING AND STRENGTH DEVELOPMENT

9.1 - Introduction

If proper precautions are taken, accelerating admixtures, Type III cement (high early strength), or additional cement can be used to shorten the times needed to achieve setting and required strength. The reduction in setting time and the acceleration of strength gain often result in savings due to a shorter protection period, faster reuse of forms, earlier removal of shores, or less labor in finishing flatwork (see ACI 302). The strength development of concrete in massive structures, in which internal temperature rise is critical, should not be accelerated.

Methods used to obtain high early strength concrete increase the heat of hydration, which can be favorable in some instances. When resistance to sulfate attack is not a concern, cement having higher percentages of tricalcium silicate and tricalcium aluminate may be advantageous in cold weather because these compounds contribute to earlier strength development and higher heat of hydration. Cements of the same type and even of the same brand name, however, can have wide variations in their setting times and rates of strength development. Tests on concrete made with the cements to be used for a particular job are recommended to show which of the alternatives will produce the desired properties. Additional information on the subject of accelerating setting and strength development may be found in ACI 212.

9.2 - Calcium chloride as an accelerating admixture

9.2.1 - Calcium chloride is a popular and widely used accelerating admixture that reduces the setting time and increases the rate of early-age strength development. The use and effects of calcium chloride are discussed in ACI 212, ACI 201, and Shideler (1952). The maximum chloride ion content of concrete is prescribed in ACI 318, and these limits govern where the code is in use.

Calcium chloride should not be used under certain conditions; these restrictions are as follows:

a. Calcium chloride should not be used in prestressed concrete because of its potential for accelerating the rate of stress corrosion (Monfore and Verbeck 1960).

b. The presence of chlorides has been associated with galvanic corrosion between galvanized and plain steel when galvanizing is used on permanent forms for roof decks or embedded parts. Calcium chloride should not be used in such construction (Wright and Jencks 1963).

c. Galvanic corrosion of metals embedded in concrete is intensified by addition of calcium chloride to the concrete. Examples of this occurrence are as follows (Wright and Jencks 1963):

1. When aluminum and steel sheets embedded in concrete were connected externally, the galvanic corrosion of the aluminum was proportional to the concentration of calcium chloride.

2. Where large slabs of reinforced concrete were cast with aluminum conduit electrically connected to embedded steel, the results showed that calcium chloride promoted galvanic corrosion.

d. Calcium chloride should not be used where sulfate resisting concrete is required.

e. Calcium chloride has been found to increase the expansion caused by cement alkali-silica reaction (Shideler 1952).

f. Varying the calcium chloride content of concrete in a single structural unit because of changes in weather conditions may create concentration cells and, in the presence of moisture, may promote corrosion of reinforcing steel in the areas of higher chloride ion concentration. This practice is dangerous and should not be permitted in structures where continuity of reinforcement exists.

g. Even where a uniform dosage of calcium chloride has been used throughout a structural element, galvanic cells can develop within the reinforcing network due solely to differences in moisture contents. The relatively dry portions can act as cathodes, due to greater amounts of available oxygen, and the relatively damp portions can act as anodes where corrosion occurs. The degree of dampness required to support anodic activity has not been established definitively; it is believed that relative humidities above 70 percent may be sufficient (Tuutti 1982).

9.2.2 - Calcium chloride, and most other chemical admixtures, added to the concrete mixture in permissi-

ble quantities will not lower the freezing point of water in concrete to any significant degree. To avoid misplaced confidence in such a practice, and to avoid use of harmful materials, any attempt to lower the freezing point of the water in concrete by the use of calcium chloride should not be permitted.

9.3 - Other accelerating admixtures

9.3.1 - Some water-reducing accelerating admixtures, conforming to Type E in ASTM C 494, have been found to accelerate setting and strength gain at ambient temperatures of 50 F (10 C) and below, and also to reduce the required water content of the mixture. Some Type E admixtures contain small percentages of calcium chloride, usually amounting to less than 0.2 percent by weight of the cement when used at recommended dosage rates (see Section 9.3.2). This amount by itself has a limited effect on early strength development of the concrete. Tests indicate, however, that other Type E water-reducing accelerating admixtures, meeting the requirements of ASTM C 494, will substantially improve the 24-hr strength of concrete maintained at 50 F (10 C). The strength of concrete containing these admixtures approaches the strength obtained by using 2 percent calcium chloride and will be appreciably greater than for some, but not all, concretes made with Type III cements. The data also indicate that water-reducing accelerating admixtures may reduce setting time as well as produce substantial strength increases at all later ages.

9.3.2 - If adequate information or past performance records are not available, tests should be made to evaluate the effect of a pa-titular admixture or admixtures on the concrete for the job. These tests should be carried out at the expected job temperatures using the materials approved for the job. The manufacturers of many proprietary admixtures claim accelerated setting and strength developmen properties. It should be determined whether the admixture under consideration contains chloride. If chloride is present, the percentage of chloride, by weight of cement, that would be introduced into the concrete if the admixture were to be used should be determined and compared with the permissible limits given in ACI 201, or ACI 318. The admixture should not be used if the limits are exceeded.

Not all accelerating admixtures contain added chlorides. If job requirements prohibit the use of admixtures containing added chloride, noncorrosive accelerating admixtures are available

CHAPTER 10 - REFERENCES

10.1 - Recommended references

The documents of the various standards-producing organizations referenced in this report are listed with their serial designation, including year of adoption or revision. The documents listed were the latest effort at the time this report was revised. Since some of these documents are revised frequently, usually in minor detail only, the user of this report should check directly with the sponsoring group if it is desired to refer to the latest revision.

American Concrete Institute

201.2R-77	Guide to Durable Concrete
207.1R-70 (Reapproved 1980)	Mass Concrete for Dams and Other Massive Structures
211.1-81	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
212.2R-81	Guide for Use of Admixtures in Concrete
301-84	Specifications for Structural Concrete for Buildings
302.1R-80	Guide for Concrete Floor and Slab Construction
306.1-87	Standard Specification for Cold Weather Concreting
308-81	Standard Practice for Curing Concrete
318-83	Building Code Requirements for Reinforced Concrete
347-78 (Reapproved 1984)	Recommended Practice for Concrete Formwork

ASTM

C 31-87a	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C 39-86	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 192-81	Standard Method of Making Curing Concrete Test Specimens in the Laboratory
C 309-81	Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
C 494-82	Standard Specification for Chemical Admixtures for Concrete
C 684-81	Standard Method of Making, Accelerated Curing, and Testing of Concrete Compression Test Specimens
C 803-82	Standard Test Method for Penetration Resistance of Hardened Concrete
C 873-85	Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
C 900-87	Standard Test Method for Pullout Strength of Hardened Concrete
C 1064-86	Standard Test Method for Temperature of Freshly Mixed Portland-cement Concrete
C 1074-87	Standard Practice for Estimating Concrete Strength by the Maturity Method

These publications are available from the following organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219-0150

ASTM
1916 Race Street
Philadelphia, PA 19103

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This report was submitted to letter ballot of the committee and was approved in accordance with ACI balloting procedures.

Designation: C 172 – 04

Standard Practice for Sampling Freshly Mixed Concrete[1]

This standard is issued under the fixed designation C 172; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This practice covers procedures for obtaining representative samples of fresh concrete as delivered to the project site on which tests are to be performed to determine compliance with quality requirements of the specifications under which the concrete is furnished (Note 1). The practice includes sampling from stationary, paving and truck mixers, and from agitating and nonagitating equipment used to transport central-mixed concrete.

1.2 The values stated in SI units are to be regarded as the standard. The values shown in parentheses are provided for information only.

NOTE 1—Composite samples are required by this practice, unless specifically excepted by procedures governing the tests to be performed such as tests to determine uniformity of consistency and mixer efficiency. Procedures used to select the specific test batches are not described in this practice, but it is recommended that random sampling be used to determine overall specification compliance.

1.3 This practice also covers the procedures to be used for preparing a sample of concrete for further testing where it is desirable or necessary to remove the aggregate larger than a designated size. This removal of larger aggregate particles is preferably accomplished by wet-sieving.

1.4 The text of this standard references notes and footnotes which provide explanatory material and shall not be considered as requirements of the practice.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.[2])

2. Referenced Documents

2.1 *ASTM Standards:* [3]

E 11 Specification for Wire-Cloth and Sieves for Testing Purposes

3. Significance and Use

3.1 This practice is intended to provide standard requirements and procedures for sampling freshly mixed concrete from different containers used in the production or transportation of concrete. The detailed requirements as to materials, mixtures, air content, temperature, number of specimens, slump, interpretation of results, and precision and bias are in specific test methods.

4. Sampling

4.1 The elapsed time shall not exceed 15 min. between obtaining the first and final portions of the composite sample.

4.1.1 Transport the individual samples to the place where fresh concrete tests are to be performed or where test specimens are to be molded. They shall be combined and remixed with a shovel the minimum amount necessary to ensure uniformity and compliance with the maximum time limits specified in 4.1.2.

4.1.2 Start tests for slump, temperature, and air content within 5 min after obtaining the final portion of the composite sample. Complete these tests expeditiously. Start molding specimens for strength tests within 15 min after fabricating the composite sample. Expeditiously obtain and use the sample and protect the sample from the sun, wind, and other sources of rapid evaporation, and from contamination.

[1] This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Testing Fresh Concrete .

Current edition approved June 1, 2004. Published June 2004. Originally approved in 1942. Last previous edition approved in 1999 as C 172 – 99.

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

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

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5. Procedure

5.1 *Size of Sample*—Make the samples to be used for strength tests a minimum of 28 L (1 ft^3). Smaller samples are not prohibited for routine air content, temperature, and slump tests. The size of the samples shall be dictated by the maximum aggregate size.

5.2 The procedures used in sampling shall include the use of every precaution that will assist in obtaining samples that are truly representative of the nature and condition of concrete sampled as follows:

NOTE 2—Sampling should normally be performed as the concrete is delivered from the mixer to the conveying vehicle used to transport the concrete to the forms; however, specifications may require other points of sampling, such as the discharge of a concrete pump.

5.2.1 *Sampling from Stationary Mixers, Except Paving Mixers*—Sample the concrete by collecting two or more portions taken at regularly spaced intervals during discharge of the middle portion of the batch. Obtain these portions within the time limit specified in Section 4. Composite the portions into one sample for testing purposes. Do not obtain portions of the composite sample from the very first or last part of the batch discharge (Note 3). Perform sampling by passing a receptacle completely through the discharge stream, or by completely diverting the discharge into a sample container. If discharge of the concrete is too rapid to divert the complete discharge stream, discharge the concrete into a container or transportation unit sufficiently large to accommodate the entire batch and then accomplish the sampling in the same manner as given above. Take care not to restrict the flow of concrete from the mixer, container, or transportation unit so as to cause segregation. These requirements apply to both tilting and nontilting mixers.

NOTE 3—No samples should be taken before 10 % or after 90 % of the batch has been discharged. Due to the difficulty of determining the actual quantity of concrete discharged, the intent is to provide samples that are representative of widely separated portions, but not the beginning and the end of the load.

5.2.2 *Sampling from Paving Mixers*—Sample the concrete after the contents of the paving mixer have been discharged. Obtain samples from at least five different portions of the pile and then composite into one sample for test purposes. Avoid contamination with subgrade material or prolonged contact with and absorptive subgrade. To preclude contamination or absorption by the subgrade, sample the concrete by placing three shallow containers on the subgrade and discharging the concrete across the container. Composite the samples so obtained into one sample for test purposes. The containers shall be of a size sufficient to provide a composite sample size that is in agreement with the maximum aggregate size.

NOTE 4—In some instances, the containers may have to be supported above the subgrade to prevent displacement during discharge.

5.2.3 *Sampling from Revolving Drum Truck Mixers or Agitators*—Sample the concrete by collecting two or more portions taken at regularly spaced intervals during discharge of the middle portion of the batch. Take the samples so obtained within the time limit specified in Section 4 and composite them into one sample for test purposes. In any case do not obtain samples until after all of the water has been added to the mixer; also do not obtain samples from the very first or last portions of the batch discharge (Note 3). Sample by repeatedly passing a receptacle through the entire discharge stream or by completely diverting the discharge into a sample container. Regulate the rate of discharge of the batch by the rate of revolution of the drum and not by the size of the gate opening.

5.2.4 *Sampling from Open-Top Truck Mixers, Agitators, Nonagitating Equipment, or Other Types of Open-Top Containers*—Take samples by whichever of the procedures described in 5.2.1, 5.2.2, or 5.2.3 is most applicable under the given conditions.

6. Additional Procedure for Large Maximum Size Aggregate Concrete

6.1 When the concrete contains aggregate larger than that appropriate for the size of the molds or equipment to be used, wet-sieve the sample as described below except perform density (unit weight) tests for use in yield computations on the full mix.

NOTE 5—The effect of wet-sieving on the test results should be considered. For example, wet-sieving concrete causes the loss of a small amount of air due to additional handling. The air content of the wet-sieved fraction of concrete is greater than that of the total concrete because the larger size aggregate which is removed does not contain air. The apparent strength of wet-sieved concrete in smaller specimens is usually greater than that of the total concrete in larger appropriate size specimens. The effect of these differences may need to be considered or determined by supplementary testing for quality control or test result evaluation purposes.

6.2 *Definition*:

6.2.1 *wet-sieving concrete*—the process of removing aggregate larger than a designated size from the fresh concrete by sieving it on a sieve of the designated size.

6.3 *Apparatus*:

6.3.1 *Sieves*, as designated, conforming to Specification E 11.

6.3.2 *Wet-Sieving Equipment*—Equipment for wet-sieving concrete shall be a sieve as noted in 6.3.1 of suitable size and conveniently arranged and supported so that one can shake it rapidly by either hand or mechanical means. Generally, a horizontal back and forth motion is preferred. The equipment shall be capable of rapidly and effectively removing the designated size of aggregate.

6.3.3 *Hand Tools*—Shovels, hand scoops, plastering trowels, and rubber gloves as required.

6.4 *Procedure*:

6.4.1 *Wet-Sieving*—After sampling the concrete, pass the concrete over the designated sieve and remove and discard the aggregate retained. This shall be done before remixing. Shake or vibrate the sieve by hand or mechanical means until no undersize material remains on the sieve. Mortar adhering to the aggregate retained on the sieve shall not be wiped from it before it is discarded. Place only enough concrete on the sieve at any one time so that after sieving, the thickness of the layer of retained aggregate is not more than one particle thick. The concrete which passes the sieve shall fall into a batch pan of suitable size which has been dampened before use or onto a

clean, moist, nonabsorbent surface. Scrape any mortar adhering to the sides of the wet-sieving equipment into the batch. After removing the larger aggregate particles by wet-sieving remix the batch with a shovel the minimum amount necessary to ensure uniformity and proceed testing immediately.

7. Keywords

7.1 air content; batch; composite sample; concrete; slump; temperature; wet-sieving

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this practice since the last issue, C 172 – 99, that may impact the use of this practice. (Approved June 1, 2004)

(*1*) Made an addition to 1.5 safety caveat.

(*2*) Replaced "unit weight" with "density" in 6.1.

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Designation: C 143/C 143M – 05a

Standard Test Method for Slump of Hydraulic-Cement Concrete[1]

This standard is issued under the fixed designation C 143/C 143M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers determination of slump of hydraulic-cement concrete, both in the laboratory and in the field.

1.2 The values stated in either inch-pound units or SI units are to be regarded separately as 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 text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.[2])

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C 172 Practice for Sampling Freshly Mixed Concrete

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. Summary of Test Method

3.1 A sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised, and the concrete allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete.

4. Significance and Use

4.1 This test method is intended to provide the user with a procedure to determine slump of plastic hydraulic-cement concretes.

NOTE 1—This test method was originally developed to provide a technique to monitor the consistency of unhardened concrete. Under laboratory conditions, with strict control of all concrete materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture, and thus to be inversely related to concrete strength. Under field conditions, however, such a strength relationship is not clearly and consistently shown. Care should therefore be taken in relating slump results obtained under field conditions to strength.

4.2 This test method is considered applicable to plastic concrete having coarse aggregate up to 1½ in. [37.5 mm] in size. If the coarse aggregate is larger than 1½ in. [37.5 mm] in size, the test method is applicable when it is performed on the fraction of concrete passing a 1½-in. [37.5-mm] sieve, with the larger aggregate being removed in accordance with the section titled "Additional Procedure for Large Maximum Size Aggregate Concrete" in Practice C 172.

4.3 This test method is not considered applicable to non-plastic and non-cohesive concrete.

NOTE 2—Concretes having slumps less than ½ in. [15 mm] may not be adequately plastic and concretes having slumps greater than about 9 in. [230 mm] may not be adequately cohesive for this test to have significance. Caution should be exercised in interpreting such results.

5. Apparatus

5.1 *Mold*—The test specimen shall be formed in a mold made of metal not readily attacked by the cement paste. The metal shall not be thinner than 0.060 in. [1.5 mm] and if formed by the spinning process, there shall be no point on the mold at which the thickness is less than 0.045 in. [1.15 mm]. The mold shall be in the form of the lateral surface of the frustum of a cone with the base 8 in. [200 mm] in diameter, the top 4 in. [100 mm] in diameter, and the height 12 in. [300 mm]. Individual diameters and heights shall be within ±⅛ in. [3 mm] of the prescribed dimensions. The base and the top shall

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Fresh Concrete Testing.

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

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

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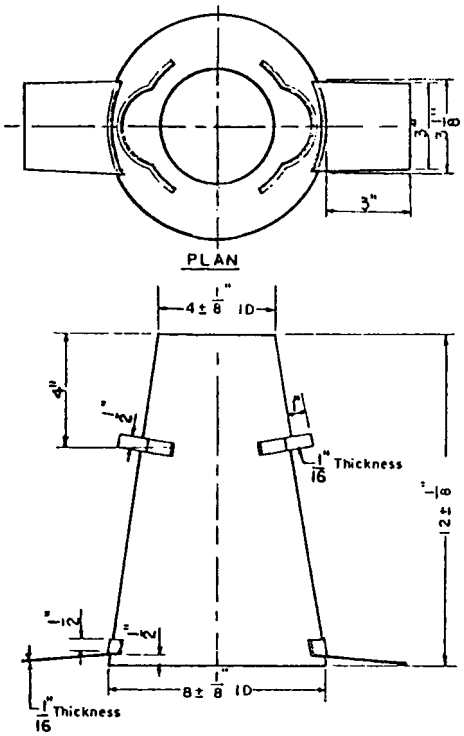
be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles similar to those shown in Fig. 1. The mold shall be constructed without a seam. The interior of the mold shall be relatively smooth and free from projections. The mold shall be free from dents, deformation, or adhered mortar. A mold which clamps to a nonabsorbent base plate is acceptable instead of the one illustrated, provided the clamping arrangement is such that it can be fully released without movement of the mold and the base is large enough to contain all of the slumped concrete in an acceptable test.

5.1.1 Check and record conformance to the mold's specified dimensions when it is purchased or first placed in service and at least annually thereafter.

5.1.2 Mold with alternative materials.

5.1.2.1 Molds other than metal are allowed if the following requirements are met: The mold shall meet the shape, height, and internal dimensional requirements of 5.1. The mold shall be sufficiently rigid to maintain the specified dimensions and tolerances during use, resistant to impact forces, and shall be nonabsorbent. The mold shall be demonstrated to provide test results comparable to those obtained when using a metal mold meeting the requirements of 5.1. Comparability shall be demonstrated on behalf of the manufacturer by an independent testing laboratory. Test for comparability shall consist of not less than 10 consecutive pairs of comparisons performed at each of 3 different slumps ranging from 2 to 8 in. [50 to 200 mm] (Note 3). No individual test results shall vary by more than 0.50 in. [15 mm] from that obtained using the metal mold.



Dimensional Units									
in.	1/16	1/8	1/2	1	3	3 1/8	4	8	12
mm	[2]	[3]	[15]	[25]	[75]	[80]	[100]	[200]	[300]

FIG. 1 Mold for Slump Test

The average test results of each slump range obtained using the mold constructed of alternative material shall not vary by more than 0.25 in. [6 mm] from the average of test results obtained using the metal mold. Manufacturer comparability test data shall be available to users and laboratory inspection authorities (Note 4). If any changes in material or method of manufacture are made, tests for comparability shall be repeated.

NOTE 3—The phrase "consecutive pairs of comparisons" does not mean without interruption or all in one day. At a schedule selected by the testing entity, the pairs of tests leading to 10 consecutive pairs may be accomplished in small groups. The word "consecutive" prevents ignoring pairs of tests which may not meet the criteria.

NOTE 4—Because the slump of concrete decreases with time and higher temperatures, it will be advantageous for the comparability tests to be performed by alternating the use of metal cones and alternative material cones, to utilize several technicians, and to minimize the time between test procedures.

5.1.2.2 If the condition of any individual mold is suspected of being out of tolerance from the as manufactured condition, a single comparative test shall be performed. If the test results differ by more than 0.50 in. [15 mm] from that obtained using the metal mold, the mold shall be removed from service.

5.2 *Tamping Rod*—A round, straight steel rod 5/8 in. [16 mm] in diameter and approximately 24 in. [600 mm] in length, having the tamping end or both ends rounded to a hemispherical tip, the diameter of which is 5/8 in. [16 mm].

5.3 *Measuring Device*—A ruler, metal roll-up measuring tape, or similar rigid or semi-rigid length measuring instrument marked in increments of 1/4 in. [5 mm] or smaller. The instruement length shall be at least 12 in. [300 mm].

6. Sample

6.1 The sample of concrete from which test specimens are made shall be representative of the entire batch. It shall be obtained in accordance with Practice C 172.

7. Procedure

7.1 Dampen the mold and place it on a flat, moist, nonabsorbent (rigid) surface. It shall be held firmly in place during filling and perimeter cleaning by the operator standing on the two foot pieces or by a clamping arrangement to a base plate as described in 5.1. From the sample of concrete obtained in accordance with Section 6, immediately fill the mold in three layers, each approximately one third the volume of the mold.

NOTE 5—One third of the volume of the slump mold fills it to a depth of 2 5/8 in. [70 mm]; two thirds of the volume fills it to a depth of 6 1/8 in. [160 mm].

7.2 Rod each layer with 25 strokes of the tamping rod. Uniformly distribute the strokes over the cross section of each layer. For the bottom layer, this will necessitate inclining the rod slightly and making approximately half of the strokes near the perimeter, and then progressing with vertical strokes spirally toward the center. Rod the bottom layer throughout its depth. Rod the second layer and the top layer each throughout its depth, so that the strokes just penetrate into the underlying layer.

7.3 In filling and rodding the top layer, heap the concrete above the mold before rodding is started. If the rodding operation results in subsidence of the concrete below the top

edge of the mold, add additional concrete to keep an excess of concrete above the top of the mold at all times. After the top layer has been rodded, strike off the surface of the concrete by means of a screeding and rolling motion of the tamping rod. Continue to hold the mold down firmly and remove concrete from the area surrounding the base of the mold to preclude interference with the movement of slumping concrete. Remove the mold immediately from the concrete by raising it carefully in a vertical direction. Raise the mold a distance of 12 in. [300 mm] in 5 ± 2 s by a steady upward lift with no lateral or torsional motion. Complete the entire test from the start of the filling through removal of the mold without interruption and complete it within an elapsed time of 2½ min.

7.4 Immediately measure the slump by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen. If a decided falling away or shearing off of concrete from one side or portion of the mass occurs (Note 6), disregard the test and make a new test on another portion of the sample.

NOTE 6—If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion of the concrete from the mass of the specimen, the concrete probably lacks necessary plasticity and cohesiveness for the slump test to be applicable.

8. Report

8.1 Report the slump in terms of inches [millimetres] to the nearest ¼ in. [5 mm] of subsidence of the specimen during the test.

9. Precision and Bias [4]

9.1 *Precision*—The estimates of precision for this test method are based upon results from tests conducted in Fayetteville, Arkansas by 15 technicians from 14 laboratories representing 3 states. All tests at 3 different slump ranges, from 1.0 in. [25 mm] to 6.5 in. [160 mm], were performed using one load of truck-mixed concrete. The concrete was delivered and tested at a low slump, with water then being added and mixed into the remaining concrete to independently produce moderate and finally high-slump concrete. The concrete mixture that used a No. 67 crushed limestone aggregate and a washed river sand, contained 500 lb of cementitious materials per cubic yard [297 kg of cementitious material per cubic metre]. The 500 lb [227 kg] were equally divided between a C150, Type I/II cement and a Class C fly ash. A double dosage of a chemical retarder was used in an attempt to minimize slump losses and maintain workability of the concrete. Concrete temperatures ranged from 86 to 93 °F [30 to 34 °C]. Slump losses averaged 0.68 in. [17 mm] during the 20 min required to perform a series of 6 tests at 1 slump range. Testing was performed alternately using metal and plastic molds, which were determined to produce comparable results. Precision data thus applies to both metal and plastic molds. A total of 270 slump tests were performed.

9.1.1 *Inch-Pound [SI]*—The data used to develop the precision statement were obtained using metric units (millimetres). The precision values shown in inch-pound units are conversions from the millimetre measurements, which were recorded to the nearest 1 mm.

9.1.2 *Measure of Variability*—The standard deviation was determined to be the most consistent measure of variability and was found to vary with the slump value.

9.1.3 *Single-Operator Precision*—The single-operator standard deviation represented by (1s) is shown in Table 1 by average slump values. The reported results for the replicate readings apply to tests conducted by the same operator performing successive tests, one immediately following the other. Acceptable results of two properly conducted tests by the same operator on the same material (Note 7) will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and single-operator precision.

9.1.4 *Multilaboratory Precision*—The multilaboratory standard deviation represented by (1s) is shown in Table 1 by average slump values. The reported results for the replicate readings apply to tests conducted by different operators from different laboratories performing tests less than 4 min apart. Therefore, acceptable results of two properly conducted slump tests on the same material (Note 7) by two different laboratories will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and multilaboratory precision.

NOTE 7—"Same materials," is used to mean freshly mixed concrete from one batch.

9.2 *Bias*—This test method has no bias since slump is defined only in terms of this test method.

10. Keywords

10.1 concrete; cone; consistency; plasticity; slump; workability

TABLE 1 Precision

Slump and Type Index	Standard Deviation (1s)[A]		Acceptable Range of Two Results (d2s)[A]	
Single-Operator Precision:	in.	[mm]	in.	[mm]
Slump 1.2 in. [30 mm]	0.23	[6]	0.65	[17]
Slump 3.4 in. [85 mm]	0.38	[9]	1.07	[25]
Slump 6.5 in. [160 mm]	0.40	[10]	1.13	[28]
Multilaboratory Precision:				
Slump 1.2 in. [30 mm]	0.29	[7]	0.82	[20]
Slump 3.4 in. [85 mm]	0.39	[10]	1.10	[28]
Slump 6.5 in. [160 mm]	0.53	[13]	1.50	[37]

[A] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670.

[4] The test data used to develop this precision statement were based on tests performed in September 1997. A report of test results is on file at ASTM International Headquarters. Request RR: C09-1022.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C 143/C 143M – 05, that may impact the use of this test method. (Approved November 1, 2005)

(*1*) Revised 7.1.

Committee C09 has identified the location of selected changes to this test method since the last issue, C 143/C 143M – 03, that may impact the use of this test method. (Approved May 1, 2005)

(*1*) Added additional safety warning with footnote to 1.4.
(*2*) Added a new 5.1.1 about checking critical dimensions and renumbered subsequent sections.
(*3*) Revised 5.1.2.1 to clarify and alter testing criteria for alternate materials.
(*4*) Added new Note 3 to clarify the term "consecutive pairs."
(*5*) Added new 5.3 to provide description of suitable measuring device to measure the subsidence of the concrete.

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Designation: C 1064/C 1064M – 05

Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete[1]

This standard is issued under the fixed designation C 1064/C 1064M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers the determination of temperature of freshly mixed hydraulic-cement concrete.

1.2 The values stated in inch-pound or SI units are to be regarded separately as standard. Within the text, 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 specification.

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

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.[2])

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C 172 Practice for Sampling Freshly Mixed Concrete

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. Significance and Use

3.1 This test method provides a means for measuring the temperature of freshly mixed concrete. It may be used to verify conformance to a specified requirement for temperature of concrete.

3.2 Concrete containing aggregate of a nominal maximum size greater than 3 in. [75 mm] may require up to 20 min for the transfer of heat from aggregate to mortar. (See ACI Committee 207.1R Report.[4])

4. Apparatus

4.1 *Container*, shall be large enough to provide at least 3 in. [75 mm] of concrete in all directions around the sensor of the temperature measuring device; concrete cover must also be at least three times the nominal maximum size of the coarse aggregate.

4.2 *Temperature Measuring Device*, shall be capable of accurately measuring the temperature of the freshly mixed concrete to ±1 °F [±0.5 °C] throughout a range of 30° to 120 °F [0° to 50 °C]. The design of the temperature measuring device shall be such that it allows 3 in. [75 mm] or more immersion during operation.

4.3 Partial immersion liquid-in-glass thermometers (and possibly other types) shall have a permanent mark to which the device must be immersed without applying a correction factor.

4.4 *Reference Temperature Measuring Device*, shall be readable and accurate to ±0.5 °F [0.2 °C] at the verification points in 5.1. A certificate or report that verifies the accuracy shall be available in the laboratory for review. Accuracy of liquid-in-glass reference temperature measuring devices shall be verified once. Verification of direct-reading resistance reference temperature measuring devices shall be performed every twelve months. The certificate or report shall provide documentation that the reference standard used in the verification is traceable to the National Institute of Standards and Technology (NIST).

5. Calibration of Temperature Measuring Device

5.1 Each temperature measuring device used for determining temperature of freshly mixed concrete shall be calibrated annually, or whenever there is a question of accuracy. This calibration shall be performed by comparing the readings of the temperature measuring device at two temperatures at least 30 °F [15 °C] apart.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Testing Fresh Concrete .

Current edition approved Jan. 1, 2005. Published January 2005. Originally approved in 1986. Last previous edition approved in 2004 as C 1064 – 04.

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

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from American Concrete Institute, Box 9094, Farmington Hills, MI 48333.

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5.2 Calibration of the temperature measuring devices may be made in oil or other suitable baths having uniform density if provision is made to:

5.2.1 Maintain the bath temperature constant within 0.5 °F [0.2 °C] during the period of the test.

5.2.2 Have both the temperature and reference temperature measuring devices maintained in the bath for a minimum of 5 min before reading temperatures.

5.2.3 Continuously circulate the bath liquid to provide a uniform temperature.

5.2.4 Slightly tap thermometers containing liquid to avoid adhesion of the liquid to the glass if the temperature exposure is being reduced.

6. Sampling Concrete

6.1 It is acceptable to measure the temperature of freshly mixed concrete in either the transporting equipment or the forms after discharge provided the sensor of the temperature measuring device has at least 3 in. [75 mm] of concrete cover in all directions.

6.2 If the transporting equipment or placement forms are not used as the container, a sample shall be prepared as follows:

6.2.1 Immediately, prior to sampling the freshly mixed concrete, dampen (with water) the sample container.

6.2.2 Sample the freshly mixed concrete in accordance with Practice C 172, except that composite samples are not required if the only purpose for obtaining the sample is to determine temperature.

6.2.3 Place the freshly mixed concrete into the container.

7. Procedure

7.1 Position the temperature measuring device so that the end of the temperature sensing portion is submerged a minimum of 3 in. [75 mm] into the freshly mixed concrete. Close the void left by the placement by gently pressing the concrete around the temperature measuring device at the surface of the concrete to prevent ambient air temperature from affecting the reading.

7.2 Leave the temperature measuring device in the freshly mixed concrete for a minimum period of 2 min or until the temperature reading stabilizes, then read and record the temperature.

7.3 Complete the temperature measurement of the freshly mixed concrete within 5 min after obtaining the sample, except for concrete that contains a nominal maximum size aggregate greater than 3 in. [75 mm]. With aggregate greater than 3 in. [75 mm], make sure that the temperature has stabilized before recording the reading (See Note 1).

NOTE 1—It may require as much as 20 min before the temperature is stabilized after mixing.

8. Report

8.1 Record the measured temperature of the freshly mixed concrete to the nearest 1 °F [0.5 °C].

9. Precision and Bias

9.1 The single operator standard deviation for measurement of concrete temperature has been found to be 0.5 °F.[5] Therefore, results of two properly conducted tests by the same operator on the same sample of material should not differ by more than 1.3 °F.[5]

9.2 The multi-operator standard deviation for the measurement of concrete temperature on the same sample has been found to be 0.7 °F.[5] Therefore, two tests properly conducted by different operators but on the same material should not differ by more than 1.9 °F.[5]

9.3 The precision values given were derived from an interlaboratory study using 11 operators on two concrete batches at around 75 °F.[6]

9.4 Since there is no accepted reference material suitable for determining the bias of this test method, no statement on bias is being made.

10. Keywords

10.1 freshly mixed concrete; temperature; temperature measuring device

[5] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670.

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: C09-1028.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this specification since the last issue, C 1064/C 1064M – 04, that may impact the use of this specification (Approved January 1, 2005).

(*1*) Deleted old 9.1 and replaced with new 9.1-9.4 and Note 1.

Committee C09 has identified the location of selected changes to this specification since the last issue, C 1064/C 1064M – 03, that may impact the use of this specification (Approved June 1, 2004).

(*1*) Changed the title of the standard.
(*2*) Revised 1.1.
(*3*) Added new 1.3 and renumbered subsequent sections.
(*4*) Added to 1.4 safety caveat.
(*5*) Revised 4.1.
(*6*) Combined 6.1 and 6.2 into a new and revised 6.1.
(*7*) Deleted 6.3.4.
(*8*) Revised 7.3.

(*9*) Added Note 1.

Committee C09 has identified the location of selected changes to this specification since the last issue, C 1064/C 1064M – 01, that may impact the use of this specification (Approved October 10, 2003).

(*1*) Revised 4.2 to require a temperature-measuring device to accommodate a 3 in. minimum immersion in the concrete.

(*2*) Revised 7.1 for clarity.

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Designation: C 138/C 138M – 01a

American Association State
Highway and Transportation Officials Standard
AASHTO No.: T121

Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete[1]

This standard is issued under the fixed designation C 138/C 138M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This test method covers determination of the density (see Note 1) of freshly mixed concrete and gives formulas for calculating the yield, cement content, and air content of the concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.

1.2 The values stated in either inch-pound or SI units shall be regarded separately as standard. The SI units are shown in brackets. The values stated might not be exact equivalents; therefore each system must be used independently of the other.

NOTE 1—Unit weight was the previous terminology used to describe the property determined by this test method, which is mass per unit volume.

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Bulk Density (Unit Weight) and Voids in Aggregate[2]

C 150 Specification for Portland Cement[3]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 188 Test Method for Density of Hydraulic Cement[3]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

3. Terminology

3.1 *Symbols*:

A = air content (percentage of voids) in the concrete
C = actual cement content, lb/yd^3 or kg/m^3
C_b = mass of cement in the batch, lb or kg
D = density (unit weight) of concrete, lb/ft^3 or kg/m^3
M = total mass of all materials batched, lb or kg (see Note 3)
M_c = mass of the measure filled with concrete, lb or kg
M_m = mass of the measure, lb or kg
R_y = relative yield
T = theoretical density of the concrete computed on an airfree basis, lb/ft^3 or kg/m^3 (see Note 2)
Y = yield, volume of concrete produced per batch, yd^3 or m^3
Y_d = volume of concrete which the batch was designed to produce, yd^3 or m^3
Y_f = volume of concrete produced per batch, ft^3
V = total absolute volume of the component ingredients in the batch, ft^3 or m^3
V_m = volume of the measure, ft^3 or m^3

NOTE 2—The theoretical density is, customarily, a laboratory determination, the value for which is assumed to remain constant for all batches made using identical component ingredients and proportions. It is calculated from the following equation:

$$T = M/V \tag{1}$$

The absolute volume of each ingredient in cubic feet is equal to the quotient of the mass of that ingredient divided by the product of its specific gravity times 62.4. The absolute volume of each ingredient in cubic metres is equal to the mass of the ingredient in kilograms divided by 1000 times its specific gravity. For the aggregate components, the bulk specific gravity and mass should be based on the saturated, surface-dry condition. For cement, the actual specific gravity should be determined by Test Method C 188. A value of 3.15 may be used for cements manufactured to meet the requirements of Specification C 150.

NOTE 3—The total mass of all materials batched is the sum of the masses of the cement, the fine aggregate in the condition used, the coarse aggregate in the condition used, the mixing water added to the batch, and any other solid or liquid materials used.

4. Apparatus

4.1 *Balance*—A balance or scale accurate to 0.1 lb [45 g] or to within 0.3 % of the test load, whichever is greater, at any point within the range of use. The range of use shall be

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Fresh Concrete Testing.

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[2] *Annual Book of ASTM Standards,* Vol 04.02.

[3] *Annual Book of ASTM Standards,* Vol 04.01.

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

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considered to extend from the mass of the measure empty to the mass of the measure plus its contents at 160 lb/ft^3 [2600 kg/m^3].

4.2 *Tamping Rod*—A round, straight steel rod, ⅝ in. [16 mm] in diameter and approximately 24 in. [600 mm] in length, having the tamping end rounded to a hemispherical tip the diameter of which is ⅝ in.

4.3 *Internal Vibrator*—Internal vibrators may have rigid or flexible shafts, preferably powered by electric motors. The frequency of vibration shall be 7000 vibrations per minute or greater while in use. The outside diameter or the side dimension of the vibrating element shall be at least 0.75 in. [19 mm] and not greater than 1.50 in. [38 mm]. The length of the shaft shall be at least 24 in. [600 mm].

4.4 *Measure*—A cylindrical container made of steel or other suitable metal (see Note 4). The minimum capacity of the measure shall conform to the requirements of Table 1 based on the nominal size of aggregate in the concrete to be tested. All measures, except for measuring bowls of air meters which are also used for Test Method C 138 tests, shall conform to the requirements of Test Method C 29/C 29M. When measuring bowls of air meters are used, they shall conform to the requirements of Test Method C 231, and shall be calibrated for volume as described in Test Method C 29/C 29M. The top rim of the air meter bowls shall be smooth and plane within 0.01 in. [0.3 mm] (see Note 5).

NOTE 4—The metal should not be readily subject to attack by cement paste. However, reactive materials such as aluminum alloys may be used in instances where as a consequence of an initial reaction, a surface film is rapidly formed which protects the metal against further corrosion.

NOTE 5—The top rim is satisfactorily plane if a 0.01-in. [0.3-mm] feeler gage cannot be inserted between the rim and a piece of ¼-in. [6-mm] or thicker plate glass laid over the top of the measure.

4.5 *Strike-Off Plate*—A flat rectangular metal plate at least ¼ in. [6 mm] thick or a glass or acrylic plate at least ½ in. [12 mm] thick with a length and width at least 2 in. [50 mm] greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance of 1⁄16 in. [2 mm].

4.6 *Mallet*—A mallet (with a rubber or rawhide head) having a mass of 1.25 ± 0.50 lb [600 ± 200 g] for use with measures of 0.5 ft^3 [14 L] or smaller, and a mallet having a mass of 2.25 ± 0.50 lb [1000 ± 200 g] for use with measures larger than 0.5 ft^3.

5. Sample

5.1 Obtain the sample of freshly mixed concrete in accordance with Practice C 172.

TABLE 1 Capacity of Measures

Nominal Maximum Size of Coarse Aggregate		Capacity of Measure[A]	
in.	mm	ft^3	L
1	25.0	0.2	6
1½	37.5	0.4	11
2	50	0.5	14
3	75	1.0	28
4½	112	2.5	70
6	150	3.5	100

[A] The indicated size of measure shall be used to test concrete containing aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95 % of the nominal volume listed.

6. Procedure

6.1 Base the selection of the method of consolidation on the slump, unless the method is stated in the specifications under which the work is being performed. The methods of consolidation are rodding and internal vibration. Rod concretes with a slump greater than 3 in. [75 mm]. Rod or vibrate concrete with a slump of 1 to 3 in. [25 to 75 mm]. Consolidate concretes with a slump less than 1 in. by vibration.

NOTE 6—Nonplastic concrete, such as is commonly used in the manufacture of pipe and unit masonry, is not covered by this test method.

6.2 *Rodding*—Place the concrete in the measure in three layers of approximately equal volume. Rod each layer with 25 strokes of the tamping rod when nominal 0.5-ft^3 [14-L] or smaller measures are used, 50 strokes when nominal 1-ft^3 [28-L] measures are used, and one stroke per 3 in.^{2} [20 cm^3] of surface for larger measures. Rod the bottom layer throughout its depth but the rod shall not forcibly strike the bottom of the measure. Distribute the strokes uniformly over the cross section of the measure and for the top two layers, penetrate about 1 in. [25 mm] into the underlying layer. After each layer is rodded, tap the sides of the measure 10 to 15 times with the appropriate mallet (see 4.6) using such force so as to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. Add the final layer so as to avoid overfilling.

6.3 *Internal Vibration*—Fill and vibrate the measure in two approximately equal layers. Place all of the concrete for each layer in the measure before starting vibration of that layer. Insert the vibrator at three different points for each layer. In compacting the bottom layer, do not allow the vibrator to rest on or touch the bottom or sides of the measure. In compacting the final layer, the vibrator shall penetrate into the underlying layer approximately 1 in. [25 mm]. Take care that the vibrator is withdrawn in such a manner that no air pockets are left in the specimen. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator (see Note 7). Continue vibration only long enough to achieve proper consolidation of the concrete (see Note 8). Observe a constant duration of vibration for the particular kind of concrete, vibrator, and measure involved.

NOTE 7—Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth.

NOTE 8—Overvibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

6.4 On completion of consolidation the measure must not contain a substantial excess or deficiency of concrete. An excess of concrete protruding approximately ⅛ in. [3 mm] above the top of the mold is optimum. A small quantity of concrete may be added to correct a deficiency. If the measure contains a great excess of concrete at completion of consolidation, remove a representative portion of the excess concrete with a trowel or scoop immediately following completion of consolidation and before the measure is struck-off.

6.5 *Strike-Off*—After consolidation, strike-off the top surface of the concrete and finish it smoothly with the flat strike-off plate using great care to leave the measure just level

full. The strike-off is best accomplished by pressing the strike-off plate on the top surface of the measure to cover about two thirds of the surface and withdrawing the plate with a sawing motion to finish only the area originally covered. Then place the plate on the top of the measure to cover the original two thirds of the surface and advance it with a vertical pressure and a sawing motion to cover the whole surface of the measure and continue to advance it until it slides completely off the measure. Several final strokes with the inclined edge of the plate will produce a smooth finished surface.

6.6 *Cleaning and Weighing*—After strike-off, clean all excess concrete from the exterior of the measure and determine the mass of the concrete and measure to an accuracy consistent with the requirements of 4.1.

7. Calculation

7.1 *Density (Unit Weight)*—Calculate the net mass of the concrete in pounds or kilograms by subtracting the mass of the measure, M_m, from the mass of the measure filled with concrete, M_c. Calculate the density, D, ft^3 or yd^3,by dividing the net mass of concrete by the volume of the measure, V_m as follows:

$$D = (M_c - M_m)/V_m \tag{2}$$

7.2 *Yield*—Calculate the yield as follows:

$$Y(\text{yd}^3) = M/(D \times 27) \tag{3}$$

or

$$Y(\text{m}^3) = M/D \tag{4}$$

7.3 *Relative Yield*—Relative yield is the ratio of the actual volume of concrete obtained to the volume as designed for the batch (see Note 9) calculated as follows:

$$R_y = Y/Y_d \tag{5}$$

NOTE 9—A value for R_y greater than 1.00 indicates an excess of concrete being produced whereas a value less than this indicates the batch to be "short" of its designed volume. In practice, a ratio of yield in cubic feet per cubic yard of design concrete mixture is frequently used, for example, 27.3 ft^3/yd^3.

7.4 *Cement Content*—Calculate the actual cement content as follows:

$$C = C_b / Y \tag{6}$$

7.5 *Air Content*—Calculate the air content as follows:

$$A = [(T - D)/T] \times 100 \tag{7}$$

or

$$A = [(Y_f - V)/Y_f] \times 100 \text{ (inch−pound units)} \tag{8}$$

or

$$A = [(Y - V)/Y] \times 100 \text{ (SI units)} \tag{9}$$

8. Precision and Bias

8.1 The following estimates of precision for this test method are based on a collection of data from various locations by the National Ready Mixed Concrete Association.[4] The data represent concrete mixtures with slump ranging from 3 to 6 in. [75 to 150 mm] and density ranging from 115 to 155 lb/ft^3 [1842 to 2483 kg/m^3] and included air-entrained and non air-entrained concrete. The study was conducted using 0.25 ft^3 [7-L] and 0.5 ft^3 [14-L] measures.

8.1.1 *Single-Operator Precision*—The single operator standard deviation of density of freshly mixed concrete has been found to be 0.65 lb/ft^3 [10.4 kg/m^3] (1s). Therefore, results of two properly conducted by the same operator on the same sample of concrete should not differ by more than 1.85 lb/ft^3 [29.6 kg/m^3] (d2s).

8.1.2 *Multi-Operator Precision*—The multi-operator standard deviation of density of freshly mixed concrete has been found to be 0.82 lb/ft^3 [13.1 kg/m^3] (1s). Therefore, results of two properly conducted tests by the two operators on the same sample of concrete should not differ by more than 2.31 lb/ft^3 [37.0 kg/m^3] (d2s).

8.2 *Bias*—This test method has no bias since the density is defined only in terms of this test method.

9. Keywords

9.1 air content; cement content; concrete; relative yield; unit weight; yield

[4] Mullings, G. M., NRMCA/NAA Joint Research Lab Study "Series D 324 Accuracy of Concrete Density Test," Feb. 17, 2000.

SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue.

(1) Designation was revised.
(2) Title was revised.
(3) Paragraphs 1.1 and 1.2 were revised.
(3) Note 1 and paragraph 1.3 were added. Subsequent notes were renumbered.
(4) Section 2 was updated.
(5) Section 3 was renamed "Terminology" and revised.
(6) Paragraphs 4.1-4.6 were revised.
(7) Paragraphs 6.1-6.6 were revised.
(8) Equations in Section 7 were revised.
(9) Paragraphs 7.1-7.5 were revised.
(10) Paragraph 8.1 was revised.

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Designation: C 231 – 04

Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[1]

This standard is issued under the fixed designation C 231; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers determination of the air content of freshly mixed concrete from observation of the change in volume of concrete with a change in pressure.

1.2 This test method is intended for use with concretes and mortars made with relatively dense aggregates for which the aggregate correction factor can be satisfactorily determined by the technique described in Section 6. It is not applicable to concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. In these cases, Test Method C 173/C 173M should be used. This test method is also not applicable to nonplastic concrete such as is commonly used in the manufacture of pipe and concrete masonry units.

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

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.)[2]

2. Referenced Documents

2.1 *ASTM Standards:* [3]

C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C 172 Practice for Sampling Freshly Mixed Concrete
C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

3. Significance and Use

3.1 This test method covers the determination of the air content of freshly mixed concrete. The test determines the air content of freshly mixed concrete exclusive of any air that may exist inside voids within aggregate particles. For this reason, it is applicable to concrete made with relatively dense aggregate particles and requires determination of the aggregate correction factor (see 6.1 and 9.1).

3.2 This test method and Test Method C 138/C 138M and C 173/C 173M provide pressure, gravimetric, and volumetric procedures, respectively, for determining the air content of freshly mixed concrete. The pressure procedure of this test method gives substantially the same air contents as the other two test methods for concretes made with dense aggregates.

3.3 The air content of hardened concrete may be either higher or lower than that determined by this test method. This depends upon the methods and amount of consolidation effort applied to the concrete from which the hardened concrete specimen is taken; uniformity and stability of the air bubbles in the fresh and hardened concrete; accuracy of the microscopic examination, if used; time of comparison; environmental exposure; stage in the delivery, placement and consolidation processes at which the air content of the unhardened concrete is determined, that is, before or after the concrete goes through a pump; and other factors.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates, and is the direct responsibility of Subcommittee C09.60 on Testing Fresh Concrete.

Current edition approved July 1, 2004. Published July 2004. Originally approved in 1949. Last previous edition approved in 2003 as C 231 – 03.

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

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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4. Apparatus

4.1 *Air Meters*—There are available satisfactory apparatus of two basic operational designs employing the principle of Boyle's law. For purposes of reference herein these are designated Meter Type A and Meter Type B.

4.1.1 *Meter Type A*—An air meter consisting of a measuring bowl and cover assembly (see Fig. 1) conforming to the requirements of 4.2 and 4.3. The operational principle of this meter consists of introducing water to a predetermined height above a sample of concrete of known volume, and the application of a predetermined air pressure over the water. The determination consists of the reduction in volume of the air in the concrete sample by observing the amount the water level is lowered under the applied pressure, the latter amount being calibrated in terms of percent of air in the concrete sample.

4.1.2 *Meter Type B*—An air meter consisting of a measuring bowl and cover assembly (see Fig. 2) conforming to the requirements of 4.2 and 4.3. The operational principle of this meter consists of equalizing a known volume of air at a known pressure in a sealed air chamber with the unknown volume of air in the concrete sample, the dial on the pressure gage being calibrated in terms of percent air for the observed pressure at which equalization takes place. Working pressures of 7.5 to 30.0 psi (51 to 207 kPa) have been used satisfactorily.

4.2 *Measuring Bowl*—The measuring bowl shall be essentially cylindrical in shape, made of steel, hard metal, or other hard material not readily attacked by the cement paste, having a minimum diameter equal to 0.75 to 1.25 times the height, and a capacity of at least 0.20 ft^3 (5.7 L). It shall be flanged or otherwise constructed to provide for a pressure tight fit between bowl and cover assembly. The interior surfaces of the bowl and surfaces of rims, flanges, and other component fitted parts shall be machined smooth. The measuring bowl and cover assembly shall be sufficiently rigid to limit the expansion factor, *D*, of the apparatus assembly (Annex A1.5) to not more than 0.1 % of air content on the indicator scale when under normal operating pressure.

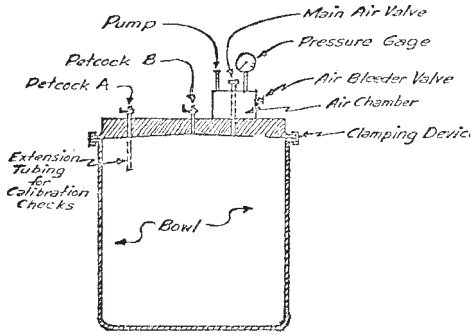

FIG. 2 Schematic Diagram—Type-B Meter

4.3 *Cover Assembly*:

4.3.1 The cover assembly shall be made of steel, hard metal, or other hard material not readily attacked by the cement paste. It shall be flanged or otherwise constructed to provide for a pressure-tight fit between bowl and cover assembly and shall have machined smooth interior surfaces contoured to provide an air space above the level of the top of the measuring bowl. The cover shall be sufficiently rigid to limit the expansion factor of the apparatus assembly as prescribed in 4.2.

4.3.2 The cover assembly shall be fitted with a means of direct reading of the air content. The cover for the Type A meter shall be fitted with a standpipe, made of a transparent graduated tube or a metal tube of uniform bore with a glass water gage attached. In the Type B meter, the dial of the pressure gage shall be calibrated to indicate the percent of air. Graduations shall be provided for a range in air content of at least 8 % readable to 0.1 % as determined by the proper air pressure calibration test.

4.3.3 The cover assembly shall be fitted with air valves, air bleeder valves, and petcocks for bleeding off or through which

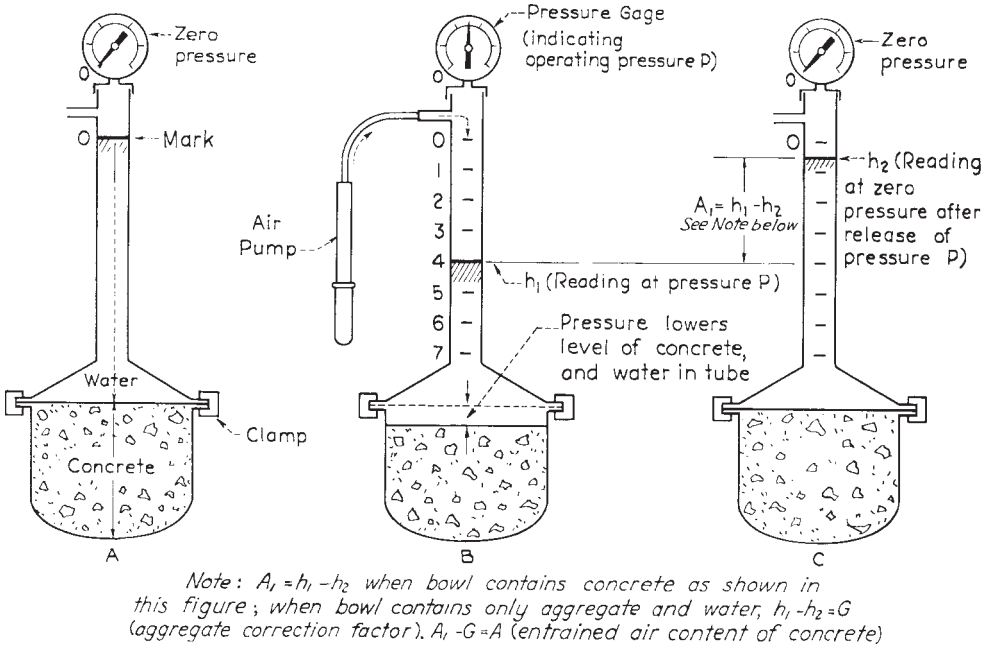

FIG. 1 Illustration of the Pressure Method for Air Content—Type-A Meter

water may be introduced as necessary for the particular meter design. Suitable means for clamping the cover to the bowl shall be provided to make a pressure-tight seal without entrapping air at the joint between the flanges of the cover and bowl. A suitable hand pump shall be provided with the cover either as an attachment or as an accessory.

4.4 *Calibration Vessel*—A measure having an internal volume equal to a percent of the volume of the measuring bowl corresponding to the approximate percent of air in the concrete to be tested; or, if smaller, it shall be possible to check calibration of the meter indicator at the approximate percent of air in the concrete to be tested by repeated filling of the measure. When the design of the meter requires placing the calibration vessel within the measuring bowl to check calibration, the measure shall be cylindrical in shape and of an inside depth ½ in. (13 mm) less than that of the bowl.

NOTE 1—A satisfactory calibration vessel to place within the measuring bowl may be machined from No. 16 gage brass tubing, of a diameter to provide the volume desired, to which a brass disk ½ in. in thickness is soldered to form an end. When design of the meter requires withdrawing of water from the water-filled bowl and cover assembly, to check calibration, the measure may be an integral part of the cover assembly or may be a separate cylindrical measure similar to the above-described cylinder.

4.5 The designs of various available types of air meters are such that they differ in operating techniques; therefore, all of the items described in 4.6-4.16 may not be required. The items required shall be those necessary for use with the particular design of apparatus used to satisfactorily determine air content in accordance with the procedures prescribed herein.

4.6 *Coil Spring or Other Device for Holding Calibration Cylinder in Place*.

4.7 *Spray Tube*—A brass tube of appropriate diameter, which may be an integral part of the cover assembly, or which may be provided separately. It shall be so constructed that when water is added to the container, it is sprayed to the walls of the cover in such a manner as to flow down the sides causing a minimum of disturbance to the concrete.

4.8 *Trowel*—A standard brick mason's trowel.

4.9 *Tamping Rod*—The tamping rod shall be a round straight steel rod ⅝ in. (16 mm) in diameter and not less than 16 in. (400 mm) in length, having the tamping end rounded to a hemispherical tip the diameter of which is ⅝ in. (16 mm).

4.10 *Mallet*—A mallet (with a rubber or rawhide head) weighing approximately 1.25 ± 0.50 lb (0.57 ± 0.23 kg) for use with measures of 0.5 ft^3 (14 L) or smaller, and a mallet weighing approximately 2.25 ± 0.50 lb (1.02 ± 0.23 kg) for use with measures larger than 0.5 ft^3 (14 L).

4.11 *Strike-Off Bar*—A flat straight bar of steel or other suitable metal at least ⅛ in. (3 mm) thick and ¾ in. (20 mm) wide by 12 in. (300 mm) long.

4.12 *Strike-Off Plate*—A flat rectangular metal plate at least ¼ in. (6 mm) thick or a glass or acrylic plate at least ½ in. (12 mm) thick with a length and width at least 2 in. (50 mm) greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance of 1⁄16 in. (1.5 mm).

4.13 *Funnel*, with the spout fitting into spray tube.

4.14 *Measure for Water*, having the necessary capacity to fill the indicator with water from the top of the concrete to the zero mark.

4.15 *Vibrator*, as described in Practice C 192/C 192M.

4.16 *Sieves*, 1½-in. (37.5-mm) with not less than 2 ft^2 (0.19 m^2) of sieving area.

5. Calibration of Apparatus

5.1 Make calibration tests in accordance with procedures prescribed in the annex. Rough handling will affect the calibration of both Types A and B meters. Changes in barometric pressure will affect the calibration of Type A meter but not Type B meter. The steps described A1.2 to A1.6, as applicable to the meter type under consideration, are prerequisites for the final calibration test to determine the operating pressure, *P*, on the pressure gage of the Type A meter as described in A1.7, or to determine the accuracy of the graduations indicating air content on the dial face of the pressure gage of the Type B meter. The steps in A1.2 to A1.6 need be made only once (at the time of initial calibration), or only occasionally to check volume constancy of the calibration cylinder and measuring bowl. The calibration test described in A1.7 and A1.9, as applicable to the meter type being checked, must be made as frequently as necessary and at intervals not to exceed three months to ensure that the proper gage pressure, *P*, is being used for the Type A meter or that the correct air contents are being indicated on the pressure gage air content scale for the Type B meter. A change in elevation of more than 600 ft (183 m) from the location at which a Type-A meter was last calibrated will require recalibration in accordance with A1.7.

6. Determination of Aggregate Correction Factor

6.1 *Procedure*—Determine the aggregate correction factor on a combined sample of fine and coarse aggregate as directed in 6.2 to 6.4. It is determined independently by applying the calibrated pressure to a sample of inundated fine and coarse aggregate in approximately the same moisture condition, amount, and proportions occurring in the concrete sample under test.

6.2 *Aggregate Sample Size*—Calculate the weights of fine and coarse aggregate present in the sample of fresh concrete whose air content is to be determined, as follows:

$$F_s = (S/B) \times F_b \quad (1)$$

$$C_s = (S/B) \times C_b \quad (2)$$

where:

F_s = mass of fine aggregate in concrete sample under test, lb (kg),

S = volume of concrete sample (same as volume of measuring bowl), ft^3 (m^3),

B = volume of concrete produced per batch (Note 2), ft^3 (m^3),

F_b = total mass of fine aggregate in the moisture condition used in batch, lb (kg),

C_s = mass of coarse aggregate in concrete sample under test, lb (kg), and

C_b = total mass of coarse aggregate in the moisture condition used in batch, lb (kg).

NOTE 2—The volume of concrete produced per batch can be determined in accordance with applicable provisions of Test Method C 138/C 138M.

NOTE 3—The term "weight" is temporarily used in this test method because of established trade usage. The word is used to mean both "force" and "mass," and care must be taken to determine which is meant in each case (SI unit for force = newton and for mass = kilogram).

6.3 *Placement of Aggregate in Measuring Bowl*—Mix representative samples of fine aggregate F_s and coarse aggregate C_s, and place in the measuring bowl filled one-third full with water. Place the mixed aggregate, a small amount at a time, into the measuring bowl; if necessary, add additional water so as to inundate all of the aggregate. Add each scoopful in a manner that will entrap as little air as possible and remove accumulations of foam promptly. Tap the sides of the bowl and lightly rod the upper 1 in. (25 mm) of the aggregate eight to twelve times. Stir after each addition of aggregate to eliminate entrapped air.

6.4 *Aggregate Correction Factor Determination*:

6.4.1 *Initial Procedure for Types A and B Meters*—When all of the aggregate has been placed in the measuring bowl, remove excess foam and keep the aggregate inundated for a period of time approximately equal to the time between introduction of the water into the mixer and the time of performing the test for air content before proceeding with the determination as directed in 6.4.2 or 6.4.3.

6.4.2 *Type A Meter*—Complete the test as described in 8.2.1 and 8.2.2. The aggregate correction factor, *G*, is equal to $h_1 - h_2$ (see Fig. 1) (Note 4).

6.4.3 *Type B Meter*—Perform the procedures as described in 8.3.1. Remove a volume of water from the assembled and filled apparatus approximately equivalent to the volume of air that would be contained in a typical concrete sample of a size equal to the volume of the bowl. Remove the water in the manner described in A1.9 for the calibration tests. Complete the test as described in 8.3.2. The aggregate correction factor, *G*, is equal to the reading on the air-content scale minus the volume of water removed from the bowl expressed as a percent of the volume of the bowl (see Fig. 1).

NOTE 4—The aggregate correction factor will vary with different aggregates. It can be determined only by test, since apparently it is not directly related to absorption of the particles. The test can be made easily. Ordinarily the factor will remain reasonably constant for given aggregates, but an occasional check test is recommended.

7. Preparation of Concrete Test Sample

7.1 Obtain the sample of freshly mixed concrete in accordance with applicable procedures of Practice C 172. If the concrete contains coarse aggregate particles that would be retained on a 2-in. (50-mm) sieve, wet-sieve a sufficient amount of the representative sample over a 1½-in. (37.5-mm) sieve, as described in Practice C 172, to yield sufficient material to completely fill the measuring bowl of the size selected for use. Carry out the wet-sieving operation with the minimum practicable disturbance of the mortar. Make no attempt to wipe adhering mortar from coarse aggregate particles retained on the sieve.

8. Procedure for Determining Air Content of Concrete

8.1 *Placement and Consolidation of Sample*:

8.1.1 Dampen the interior of the measuring bowl and place it on a flat, level, firm surface. Place a representative sample of the concrete, prepared as described in Section 7, in the measuring bowl in equal layers. Consolidate each layer by the rodding procedure (8.1.2) or by vibration (8.1.3). Strike-off the finally consolidated layer (8.1.4). Rod concretes with a slump greater than 3 in. (75 mm). Rod or vibrate concrete with a slump of 1 to 3 in. (25 to 75 mm). Consolidate concretes with a slump less than 1 in. (25 mm) by vibration.

8.1.2 *Rodding*—Place the concrete in the measuring bowl in three layers of approximately equal volume. Consolidate each layer of concrete by 25 strokes of the tamping rod evenly distributed over the cross section. After each layer is rodded, tap the sides of the measure smartly 10 to 15 times with the mallet to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. Rod the bottom layer throughout its depth, but the rod shall not forcibly strike the bottom of the measure. In rodding the second and final layers, use only enough force to cause the rod to penetrate the surface of the previous layer about 1 in. (25 mm). Add the final layer of concrete in a manner to avoid excessive overfilling (8.1.4).

8.1.3 *Vibration*—Place the concrete in the measuring bowl in two layers of approximately equal volume. Place all of the concrete for each layer before starting vibration of that layer. Consolidate each layer by three insertions of the vibrator evenly distributed over the cross section. Add the final layer in a manner to avoid excessive overfilling (8.1.4). In consolidating each layer, do not allow the vibrator to rest on or touch the measuring bowl. Take care in withdrawing the vibrator to ensure that no air pockets are left in the specimen. Observe a standard duration of vibration for the particular kind of concrete, vibrator, and measuring bowl involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Continue vibration until the concrete is properly consolidated. Never continue vibration long enough to cause escape of froth from the sample.

NOTE 5—Overvibration may cause segregation and loss of intentionally entrained air. Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and has a glazed appearance.

8.1.4 *Strike Off*—After consolidation of the concrete, strike off the top surface by sliding the strike-off bar across the top flange or rim of the measuring bowl with a sawing motion until the bowl is just level full. On completion of consolidation, the bowl must not contain an excess or deficiency of concrete. Removal of ⅛ in. (3 mm) during strike off is optimum. When a strike-off plate is used, strike off concrete as prescribed in Test Method C 138/C 138M.

NOTE 6—A small quantity of representative concrete may be added to correct a deficiency. If the measure contains a great excess, remove a representative portion of concrete with a trowel or scoop before the measure is struck off.

NOTE 7—The use of the strike-off plate on cast aluminum or other relatively soft metal air meter bases may cause rapid wear of the rim and

require frequent maintenance, calibration, and ultimately, replacement.

8.1.5 *Application of Test Method*—Any portion of the test method not specifically designated as pertaining to Type A or Type B meter shall apply to both types.

8.2 *Procedure—Type A Meter*:

8.2.1 *Preparation for Test*—Thoroughly clean the flanges or rims of the bowl and of the cover assembly so that when the cover is clamped in place a pressure-tight seal will be obtained. Assemble the apparatus and add water over the concrete by means of the tube until it rises to about the halfway mark in the standpipe. Incline the apparatus assembly about 30° from vertical and, using the bottom of the bowl as a pivot, describe several complete circles with the upper end of the column, simultaneously tapping the cover lightly to remove any entrapped air bubbles above the concrete sample. Return the apparatus assembly to a vertical position and fill the water column slightly above the zero mark, while lightly tapping the sides of the bowl. Bring the water level to the zero mark of the graduated tube before closing the vent at the top of the water column (see Fig. 1 A).

NOTE 8—Some Type A meters have a calibrated starting fill mark above the zero mark. Generally, this starting mark should not be used since, as noted in 8.2.3, the apparent air content is the difference between the water level reading H, at pressure P and the water level h_2 at zero pressure after release of pressure P.

8.2.2 The internal surface of the cover assembly shall be kept clean and free from oil or grease; the surface shall be wet to prevent adherence of air bubbles that might be difficult to dislodge after assembly of the apparatus.

8.2.3 *Test Procedure*—Apply more than the desired test pressure, P, (about 0.2 psi (1380 Pa) more) to the concrete by means of the small hand pump. To relieve local restraints, tap the sides of the measure sharply and, when the pressure gage indicates the exact test pressure, P, as determined in accordance with A1.7, read the water level, h_1, and record to the nearest division or half-division on the graduated precision-bore tube or gage glass of the standpipe (see Fig. 1 B). For extremely harsh mixes tap the bowl vigorously until further tapping produces no change in the indicated air content. Gradually release the air pressure through the vent at the top of the water column and tap the sides of the bowl lightly for about 1 min. Record the water level, h_2, to the nearest division or half-division (see Fig. 1 C). Calculate the apparent air content as follows:

$$A_1 = h_1 - h_2 \tag{3}$$

where:
A_1 = apparent air content,
h_1 = water level reading at pressure, P (see Note 9), and
h_2 = water level reading at zero pressure after release of pressure, P.

8.2.4 *Check Test*—Repeat the steps described in 8.2.3 without adding water to reestablish the water level at the zero mark. The two consecutive determinations of apparent air content should check within 0.2 % of air and shall be averaged to give the value A_1 to be used in calculating the air content, A_s, in accordance with Section 9.

8.2.5 In the event the air content exceeds the range of the meter when it is operated at the normal test pressure P, reduce the test pressure to the alternative test pressure P_1 and repeat the steps outlined in 8.2.2 and 8.2.3.

NOTE 9—See A1.7 for exact calibration procedures. An approximate value of the alternative pressure, P_1, such that the apparent air content will equal twice the meter reading can be computed from the following relationship:

$$P_1 = P_a P/(2P_a + P) \tag{4}$$

where:
P_1 = alternative test pressure, psi (or kPa),
P_a = atmospheric pressure, psi (approximately 14.7 psi (101 kPa) but will vary with altitude and weather conditions) (or kPa), and
P = normal test or operating gage pressure, psi (or kPa).

8.3 *Procedure—Type B Meter*:

8.3.1 *Preparation for Test*—Thoroughly clean the flanges or rims of the bowl and the cover assembly so that when the cover is clamped in place a pressure-tight seal will be obtained. Assemble the apparatus. Close the air valve between the air chamber and the measuring bowl and open both petcocks on the holes through the cover. Using a rubber syringe, inject water through one petcock until water emerges from the opposite petcock. Jar the meter gently until all air is expelled from this same petcock.

8.3.2 *Test Procedure*—Close the airbleeder valve on the air chamber and pump air into the air chamber until the gage hand is on the initial pressure line. Allow a few seconds for the compressed air to cool to normal temperature. Stabilize the gage hand at the initial pressure line by pumping or bleeding-off air as necessary, tapping the gage lightly by hand. Close both petcocks on the holes through the cover. Open the air valve between the air chamber and the measuring bowl. Tap the sides of the measuring bowl smartly with the mallet to relieve local restraints. Lightly tap the pressure gage by hand to stabilize the gage hand. Read the percentage of air on the dial of the pressure gage. Failure to close the main air valve before releasing the pressure from either the container or the air chamber will result in water being drawn into the air chamber, thus introducing error in subsequent measurements. In the event water enters the air chamber, it must be bled from the air chamber through the bleeder valve followed by several strokes of the pump to blow out the last traces of water. Release the pressure by opening both petcocks (Fig. 2) before removing the cover.

9. Calculation

9.1 *Air Content of Sample Tested*—Calculate the air content of the concrete in the measuring bowl as follows:

$$A_s = A_1 - G \tag{5}$$

where:
A_s = air content of the sample tested, %,
A_1 = apparent air content of the sample tested, % (see 8.2.3 and 8.3.2), and
G = aggregate correction factor, % (Section 6).

9.2 *Air Content of Full Mixture*—When the sample tested represents that portion of the mixture that is obtained by wet

sieving to remove aggregate particles larger than a 1½-in. (37.5-mm) sieve, the air content of the full mixture is calculated as follows:

$$A_t = 100\, A_s V_c /(100\, V_t - A_s V_a) \quad (6)$$

where: (Note 10):

A_t = air content of the full mixture, %,

V_c = absolute volume of the ingredients of the mixture passing a 1½-in. (37.5-mm) sieve, airfree, as determined from the original batch weights, $ft^3(m^3)$,

V_t = absolute volume of all ingredients of the mixture, airfree, ft^3 (m^3), and

V_a = absolute volume of the aggregate in the mixture coarser than a 1½-in. (37.5-mm) sieve, as determined from original batch weights, $ft^3(m^3)$.

9.3 *Air Content of the Mortar Fraction*—When it is desired to know the air content of the mortar fraction of the mixture, calculate it as follows:

$$A_m = 100\, A_s\, V_c /[100\, V_m + A_s (V_c - V_m)] \quad (7)$$

where: (Note 10):

A_m = air content of the mortar fraction, %, and

V_m = absolute volume of the ingredients of the mortar fraction of the mixture, airfree, ft^3 (m^3).

NOTE 10—The values for use in Eq 6 and Eq 7 are most conveniently obtained from data on the concrete mixture tabulated as follows for a batch of any size:

		Absolute Volume, $ft^3(m^3)$	
Cement	_____	V_m	V_c
Water	_____		
Fine aggregate	_____		
Coarse aggregate (No. 4 (4.75-mm) to 1½-in. (37.5-mm))	_____		
Coarse aggregate (1½-in.) (37.5-mm)	_____	V_a	
Total	_____	V_t	

10. Precision and Bias

10.1 *Precision*:

10.1.1 *Single-Operator Precision*—The single-operator standard deviation cannot be established because the sampling requirements for this test, as established in Practice C 172, do not allow a single operator time to conduct more than one test on a sample.

10.1.2 *Multilaboratory Precision*—The multilaboratory standard deviation has not been established.

10.1.3 *Multioperator Precision*—The multioperator standard deviation of a single test result has been found to be 0.28 % air by volume of concrete for Type A air meters as long as the air content does not exceed 7 %. Therefore results of two tests properly conducted by different operators but on the same material should not differ by more than 0.8 % air by volume of concrete (see Practice E 177, Note 11 and Note 12).

NOTE 11—These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision statements are based on the variations in tests on three different concretes, each tested by eleven different operators.[4]

NOTE 12—The precision of this test method using Type B air meters has not been determined.

10.2 *Bias*—This test method has no bias because the air content of freshly mixed concrete can only be defined in terms of the test methods.

11. Keywords

11.1 air content; calibration; concrete; correction factor; measuring bowl; meter; pressure; pump; unit weight

[4] Reidenour, D. R., and Howe, R. H., "Air Content of Plastic and Hardened Concrete," presented at the 2nd International Conference on" Durability of Building Materials and Components" Sept. 14–16, 1981. Reprints compiled by: G. Frohnsdorff and B. Horner, National Institute for Standards and Technology, Gaithersburg, MD 20899, formerly National Bureau of Standards, Washington, DC 20234.

ANNEX

(Mandatory Information)

A1. CALIBRATION OF APPARATUS

A1.1 Calibration tests shall be performed in accordance with the following procedures as applicable to the meter type being employed.

A1.2 *Calibration of the Calibration Vessel*—Determine accurately the weight of water, *w*, required to fill the calibration vessel, using a scale accurate to 0.1 % of the weight of the vessel filled with water. This step shall be performed for Type A and B meters.

A1.3 *Calibration of the Measuring Bowl*—Determine the weight of water, *W*, required to fill the measuring bowl, using a scale accurate to 0.1 % of the weight of the bowl filled with water. Slide a glass plate carefully over the flange of the bowl in a manner to ensure that the bowl is completely filled with water. A thin film of cup grease smeared on the flange of the bowl will make a watertight joint between the glass plate and the top of the bowl. This step shall be performed for Type A and B meters.

A1.4 *Effective Volume of the Calibration Vessel, R*—The constant *R* represents the effective volume of the calibration vessel expressed as a percentage of the volume of the measuring bowl.

A1.4.1 For meter Types A, calculate *R* as follows (Note A1.1):

$$R = 0.98\, w/W \quad (A1.1)$$

where:

w = weight of water required to fill the calibration vessel, and

W = weight of water required to fill the measuring bowl.

NOTE A1.1—The factor 0.98 is used to correct for the reduction in the volume of air in the calibration vessel when it is compressed by a depth of water equal to the depth of the measuring bowl. This factor is approximately 0.98 for an 8-in. (203-mm) deep measuring bowl at sea level. Its value decreases to approximately 0.975 at 5000 ft (1524 m) above sea level and 0.970 at 13 000 ft (3962 m) above sea level. The value of this constant will decrease by about 0.01 for each 4-in. (102-mm) increase in bowl depth. The depth of the measuring bowl and atmospheric pressure do not affect the effective volume of the calibration vessel for meter Types B.

A1.4.2 For meter Types B calculate R as follows (Note A1.1):

$$R = w/W \tag{A1.2}$$

A1.5 *Determination of, or Check of, Allowance for Expansion Factor, D*:

A1.5.1 For meter assemblies of Type A determine the expansion factor, D (Note A1.2) by filling the apparatus with water only (making certain that all entrapped air has been removed and the water level is exactly on the zero mark (Note A1.3) and applying an air pressure approximately equal to the operating pressure, P, determined by the calibration test described in A1.7. The amount the water column lowers will be the equivalent expansion factor, D, for that particular apparatus and pressure (Note A1.5).

NOTE A1.2—Although the bowl, cover, and clamping mechanism of the apparatus must of necessity be sturdily constructed so that it will be pressure-tight, the application of internal pressure will result in a small increase in volume. This expansion will not affect the test results because, with the procedure described in Sections 6 and 8, the amount of expansion is the same for the test for air in concrete as for the test for aggregate correction factor on combined fine and coarse aggregates, and is thereby automatically cancelled. However, it does enter into the calibration test to determine the air pressure to be used in testing fresh concrete.

NOTE A1.3—The water columns on some meters of Type-A design are marked with an initial water level and a zero mark, the difference between the two marks being the allowance for the expansion factor. This allowance should be checked in the same manner as for meters not so marked and in such a case, the expansion factor should be omitted in computing the calibration readings in A1.7.

NOTE A1.4—It will be sufficiently accurate for this purpose to use an approximate value for P determined by making a preliminary calibration test as described in A1.7 except that an approximate value for the calibration factor, K, should be used. For this test $K = 0.98R$ which is the same as Eq A1.2 except that the expansion reading, D, as yet unknown, is assumed to be zero.

A1.5.2 For meters of Type B design, the allowance for the expansion factor, D, is included in the difference between the initial pressure indicated on the pressure gage and the zero percent mark on the air-content scale on the pressure gage. This allowance shall be checked by filling the apparatus with water (making certain that all entrapped air has been removed), pumping air into the air chamber until the gage hand is stabilized at the indicated initial pressure line, and then releasing the air to the measuring bowl (Note A1.5). If the initial pressure line is correctly positioned, the gage should read zero percent. The initial pressure line shall be adjusted if two or more determinations show the same variation from zero percent and the test repeated to check the adjusted initial pressure line.

NOTE A1.5—This procedure may be accomplished in conjunction with the calibration test described in A1.9.

A1.6 *Calibration Reading, K*—The calibration reading, K, is the final meter reading to be obtained when the meter is operated at the correct calibration pressure.

A1.6.1 For meter Types A, the calibration reading, K, is as follows:

$$K = R + D \tag{A1.3}$$

where:

R = effective volume of the calibration vessel (A1.4.1), and

D = expansion factor (A1.5.1, Note A1.6).

A1.6.2 For meter Types B the calibration reading, K, equals the effective volume of the calibration vessel (A4.2) as follows:

$$K = R \tag{A1.4}$$

NOTE A1.6—If the water column indicator is graduated to include an initial water level and a zero mark, the difference between the two marks being equivalent to the expansion factor, the term D shall be omitted from Eq A1.3.

A1.7 *Calibration Test to Determine Operating Pressure, P, on Pressure Gage, Type A Meter*—If the rim of the calibration cylinder contains no recesses or projections, fit it with three or more spacers equally spaced around the circumference. Invert the cylinder and place it at the center of the dry bottom of the measuring bowl. The spacers will provide an opening for flow of water into the calibration cylinder when pressure is applied. Secure the inverted cylinder against displacement and carefully lower the cover assembly. After the cover is clamped in place, carefully adjust the apparatus assembly to a vertical position and add water at air temperature, by means of the tube and funnel, until it rises above the zero mark on the standpipe. Close the vent and pump air into the apparatus to the approximate operating pressure. Incline the assembly about 30° from vertical and, using the bottom of the bowl as a pivot, describe several complete circles with the upper end of the standpipe, simultaneously tapping the cover and sides of the bowl lightly to remove any entrapped air adhering to the inner surfaces of the apparatus. Return the apparatus to a vertical position, gradually release the pressure (to avoid loss of air from the calibration vessel), and open the vent. Bring the water level exactly to the zero mark by bleeding water through the petcock in the top of the conical cover. After closing the vent, apply pressure until the water level has dropped an amount equivalent to about 0.1 to 0.2 % of air more than the value of the calibration reading, K, determined as described in A1.6. To relieve local restraints, lightly tap the sides of the bowl, and when the water level is exactly at the value of the calibration reading, K, read the pressure, P, indicated by the gage and record to the nearest 0.1 psi (690 Pa). Gradually release the pressure and open the vent to determine whether the water level returns to the zero mark when the sides of the bowl are tapped lightly (failure to do so indicates loss of air from the calibration vessel or loss of water due to a leak in the assembly). If the water levels fails to return to within 0.05 % air of the zero mark and no leakage beyond a few drops of water is found, some air probably was lost from the calibration

cylinder. In this case, repeat the calibration procedure step by step from the beginning of this paragraph. If the leakage is more than a few drops of water, tighten the leaking joint before repeating the calibration procedure. Check the indicated pressure reading promptly by bringing the water level exactly to the zero mark, closing the vent, and applying the pressure, *P*, just determined. Tap the gage lightly with a finger. When the gage indicates the exact pressure, *P*, the water column should read the value of the calibration factor, *K*, used in the first pressure application within about 0.05 % of air.

A1.7.1 The apparatus assembly must not be moved from the vertical position until pressure has been applied, which will force water about one third of the way up into the calibration cylinder. Any loss of air from this cylinder will nullify the calibration.

A1.8 *Calibration Test to Determine Alternative Operating Pressure P_1—Meter Type A*—The range of air contents which can be measured with a given meter can be doubled by determining an alternative operating pressure P_1 such that the meter reads half of the calibration reading, *K*, (Eq A1.3). Exact calibration will require determination of the expansion factor at the reduced pressure in A1.5. For most purposes the change in expansion factor can be disregarded and the alternative operating pressure determined during the determination of the regular operating pressure in A1.7.

A1.9 *Calibration Test to Check the Air Content Graduations on the Pressure Gage, Type B Meter*—Fill the measuring bowl with water as described in A1.3. Screw the short piece of tubing or pipe furnished with the apparatus into the threaded petcock hole on the underside of the cover assembly. Assemble the apparatus. Close the air valve between the air chamber and the measuring bowl and open the two petcocks on holes through the cover assembly. Add water through the petcock on the cover assembly having the extension below until all air is expelled from the second petcock. Pump air into the air chamber until the pressure reaches the indicated initial pressure line. Allow a few seconds for the compressed air to cool to normal temperature. Stabilize the gage hand at the initial pressure line by pumping or bleeding off air as necessary, tapping the gage lightly. Close the petcock not provided with the tube or pipe extension on the under side of the cover. Remove water from the assembly to the calibrating vessel controlling the flow, depending on the particular meter design, by opening the petcock provided with the tube or pipe extension and cracking the air valve between the air chamber and the measuring bowl, or by opening the air valve and using the petcock to control flow. Perform the calibration at an air content which is within the normal range of use. If the calibration vessel (A1.2) has a capacity within the normal range of use, remove exactly that amount of water. With some meters the calibrating vessel is quite small and it will be necessary to remove several times that volume to obtain an air content within the normal range of use. In this instance, carefully collect the water in an auxiliary container and determine the amount removed by weighing to the nearest 0.1 %. Calculate the correct air content, *R*, by using Eq A1.2. Release the air from the apparatus at the petcock not used for filling the calibration vessel and if the apparatus employs an auxiliary tube for filling the calibration container, open the petcock to which the tube is connected to drain the tube back into the measuring bowl (see A1.7.1). At this point of procedure the measuring bowl contains the percentage of air determined by the calibration test of the calibrating vessel. Pump air into the air chamber until the pressure reaches the initial pressure line marked on the pressure gage, close both petcocks in the cover assembly, and then open the valve between the air chamber and the measuring bowl. The indicated air content on the pressure gage dial should correspond to the percentage of air determined to be in the measuring bowl. If two or more determinations show the same variation from the correct air content, the dial hand shall be reset to the correct air content and the test repeated until the gage reading corresponds to the calibrated air content within 0.1 %. If the dial hand was reset to obtain the correct air content, recheck the initial pressure mark as in A1.5.2. If a new initial pressure reading is required, repeat the calibration to check the accuracy of the graduation on the pressure gage described earlier in this section. If difficulty is encountered in obtaining consistent readings, check for leaks, for the presence of water inside the air chamber (see Fig. 2), or the presence of air bubbles clinging to the inside surfaces of the meter from the use of cool aerated water. In this latter instance use deaerated water which can be obtained by cooling hot water to room temperature.

NOTE A1.7—If the calibrating vessel is an integral part of the cover assembly, the petcock used in filling the vessel should be closed immediately after filling the calibration vessel and not opened until the test is complete.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue, C 231 – 03, that may impact the use of this test method. (Approved July 1, 2004)

(*1*) Revised 5.1 to include a minimum calibration frequency.

Committee C09 has identified the location of selected changes to this test method since the last issue, C 231 – 97$^{\epsilon 1}$, that may impact the use of this test method. (Approved July 10, 2003)

(*1*) Revised 1.5 by adding warning, deleting reference to procedural note, and adding footnote.
(*2*) Revised 2.1 to update referenced designations and correct titles.
(*3*) Corrected reference to dual designations in 1.2, 3.2, 4.15, 8.1.4, and Note 2.
(*4*) Changed Note A1.7 to section A1.7.1 and renumbered subsequent Note A1.8 to Note A1.7.
(*5*) Revised reference to Note A1.7 to reference section A1.7.1 in section A1.9.
(*6*) Editorially corrected spelling, punctuation, references, and SI unit equivalents in Note 1, 4.5, 4.7, 6.2, 8.2.3, 8.3.2, 9.1, 9.2, Note 10, 10.1.3, and A1.4.1.
(*7*) Revised 3.1 and 8.1.3 to improve wording.
(*8*) Note 4 altered to remove mandatory language.
(*9*) Volumetric SI units in 4.2 and 4.10 changed to litres.

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Designation: C 173/C 173M – 01$^{\epsilon 1}$

Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[1]

This standard is issued under the fixed designation C 173/C 173M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ϵ[1] NOTE—7.5.2.2 was editorially corrected November 2001.

1. Scope*

1.1 This test method covers determination of the air content of freshly mixed concrete containing any type of aggregate, whether it be dense, cellular, or lightweight.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Unit Weight and Voids in Aggregate[2]

C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[2]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

3. Significance and Use

3.1 This test method covers the determination of the air content of freshly mixed concrete. It measures the air contained in the mortar fraction of the concrete, but is not affected by air that may be present inside porous aggregate particles.

3.1.1 Therefore, this is the appropriate test to determine the air content of concretes containing lightweight aggregates, air-cooled slag, and highly porous or vesicular natural aggregates.

3.2 This test method requires the addition of sufficient isopropyl alcohol, when the meter is initially being filled with water, so that after the first or subsequent rollings little or no foam collects in the neck of the top section of the meter. If more foam is present than that equivalent to 2 % air above the water level, the test is declared invalid and must be repeated using a larger quantity of alcohol. Addition of alcohol to dispel foam any time after the initial filling of the meter to the zero mark is not permitted.

3.3 The air content of hardened concrete may be either higher or lower than that determined by this test method. This depends upon the methods and amounts of consolidation effort applied to the concrete from which the hardened concrete specimen is taken; uniformity and stability of the air bubbles in the fresh and hardened concrete; accuracy of the microscopic examination, if used; time of comparison; environmental exposure; stage in the delivery, placement and consolidation processes at which the air content of the unhardened concrete is determined, that is, before or after the concrete goes through a pump; and other factors.

4. Apparatus

4.1 *Airmeter*—An airmeter consisting of a bowl and a top section (Fig. 1) conforming to the following requirements:

4.1.1 The bowl and top sections shall be of sufficient thickness and rigidity to withstand rough field use. The material shall not be attacked by high pH cement paste, deform when stored at high temperatures in closed spaces, or become brittle or crack at low temperatures. A watertight seal must be obtained when the top section is attached to the bowl.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Fresh Concrete Testing.

Current edition approved March 10, 2001. Published June 2001. Originally published as C 173 – 42. Last previous edition C 173 – 94a$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

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

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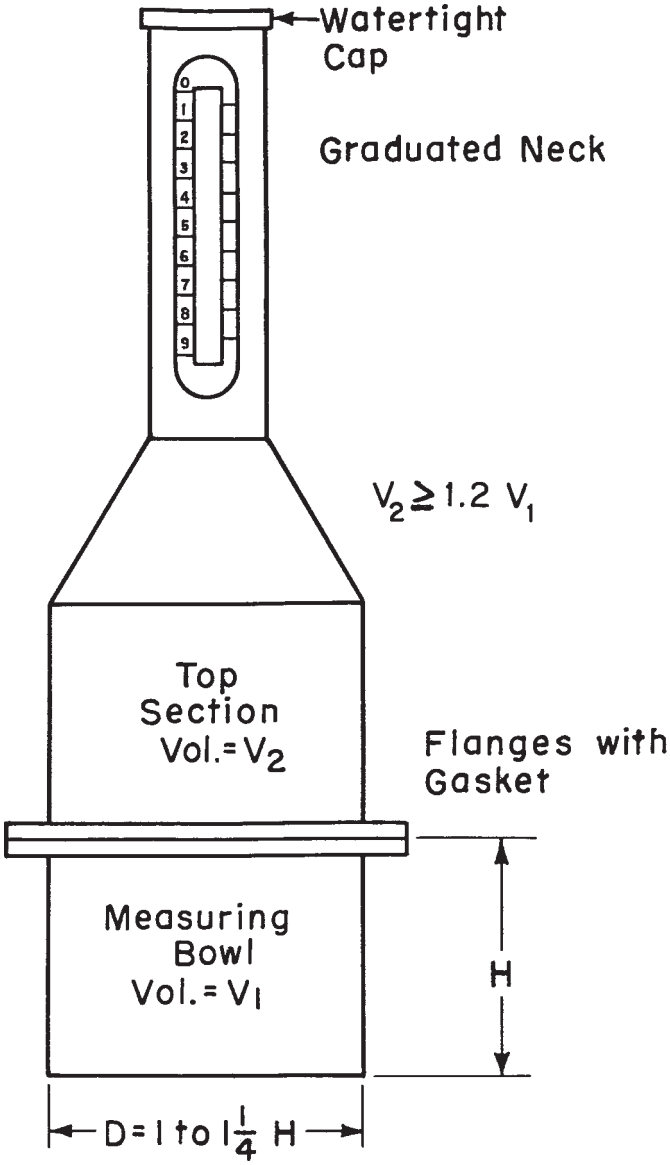

FIG. 1 Apparatus for Measuring Air Content of Fresh Concrete by Volumetric Method

4.1.2 *Bowl*—The bowl shall have a diameter equal to 1 to 1.25 times the height and be constructed with a flange at or near the top surface. Bowls shall not have a capacity of less than 0.075 ft^3 [2.0 L].

4.1.3 *Top Section*—The top section shall have a capacity at least 20 % larger than the bowl and shall be equipped with a flexible gasket and a device to attach the top section to the bowl. The top section shall be equipped with a transparent scale, graduated in increments not greater than 0.5 % from 0 at the top to 9 %, or more, of the volume of the bowl. Graduations shall be accurate to ±0.1 % by volume of the bowl. The upper end of the neck shall have a watertight cap that will maintain a watertight seal when the meter is inverted and rolled.

4.2 *Funnel*—A funnel with a spout of a size permitting it to be inserted through the neck of the top section and long enough to extend to a point just above the bottom of the top section. The discharge end of the spout shall be so constructed that when water is added to the container there will be a minimum disturbance of the concrete.

4.3 *Tamping Rod*—A round, smooth, straight ⅝ ± 1⁄16-in. [16 ± 2-mm] diameter rod at least 12 in. [300 mm] long with both ends rounded to a hemispherical tip of the same diameter. The rod shall be made of steel, high-density polyethylene, or other plastic of equal or greater abrasion resistance.

4.4 *Strike-off Bar*—A flat, straight steel bar at least ⅛ by ¾ by 12 in. [3 by 20 by 300 mm] or a flat, straight high-density polyethylene bar, or other plastic of equal or greater abrasion resistance, at least ¼ by ¾ by 12 in. [6 by 20 by 300 mm].

4.5 *Calibrated Cup*—A metal or plastic cup either having a capacity of or being graduated in increments equal to 1.00 ± 0.04 % of the volume of the bowl of the air meter. The calibrated cup is only to be used to add water when the concrete air content exceeds 9 % or the calibrated range of the meter.

4.6 *Measuring Vessel for Isopropyl Alcohol*—A vessel with a minimum capacity of at least 1 pt [500 mL] with graduations not larger than 4 oz [100 mL] for measuring a quantity of isopropyl alcohol.

4.7 *Syringe*—A rubber syringe having a capacity of at least 2 oz [50 mL].

4.8 *Pouring Vessel for Water*—A container of approximately 1 qt [1 L] capacity.

4.9 *Scoop*—A small metal scoop.

4.10 *Isopropyl Alcohol*—Use 70 % by volume isopropyl alcohol (approximately 65 % by weight) (Note 1). Other foam-dispersing agents are permitted if tests demonstrate that the use of the agent does not change the indicated air content, in the amounts being used, by more than 0.1 % or if correction factors are developed similar to those in Table 1. When other dispersing agents are used, a copy of the records documenting the testing or calculations shall be available in the laboratory.

NOTE 1—Seventy percent isopropyl alcohol is commonly available as rubbing alcohol. More concentrated grades can be diluted with water to the required concentration.

4.11 *Mallet*—A mallet (with a rubber or rawhide head) with a mass of approximately 1.25 ± 0.5 lb [600 ± 200 g].

TABLE 1 Correction for the Effect of Isopropyl Alcohol on C 173/C 173M Air Meter Reading

70 % Isopropyl Alcohol Used			Correction
Pints	Ounces	Litres	(Subtract)[A]
0.5	8	0.2	0.0[B]
1.0	16	0.5	0.0[B]
1.5	24	0.7	0.0[B]
2.0	32	0.9	0.0[B]
3.0	48	1.4	0.3
4.0	64	1.9	0.6
5.0	80	2.4	0.9

[A] Subtract from final meter reading.

[B] Corrections less than 0.125 are not significant and are to be applied only when 2.5 pt [1.2 L] or more alcohol is used. The effect occurs when the meter is inverted after being filled with an alcohol-water solution which then becomes further diluted when it is mixed with the water in the concrete. The values given are for air meters that have a bowl volume of 0.075 ft^3 [2.1 L] and a top section that is 1.2 times the volume of the bowl.

5. Calibration

5.1 Calibrate the meter and calibrated cup initially and annually or whenever there is reason to suspect damage or deformation of the meter or calibrated cup.

5.2 Determine the volume of the bowl with an accuracy of at least 0.1 % by determining the mass of water required to fill it at room temperature and dividing it by the density of the water at the same temperature. Follow the calibration procedure outlined in Test Method C 29/C 29M.

5.3 Determine the accuracy of the graduations on the neck of the top section of the airmeter by filling the assembled measuring bowl and top section with water to the level of the mark for highest air content graduation.

5.3.1 Add water in increments of 1.0 % of the volume of the bowl to check accuracy throughout the graduated range of air content. The error at any point throughout the graduated range shall not exceed 0.1 % of air.

5.4 Determine the volume of the calibrated cup using water at 70°F [21.1°C] by the method outlined in 5.2. A quick check can be made by adding one or more calibrated cups of water to the assembled apparatus and observing the increase in the height of the water column after filling to a given level.

6. Sampling

6.1 Obtain the sample of freshly mixed concrete in accordance with Practice C 172. If the concrete contains coarse aggregate particles that would be retained on a 1½-in. [37.5-mm] sieve, wet sieve a representative sample over a 1-in. [25-mm] sieve to yield somewhat more than enough material to fill the measuring bowl. The wet sieving procedure is described in Practice C 172. Carry out the wet sieving operation with the minimum practicable disturbance of the mortar. Make no attempt to wipe adhering mortar from coarse aggregate particles retained on the sieve.

7. Procedure

7.1 *Rodding and Tapping*—Wet the inside of the bowl and dry it to a damp but not shiny appearance. Using the scoop, fill the bowl with freshly mixed concrete in two layers of equal depth. Rod each layer 25 times with the tamping rod. Do not forcibly strike the bottom of the bowl when rodding the first layer. When rodding the second layer, penetrate the prior layer approximately 1 in. [25 mm]. After each layer is rodded, tap the sides of the bowl 10 to 15 times with the mallet to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. After tapping the final layer, a slight excess of concrete, ⅛ in. [3 mm] or less, above the rim is acceptable. Add or remove a representative sample of concrete if necessary to obtain the required amount of concrete.

7.2 *Striking Off*—After rodding and tapping of the second layer, strike off the excess concrete with the strike-off bar until the surface is flush with the top of the bowl. Wipe the flange of the bowl clean.

7.3 *Adding Water and Alcohol*—Wet the inside of the top section of the meter, including the gasket. Attach the top section to the bowl and insert the funnel. Add at least 1 pt [0.5 L] of water followed by the selected amount (Note 2) of isopropyl alcohol. Record the amount of isopropyl alcohol added. Continue adding water until it appears in the graduated neck of the top section (Note 3). Remove the funnel. Adjust the liquid level until the bottom of the meniscus is level with the zero mark. A rubber syringe is useful for this purpose. Attach and tighten the watertight cap.

NOTE 2—The amount of isopropyl alcohol necessary to obtain a stable reading and a minimum of foam at the top of the water column will depend upon a number of factors. Many concretes made with less than 500 lb/yd^3 [300 kg/m^3] of cement and air contents less than 4 % may require less than 0.5 pt [200 mL] of alcohol. Some high-cement mixes made with silica fume that have air contents of 6 % or more may require more than 3 pt [1400 mL] of alcohol. The amount required will vary with the concrete air content, the amount and type of air-entraining admixture, the cement content and cement alkali content, and perhaps other factors. Generally, the amount of alcohol necessary can be established for given mixture proportions and should not change greatly during the course of a job.

NOTE 3—When, if ever, it is necessary to use more than 4 or 4.5 pt [2.0 L] of isopropyl alcohol, it may be necessary to restrict the amount of water added initially to avoid overfilling the meter. However, it is desirable to initially add at least some water initially to aid in mixing the alcohol and limit the contact of the concentrated alcohol with the top surface of the concrete.

7.4 *Displacing the Volume of Air in the Concrete Specimen Using These Procedures*:

7.4.1 *Free the Concrete from the Base*— Quickly invert the meter, shake the base horizontally, and return the meter to the upright position. To prevent the aggregate from lodging in the neck of the unit, do not keep it inverted for more than 5 seconds at a time. Repeat the inversion and shaking process for a minimum of 45 seconds and until the concrete has broken free and the aggregate can be heard moving in the meter as it is inverted.

7.4.2 *Rolling*—Place one hand on the neck of the meter and the other on the flange. Using the hand on the neck, tilt the top of the meter approximately 45° from the vertical position with the bottom edge of the base of the meter resting on the floor or on the work surface. Maintain this position through the procedures described in this section. Using the hand on the flange to rotate the meter, vigorously roll the meter ¼ to ½ turn forward and back several times, quickly starting and stopping the roll. Turn the base of the meter about ⅓ turn and repeat the rolling procedure as stated previously. Continue the turning and rolling procedures for approximately 1 min. The aggregate must be heard sliding in the meter during this process.

7.4.2.1 If, at any time, during the inversion and rolling procedures liquid is found to be leaking from the meter, the test is invalid and a new test shall be started as in 6.1.

7.4.2.2 Set the unit upright and loosen the top to allow any pressure to stabilize. Allow the meter to stand while the air rises to the top and until the liquid level stabilizes. The liquid level is considered stable when it does not change more than 0.25 % air within a 2-min period.

7.4.2.3 If it takes more than 6 min for the liquid level to stabilize or if there is more foam than that equivalent to 2 full percent air content divisions on the meter scale over the liquid level, discard the trial and start a new test as in 6.1. Use a larger addition of alcohol than was used in the initial trial.

7.4.2.4 If the level is stable without excessive foam, read the bottom of the meniscus to the nearest 0.25 % and record the *initial meter reading*.

7.4.2.5 If the air content is greater than the 9 % range of the meter, add a sufficient number of calibrated cups of water to bring the liquid level within the graduate range. Read the bottom of the meniscus to the nearest 0.25 %. Record the number of calibrated cups of water to be added to the final meter reading in 8.1.3.

7.5 *Confirmation of the Initial Meter Reading*:

7.5.1 When an initial meter reading is obtained as in 7.4.2.4, retighten the top and repeat the 1-min rolling as in 7.4.2, 7.4.2.2, and 7.4.2.3.

7.5.2 When the liquid level is stable as in 7.4.2.2 and the requirements of 7.4.2.3 are met, make a direct reading to the bottom of the meniscus and estimate to 0.25 % air. If this reading has not changed more than 0.25 % from the initial meter reading in 7.4.2.4, record it as the *final meter reading* of the sample tested.

7.5.2.1 If the reading has changed from the *initial meter reading* by more than 0.25 % air, record this reading as a new "*initial reading*" and repeat the 1-min rolling as in 7.4.2. Read the indicated air content. If this reading has not changed by more than 0.25 % air from the "*newest initial reading*" record it as the *final meter reading*.

7.5.2.2 If the reading has changed by more than 0.25 %, discard the test and start a new test on a new sample of concrete as in 6.1 using more alcohol.

7.6 Disassemble the apparatus. Dump the base and examine the contents to be sure that there are no portions of undisturbed, tightly packed concrete in the base. If portions of undisturbed concrete are found, the test is invalid.

8. Calculation

8.1 The final meter reading tends to be slightly higher than the actual air content of the sample when 2.5 pt [1.2 L] or more of isopropyl alcohol is used. See Note 4.

8.1.1 When less than 2.5 pt [1.2 L] of isopropyl alcohol is used, the final meter reading is the air content of the sample of concrete tested except as modified in 8.1.3 or 8.2.

8.1.2 When 2.5 pt [1.2 L] or more isopropyl alcohol is used, subtract the correction from Table 1 from the final meter reading to obtain the air content of the concrete sample tested except as modified in 8.1.3 or 8.2.

NOTE 4—Use linear interpolation to obtain a correction factor if the quantity of isopropyl used falls between amounts listed in Table 1.

8.1.3 If it was necessary to add calibrated cups of water to obtain a reading as in 7.4.2.5, add the number of cups recorded to the air content found in 8.1.1 or 8.1.2.

8.1.4 Report the air content to the nearest 0.25 % air.

NOTE 5—When the top section is initially filed to the zero mark with water and isopropyl alcohol that mixture has a defined volume; however, when that solution is further mixed with the water present in the concrete, the concentration of alcohol changes and the new solution occupies a volume slightly smaller than it did when the meter was initially filled to the zero mark. For this reason, the meter tends to indicate a higher than actual air content when more than about 2.5 pt [1.2 L] of alcohol is used. Therefore, when large amounts of alcohol are used, the correction factors in Table 1 reduce the air content indicated by the meter.

8.2 When the sample tested represents that portion of the mixture obtained by wet sieving over a 1-in. (25-mm) sieve, calculate the air content of the mortar or of the full mixture using the formulas given in Test Method C 231. Use appropriate quantities coarser or finer than the 1-in. sieve instead of the 1½-in. (37.5-mm) sieve specified in Test Method C 231.

9. Precision and Bias

9.1 The standard deviation is essentially proportional to the average for different levels of air content. The following precision statement is based on 979 tests made in 6 field experiments by the West Virginia D.O.T. The multi-operator coefficient of variation has been found to be 11 % of the measured air content. Therefore, results of tests by two different operators on specimens taken from a single concrete sample should not differ from each other by more than 32 % of their average air content (Note 6).

NOTE 6—These numbers represent, respectively, the 1s % and d2s % limits described in Practice C 670. The data collected for the precision statement was obtained using procedures standard prior to the use of large amounts of isopropyl alcohol in Test Method C 173/C 173M-01.

9.2 This test method provides volumetric procedures for determining the air content of freshly mixed concrete. When conducted properly, this test method has no bias because the value of the air content can only be defined in terms of this test method.

10. Keywords

10.1 air content; calibration; concrete; correction factor; freshly mixed concrete; measuring bowl; meter; volumetric method

APPENDIX

(Nonmandatory Information)

X1. A Check List for Performing the Volumetric Air Content Test Method

X1.1 The following outline (see Fig. X1.1) does not include all steps and precautions required to perform this test method properly. It is provided to help new users follow the sequence of the procedures.

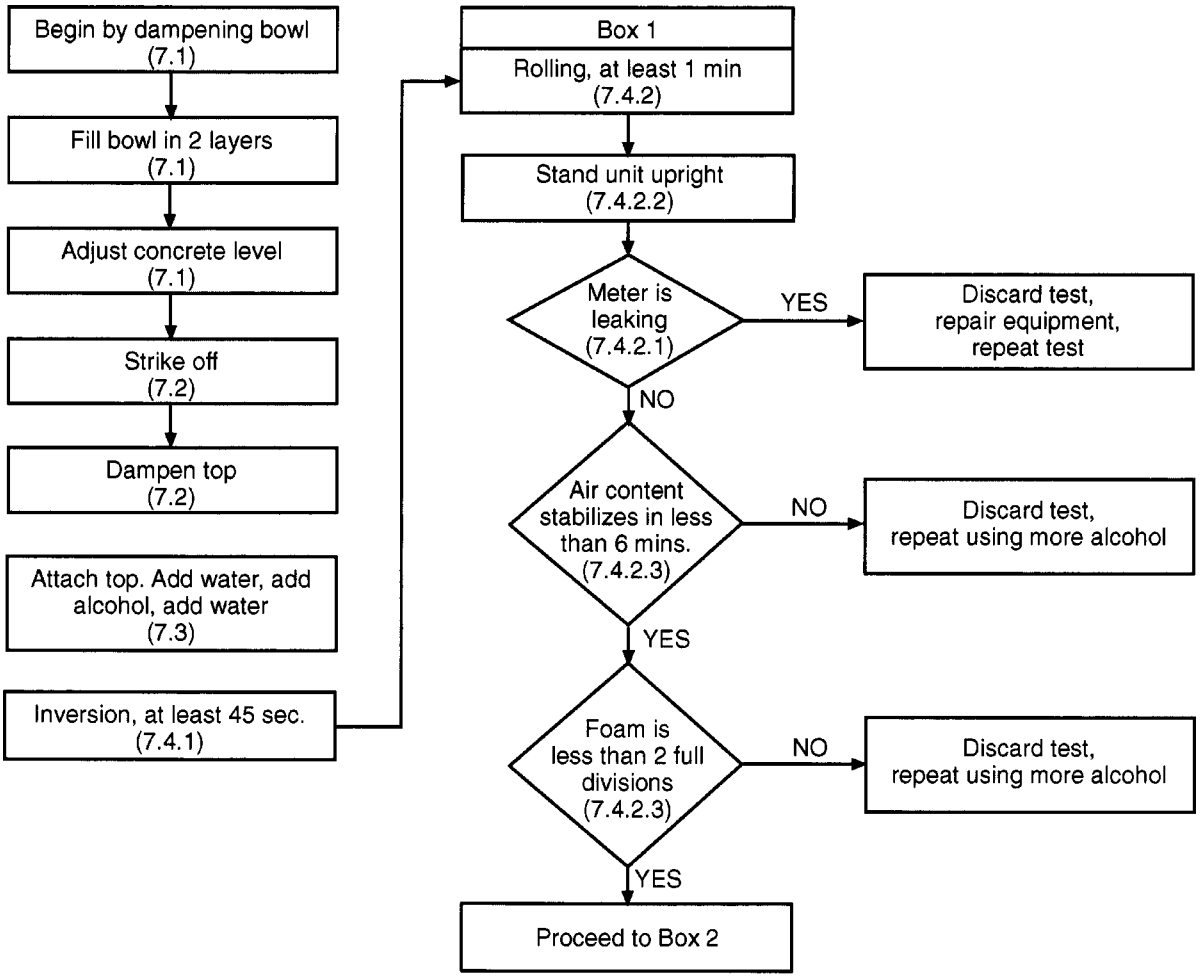

FIG. X1.1 Outline of Check List for Performing the Volumetric Air Content Test Method

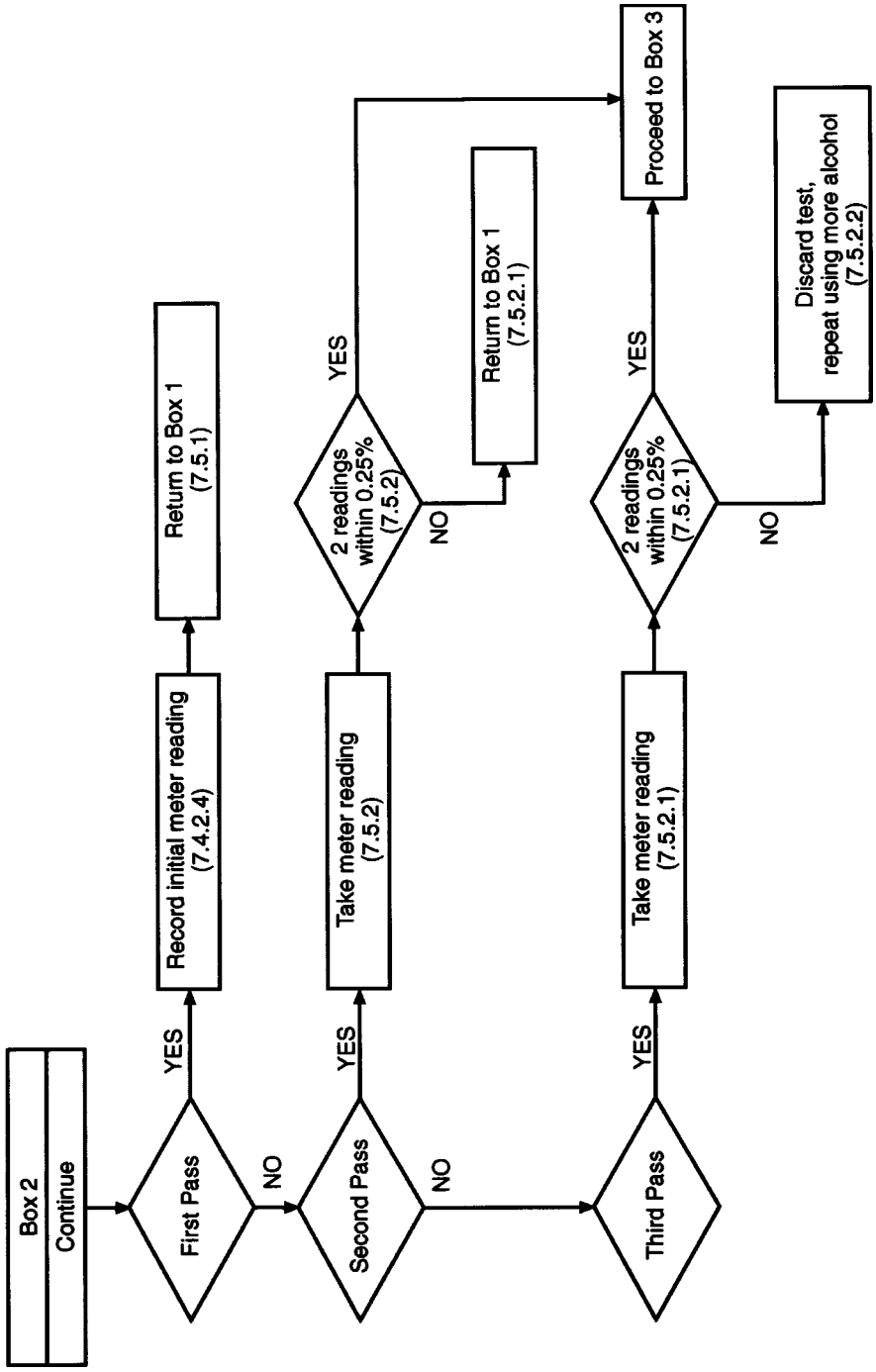

FIG. X1.1 Outline of Check List for Performing the Volumetric Air Content Test Method *(continued)*

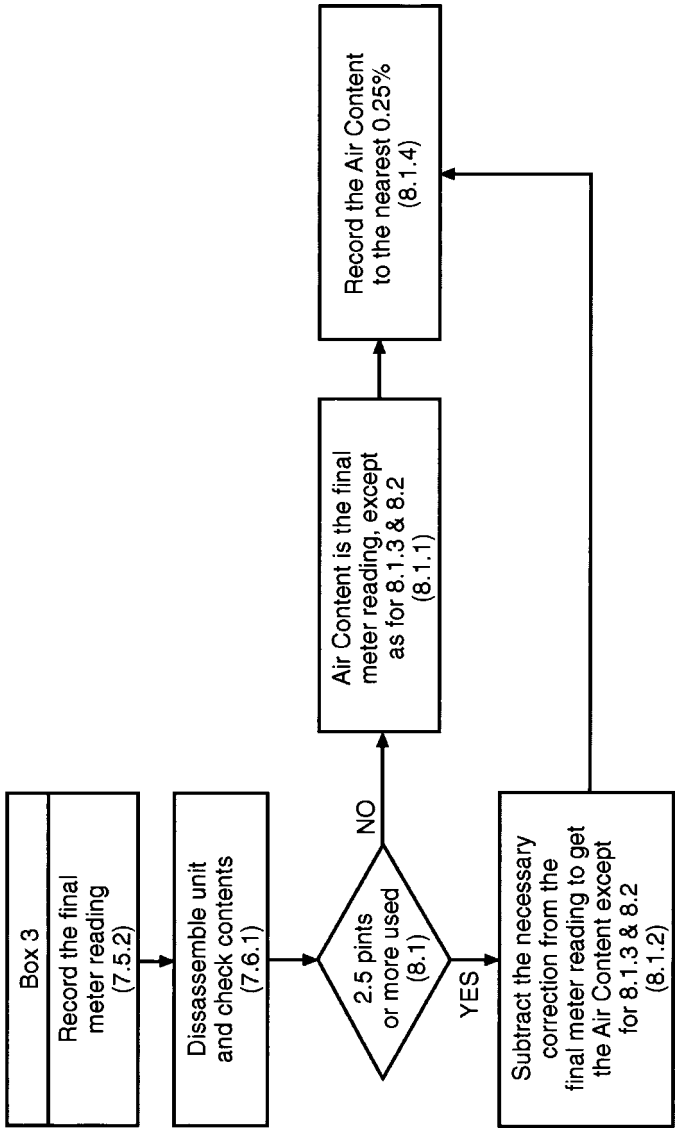

FIG. X1.1 Outline of Check List for Performing the Volumetric Air Content Test Method *(continued)*

SUMMARY OF CHANGES

This section identifies the location of changes to this test method that have been incorporated since the last issue.

(1) Paragraph 1.2 was revised.
(2) Paragraph 3.2 was revised.
(3) Section 4 was revised throughout.
(4) Paragraphs 7.1 through 7.4.2 were revised.
(5) Paragraphs 7.5 through 7.5.2.2 were revised.
(6) Paragraphs 8.1 through 8.1.4 were revised.
(7) Appendix X1 was added.

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Designation: C 31/C 31M – 03a

Standard Practice for Making and Curing Concrete Test Specimens in the Field[1]

This standard is issued under the fixed designation C 31/C 31M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers procedures for making and curing cylinder and beam specimens from representative samples of fresh concrete for a construction project.

1.2 The concrete used to make the molded specimens shall be sampled after all on-site adjustments have been made to the mixture proportions, including the addition of mix water and admixtures. This practice is not satisfactory for making specimens from concrete not having measurable slump or requiring other sizes or shapes of specimens.

1.3 The values stated in either inch-pound units or SI units shall be regarded separately as standard. The SI units are shown in brackets. The values stated may not be exact equivalents; therefore each system must be used independently of the other. Combining values from the two units may result in nonconformance.

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

1.5 The text of this standard references notes which provide explanatory material. These notes shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete[2]

C 143/C 143M Test Method for Slump of Hydraulic Cement Concrete[2]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[2]

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]

C 330 Specification for Lightweight Aggregates for Structural Concrete[2]

C 403/C 403M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance[2]

C 470/C 470M Specification for Molds for Forming Concrete Test Cylinders Vertically[2]

C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[3]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

C 1064/C 1064M Test Method for Temperature of Freshly Mixed Portland Cement Concrete[2]

2.2 *American Concrete Institute Publication:*[4]

CP-1 Concrete Field Testing Technician, Grade I

309R Guide for Consolidation of Concrete

3. Terminology

3.1 For definitions of terms used in this practice, refer to Terminology C 125.

4. Significance and Use

4.1 This practice provides standardized requirements for making, curing, protecting, and transporting concrete test specimens under field conditions.

4.2 If the specimens are made and standard cured, as stipulated herein, the resulting strength test data when the specimens are tested are able to be used for the following purposes:

4.2.1 Acceptance testing for specified strength,

4.2.2 Checking adequacy of mixture proportions for strength, and

[1] This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing for Strength.

Current edition approved Feb. 10, 2003. Published April 2003. Originally approved in 1920. Last previous edition approved in 2003 as C 31/C 31M-03.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] Available from American Concrete Institute, P.O. Box 9094, Farmington Hills, MI 48333-9094.

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4.2.3 Quality control.

4.3 If the specimens are made and field cured, as stipulated herein, the resulting strength test data when the specimens are tested are able to be used for the following purposes:

4.3.1 Determination of whether a structure is capable of being put in service,

4.3.2 Comparison with test results of standard cured specimens or with test results from various in-place test methods,

4.3.3 Adequacy of curing and protection of concrete in the structure, or

4.3.4 Form or shoring removal time requirements.

5. Apparatus

5.1 *Molds, General*— Molds for specimens or fastenings thereto in contact with the concrete shall be made of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall hold their dimensions and shape under all conditions of use. Molds shall be watertight during use as judged by their ability to hold water poured into them. Provisions for tests of water leakage are given in the Test Methods for Elongation, Absorption, and Water Leakage section of Specification C 470/C 470M. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax shall be used where necessary to prevent leakage through the joints. Positive means shall be provided to hold base plates firmly to the molds. Reusable molds shall be lightly coated with mineral oil or a suitable nonreactive form release material before use.

5.2 *Cylinder Molds*— Molds for casting concrete test specimens shall conform to the requirements of Specification C 470/C 470M.

5.3 *Beam Molds*—Beam molds shall be of the shape and dimensions required to produce the specimens stipulated in 6.2. The inside surfaces of the molds shall be smooth. The sides, bottom, and ends shall be at right angles to each other and shall be straight and true and free of warpage. Maximum variation from the nominal cross section shall not exceed ⅛ in. [3 mm] for molds with depth or breadth of 6 in. [150 mm] or more. Molds shall produce specimens at least as long but not more than 1⁄16 in. [2 mm] shorter than the required length in 6.2.

5.4 *Tamping Rod*— A round, straight steel rod with the dimensions conforming to those in Table 1, having the tamping end or both ends rounded to a hemispherical tip of the same diameter as the rod.

5.5 *Vibrators*—Internal vibrators shall be used. The vibrator frequency shall be at least 7000 vibrations per minute [150 Hz] while the vibrator is operating in the concrete. The diameter of a round vibrator shall be no more than one-fourth the diameter of the cylinder mold or one-fourth the width of the beam mold. Other shaped vibrators shall have a perimeter equivalent to the circumference of an appropriate round vibrator. The combined length of the vibrator shaft and vibrating element shall exceed the depth of the section being vibrated by at least 3 in. [75 mm]. The vibrator frequency shall be checked periodically.

TABLE 1 Tamping Rod Requirements

Diameter of Cylinder or Width of Beam in. [mm]	Rod Dimensions[A]	
	Diameter in. [mm]	Length of Rod in. [mm]
<6 [150]	3/8 [10]	12 [300]
6 [150]	5/8 [16]	20 [500]
9 [225]	5/8 [16]	26 [650]

[A] Rod tolerances length ±4 in. [100 mm] and diameter ±1⁄16 in. [2 mm].

NOTE 1—For information on size and frequency of various vibrators and a method to periodically check vibrator frequency see ACI 309.

5.6 *Mallet*—A mallet with a rubber or rawhide head weighing 1.25 ± 0.50 lb [0.6 ± 0.2 kg] shall be used.

5.7 *Small Tools*— Shovels, hand-held floats, scoops, and a vibrating-reed tachometer shall be provided.

5.8 *Slump Apparatus*— The apparatus for measurement of slump shall conform to the requirements of Test Method C 143/C 143M.

5.9 *Sampling Receptacle*—The receptacle shall be a suitable heavy gage metal pan, wheelbarrow, or flat, clean nonabsorbent board of sufficient capacity to allow easy remixing of the entire sample with a shovel or trowel.

5.10 *Air Content Apparatus*—The apparatus for measuring air content shall conform to the requirements of Test Methods C 173/C 173M or C 231.

5.11 *Temperature Measuring Devices*—The temperature measuring devices shall conform to the applicable requirements of Test Method C 1064/C 1064M.

6. Testing Requirements

6.1 *Cylindrical Specimens*—Compressive or splitting tensile strength specimens shall be cylinders cast and allowed to set in an upright position. The length shall be twice the diameter. The cylinder diameter shall be at least 3 times the nominal maximum size of the coarse aggregate. When the nominal maximum size of the coarse aggregate exceeds 2 in. [50 mm], the concrete sample shall be treated by wet sieving through a 2-in. [50-mm] sieve as described in Practice C 172. For acceptance testing for specified compressive strength, cylinders shall be 6 by 12 in. [150 by 300 mm] or when specified 4 × 8 in. [100 × 200 mm] (Note 2).

NOTE 2—When molds in SI units are required and not available, equivalent inch-pound unit size mold should be permitted.

6.2 *Beam Specimens*— Flexural strength specimens shall be beams of concrete cast and hardened in the horizontal position. The length shall be at least 2 in. [50 mm] greater than three times the depth as tested. The ratio of width to depth as molded shall not exceed 1.5. The standard beam shall be 6 by 6 in. [150 by 150 mm] in cross section, and shall be used for concrete with nominal maximum size coarse aggregate up to 2 in. [50 mm]. When the nominal maximum size of the coarse aggregate exceeds 2 in. [50 mm], the smaller cross sectional dimension of the beam shall be at least three times the nominal maximum size of the coarse aggregate. Unless required by project specifications, beams made in the field shall not have a width or depth of less than 6 in. [150 mm].

6.3 *Field Technicians*—The field technicians making and curing specimens for acceptance testing shall be certified ACI Field Testing Technicians, Grade I or equivalent. Equivalent personnel certification programs shall include both written and performance examinations, as outlined in ACI CP-1.

7. Sampling Concrete

7.1 The samples used to fabricate test specimens under this standard shall be obtained in accordance with Practice C 172 unless an alternative procedure has been approved.

7.2 Record the identification of the sample with respect to the location of the concrete represented and the time of casting.

8. Slump, Air Content, and Temperature

8.1 *Slump*—Measure and record the slump of each batch of concrete from which specimens are made immediately after remixing in the receptacle, as required in Test Method C 143/C 143M.

8.2 *Air Content*— Determine and record the air content in accordance with either Test Method C 173/C 173M or Test Method C 231. The concrete used in performing the air content test shall not be used in fabricating test specimens.

8.3 *Temperature*— Determine and record the temperature in accordance with Test Method C 1064/C 1064M.

NOTE 3—Some specifications may require the measurement of the unit weight of concrete. The volume of concrete produced per batch may be desired on some projects. Also, additional information on the air content measurements may be desired. Test Method C 138/C 138M is used to measure the unit weight, yield, and gravimetric air content of freshly mixed concrete.

9. Molding Specimens

9.1 *Place of Molding*— Mold specimens promptly on a level, rigid surface, free of vibration and other disturbances, at a place as near as practicable to the location where they are to be stored.

9.2 *Casting Cylinders*—Select the proper tamping rod from 5.4 and Table 1 or the proper vibrator from 5.5. Determine the method of consolidation from Table 2, unless another method is specified. If the method of consolidation is rodding, determine molding requirements from Table 3. If the method of consolidation is vibration, determine molding requirements from Table 4. Select a small tool of a size and shape large enough so each amount of concrete obtained from the sampling receptacle will be representative and small enough so concrete is not lost when being placed in the mold. While placing the concrete in the mold, move the small tool around the perimeter of the mold opening to ensure an even distribution of the concrete and minimize segregation. Each layer of concrete shall be consolidated as required. In placing the final layer, add an amount of concrete that will fill the mold after consolidation.

9.3 *Casting Beams*— Select the proper tamping rod from 5.4 and Table 1 or proper vibrator from 5.5. Determine the method of consolidation from Table 2, unless another method is specified. If the method of consolidation is rodding, determine the molding requirements from Table 3. If the method of consolidation is vibration, determine the molding requirements from Table 4. Determine the number of roddings per layer, one for each 2 in.^{2} [14 cm^2] of the top surface area of the beam. Select a small tool, of the size and shape large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so concrete is not lost when placed in the mold. Each layer shall be consolidated as required. In placing the final layer, add an amount of concrete that will fill the mold after consolidation. Place the concrete so that it is uniformly distributed within each layer with a minimum of segregation.

9.4 *Consolidation*— The methods of consolidation for this practice are rodding or internal vibration.

9.4.1 *Rodding*—Place the concrete in the mold, in the required number of layers of approximately equal volume. Rod each layer with the rounded end of the rod using the required number of roddings. Rod the bottom layer throughout its depth. Distribute the roddings uniformly over the cross section of the mold. For each upper layer, allow the rod to penetrate through the layer being rodded and into the layer below approximately 1 in. [25 mm]. After each layer is rodded, tap the outsides of the mold lightly 10 to 15 times with the mallet, to close any holes left by rodding and to release any large air bubbles that may have been trapped. Use an open hand to tap light-gage single-use cylinder molds which are susceptible to damage if tapped with a mallet. After tapping, spade each layer of the concrete along the sides and ends of beam molds with a trowel or other suitable tool. Underfilled molds shall be adjusted with representative concrete during consolidation of the top layer. Overfilled molds shall have excess concrete removed.

TABLE 2 Method of Consolidation Requirements

Slump in. (mm)	Method of Consolidation
≥ 1 [25]	rodding or vibration
< 1 [25]	vibration

TABLE 3 Molding Requirements by Rodding

Specimen Type and Size	Number of Layers of Approximately Equal Depth	Number of Roddings per Layer
Cylinders:		
Diameter, in. [mm]		
4 [100]	2	25
6 [150]	3	25
9 [225]	4	50
Beams:		
Width, in. [mm]		
6 [150] to 8 [200]	2	see 9.3
>8 [200]	3 or more equal depths, each not to exceed 6 in. [150 mm].	see 9.3

TABLE 4 Molding Requirements by Vibration

Specimen Type and Size	Number of Layers	Number of Vibrator Insertions per Layer	Approximate Depth of Layer, in. [mm]
Cylinders:			
Diameter, in. [mm]			
4 [100]	2	1	one-half depth of specimen
6 [150]	2	2	one-half depth of specimen
9 [225]	2	4	one-half depth of specimen
Beams:			
Width, in. [mm]			
6 [150] to 8 [200]	1	see 9.4.2	depth of specimen
over 8 [200]	2 or more	see 9.4.2	8 [200] as near as practicable

9.4.2 *Vibration*—Maintain a uniform duration of vibration for the particular kind of concrete, vibrator, and specimen mold involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete has become relatively smooth and large air bubbles cease to break through the top surface. Continue vibration only long enough to achieve proper consolidation of the concrete (see Note 4). Fill the molds and vibrate in the required number of approximately equal layers. Place all the concrete for each layer in the mold before starting vibration of that layer. In compacting the specimen, insert the vibrator slowly and do not allow it to rest on the bottom or sides of the mold. Slowly withdraw the vibrator so that no large air pockets are left in the specimen. When placing the final layer, avoid overfilling by more than ¼ in. [6 mm].

NOTE 4—Generally, no more than 5 s of vibration should be required for each insertion to adequately consolidate concrete with a slump greater than 3 in. [75 mm]. Longer times may be required for lower slump concrete, but the vibration time should rarely have to exceed 10 s per insertion.

9.4.2.1 *Cylinders*—The number of insertions of the vibrator per layer is given in Table 4. When more than one insertion per layer is required distribute the insertion uniformly within each layer. Allow the vibrator to penetrate through the layer being vibrated, and into the layer below, approximately 1 in. [25 mm]. After each layer is vibrated, tap the outsides of the mold at least 10 times with the mallet, to close holes that remain and to release entrapped air voids. Use an open hand to tap cardboard and single-use metal molds that are susceptible to damage if tapped with a mallet.

9.4.2.2 *Beams*—Insert the vibrator at intervals not exceeding 6 in. [150 mm] along the center line of the long dimension of the specimen. For specimens wider than 6 in., use alternating insertions along two lines. Allow the shaft of the vibrator to penetrate into the bottom layer approximately 1 in. (25 mm). After each layer is vibrated, tap the outsides of the mold sharply at least 10 times with the mallet to close holes left by vibrating and to release entrapped air voids.

9.5 *Finishing*—After consolidation, strike off excess concrete from the surface and float or trowel as required. Perform all finishing with the minimum manipulation necessary to produce a flat even surface that is level with the rim or edge of the mold and that has no depressions or projections larger than ⅛ in. [3.3 mm].

9.5.1 *Cylinders*—After consolidation, finish the top surfaces by striking them off with the tamping rod where the consistency of the concrete permits or with a wood float or trowel. If desired, cap the top surface of freshly made cylinders with a thin layer of stiff portland cement paste which is permitted to harden and cure with the specimen. See section on Capping Materials of Practice C 617.

9.5.2 *Beams*—After consolidation of the concrete, use a hand-held float to strike off the top surface to the required tolerance to produce a flat, even surface.

9.6 *Identification*— Mark the specimens to positively identify them and the concrete they represent. Use a method that will not alter the top surface of the concrete. Do not mark the removable caps. Upon removal of the molds, mark the test specimens to retain their identities.

10. Curing

10.1 *Standard Curing*— Standard curing is the curing method used when the specimens are made and cured for the purposes stated in 4.2.

10.1.1 *Storage*—If specimens cannot be molded at the place where they will receive initial curing, immediately after finishing move the specimens to an initial curing place for storage. The supporting surface on which specimens are stored shall be level to within ¼ in. per ft [20 mm per m]. If cylinders in the single use molds are moved, lift and support the cylinders from the bottom of the molds with a large trowel or similar device. If the top surface is marred during movement to place of initial storage, immediately refinish.

10.1.2 *Initial Curing*— Immediately after molding and finishing, the specimens shall be stored for a period up to 48 h in a temperature range from 60 and 80°F [16 and 27°C] and in an environment preventing moisture loss from the specimens. For concrete mixtures with a specified strength of 6000 psi [40 MPa] or greater, the initial curing temperature shall be between 68 and 78°F [20 and 26°C]. Various procedures are capable of being used during the initial curing period to maintain the specified moisture and temperature conditions. An appropriate procedure or combination of procedures shall be used (Note 5). Shield all specimens from the direct sunlight and, if used, radiant heating devices. The storage temperature shall be controlled by use of heating and cooling devices, as necessary. Record the temperature using a maximum-minimum thermometer. If cardboard molds are used, protect the outside surface of the molds from contact with wet burlap or other sources of water.

NOTE 5—A satisfactory moisture environment can be created during the initial curing of the specimens by one or more of the following procedures: (1) immediately immerse molded specimens with plastic lids in water saturated with calcium hydroxide, (2) store in properly constructed wooden boxes or structures, (3) place in damp sand pits, (4) cover with removable plastic lids, (5) place inside plastic bags, or (6) cover with plastic sheets or nonabsorbent plates if provisions are made to avoid drying and damp burlap is used inside the enclosure, but the burlap is prevented from contacting the concrete surfaces. A satisfactory temperature environment can be controlled during the initial curing of the specimens by one or more of the following procedures: (1) use of ventilation, (2) use of ice, (3) use of thermostatically controlled heating or cooling devices, or (4) use of heating methods such as stoves or light bulbs. Other suitable methods may be used provided the requirements limiting specimen storage temperature and moisture loss are met. For concrete mixtures with a specified strength of 6000 psi [40 MPa] or greater, heat generated during the early ages may raise the temperature above the required storage temperature. Immersion in water saturated with calcium hydroxide may be the easiest method to maintain the required storage temperature. When specimens are to be immersed in water saturated with calcium hydroxide, specimens in cardboard molds or other molds that expand when immersed in water should not be used. Early-age strength test results may be lower when stored at 60°F [16°C] and higher when stored at 80°F [27°C]. On the other hand, at later ages, test results may be lower for higher initial storage temperatures.

10.1.3 *Final Curing:*

10.1.3.1 *Cylinders*—Upon completion of initial curing and within 30 min after removing the molds, cure specimens with

free water maintained on their surfaces at all times at a temperature of 73 ± 3°F [23 ± 2°C] using water storage tanks or moist rooms complying with the requirements of Specification C 511, except when capping with sulfur mortar capping compound and immediately prior to testing. When capping with sulfur mortar capping compound, the ends of the cylinder shall be dry enough to preclude the formation of steam or foam pockets under or in cap larger than ¼ in. [6 mm] as described in Practice C 617. For a period not to exceed 3 h immediately prior to test, standard curing temperature is not required provided free moisture is maintained on the cylinders and ambient temperature is between 68 and 86°F [20 and 30°C].

10.1.3.2 *Beams*—Beams are to be cured the same as cylinders (see 10.1.3.1) except that they shall be stored in water saturated with calcium hydroxide at 73 ± 3°F [23 ± 2°C] at least 20 h prior to testing. Drying of the surfaces of the beam shall be prevented between removal from water storage and completion of testing.

NOTE 6—Relatively small amounts of surface drying of flexural specimens can induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

10.2 *Field Curing*— Field curing is the curing method used for the specimens made and cured as stated in 4.3.

10.2.1 *Cylinders*—Store cylinders in or on the structure as near to the point of deposit of the concrete represented as possible. Protect all surfaces of the cylinders from the elements in as near as possible the same way as the formed work. Provide the cylinders with the same temperature and moisture environment as the structural work. Test the specimens in the moisture condition resulting from the specified curing treatment. To meet these conditions, specimens made for the purpose of determining when a structure is capable of being put in service shall be removed from the molds at the time of removal of form work.

10.2.2 *Beams*—As nearly as practicable, cure beams in the same manner as the concrete in the structure. At the end of 48 ± 4 h after molding, take the molded specimens to the storage location and remove from the molds. Store specimens representing pavements of slabs on grade by placing them on the ground as molded, with their top surfaces up. Bank the sides and ends of the specimens with earth or sand that shall be kept damp, leaving the top surfaces exposed to the specified curing treatment. Store specimens representing structure concrete as near the point in the structure they represent as possible, and afford them the same temperature protection and moisture environment as the structure. At the end of the curing period leave the specimens in place exposed to the weather in the same manner as the structure. Remove all beam specimens from field storage and store in water saturated with calcium hydroxide at 73 ± 3°F [23 ± 2°C] for 24 ± 4 h immediately before time of testing to ensure uniform moisture condition from specimen to specimen. Observe the precautions given in 10.1.3.2 to guard against drying between time of removal from curing to testing.

10.3 *Structural Lightweight Concrete Curing*—Cure structural lightweight concrete cylinders in accordance with Specification C 330.

11. Transportation of Specimens to Laboratory

11.1 Prior to transporting, cure and protect specimens as required in Section 10. Specimens shall not be transported until at least 8 h after final set. (See Note 7). During transporting, protect the specimens with suitable cushioning material to prevent damage from jarring. During cold weather, protect the specimens from freezing with suitable insulation material. Prevent moisture loss during transportation by wrapping the specimens in plastic, wet burlap, by surrounding them with wet sand, or tight fitting plastic caps on plastic molds. Transportation time shall not exceed 4 h.

NOTE 7—Setting time may be measured by Test Method C 403.

12. Report

12.1 Report the following information to the laboratory that will test the specimens:

12.1.1 Identification number,

12.1.2 Location of concrete represented by the samples,

12.1.3 Date, time and name of individual molding specimens,

12.1.4 Slump, air content, and concrete temperature, test results and results of any other tests on the fresh concrete and any deviations from referenced standard test methods, and

12.1.5 Curing method. For standard curing method, report the initial curing method with maximum and minimum temperatures and final curing method. For field curing method, report the location where stored, manner of protection from the elements, temperature and moisture environment, and time of removal from molds.

13. Keywords

13.1 beams; casting samples; concrete; curing; cylinders; testing

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Designation: C 39/C 39M – 05

Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens[1]

This standard is issued under the fixed designation C 39/C 39M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excess of 50 lb/ft^3 [800 kg/m^3].

1.2 The values stated in either inch-pound or SI units are to be regarded separately as standard. The SI units are shown in brackets. The values stated in each system may not be 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 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Means should be provided to contain concrete fragments during sudden rupture of specimens. Tendency for sudden rupture increases with increasing concrete strength and it is more likely when the testing machine is relatively flexible. The safety precautions given in the Manual of Aggregate and Concrete Testing are recommended.)

1.4 The text of this standard references notes which provide explanatory material. These notes shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 31/C 31M Practice for Making and Curing Concrete Test Specimens in the Field
C 42/C 42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 617 Practice for Capping Cylindrical Concrete Specimens
C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
C 873 Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
C 1231/C 1231M Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders
E 4 Practices for Force Verification of Testing Machines
E 74 Practice for Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
Manual of Aggregate and Concrete Testing

3. Summary of Test Method

3.1 This test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

4. Significance and Use

4.1 Care must be exercised in the interpretation of the significance of compressive strength determinations by this test method since strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on the size and shape of the specimen, batching, mixing

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing Concrete for Strength.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

4.2 This test method is used to determine compressive strength of cylindrical specimens prepared and cured in accordance with Practices C 31/C 31M, C 192/C 192M, C 617, and C 1231/C 1231M and Test Methods C 42/C 42M and C 873.

4.3 The results of this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures; and similar uses.

4.4 The individual who tests concrete cylinders for acceptance testing shall meet the concrete laboratory technician requirements of Practice C 1077, including an examination requiring performance demonstration that is evaluated by an independent examiner.

NOTE 1—Certification equivalent to the minimum guidelines for ACI Concrete Laboratory Technician, Level I or ACI Concrete Strength Testing Technician will satisfy this equivalent.

5. Apparatus

5.1 *Testing Machine*—The testing machine shall be of a type having sufficient capacity and capable of providing the rates of loading prescribed in 7.5.

5.1.1 Verify calibration of the testing machines in accordance with Practices E 4, except that the verified loading range shall be as required in 5.3. Verification is required under the following conditions:

5.1.1.1 At least annually, but not to exceed 13 months,

5.1.1.2 On original installation or immediately after relocation,

5.1.1.3 Immediately after making repairs or adjustments that affect the operation of the force applying system or the values displayed on the load indicating system, except for zero adjustments that compensate for the mass of bearing blocks or specimen, or both, or

5.1.1.4 Whenever there is reason to suspect the accuracy of the indicated loads.

5.1.2 *Design*—The design of the machine must include the following features:

5.1.2.1 The machine must be power operated and must apply the load continuously rather than intermittently, and without shock. If it has only one loading rate (meeting the requirements of 7.5), it must be provided with a supplemental means for loading at a rate suitable for verification. This supplemental means of loading may be power or hand operated.

5.1.2.2 The space provided for test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device which is of sufficient capacity to cover the potential loading range of the testing machine and which complies with the requirements of Practice E 74.

NOTE 2—The types of elastic calibration devices most generally available and most commonly used for this purpose are the circular proving ring or load cell.

5.1.3 *Accuracy*—The accuracy of the testing machine shall be in accordance with the following provisions:

5.1.3.1 The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed ±1.0 % of the indicated load.

5.1.3.2 The accuracy of the testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one third of the difference between the maximum and minimum test loads.

5.1.3.3 The test load as indicated by the testing machine and the applied load computed from the readings of the verification device shall be recorded at each test point. Calculate the error, E, and the percentage of error, E_p, for each point from these data as follows:

$$E = A - B \tag{1}$$

$$E_p = 100(A - B)/B$$

where:

A = load, lbf [kN] indicated by the machine being verified, and

B = applied load, lbf [kN] as determined by the calibrating device.

5.1.3.4 The report on the verification of a testing machine shall state within what loading range it was found to conform to specification requirements rather than reporting a blanket acceptance or rejection. In no case shall the loading range be stated as including loads below the value which is 100 times the smallest change of load estimable on the load-indicating mechanism of the testing machine or loads within that portion of the range below 10 % of the maximum range capacity.

5.1.3.5 In no case shall the loading range be stated as including loads outside the range of loads applied during the verification test.

5.1.3.6 The indicated load of a testing machine shall not be corrected either by calculation or by the use of a calibration diagram to obtain values within the required permissible variation.

5.2 The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note 3), one of which is a spherically seated block that will bear on the upper surface of the specimen, and the other a solid block on which the specimen shall rest. Bearing faces of the blocks shall have a minimum dimension at least 3 % greater than the diameter of the specimen to be tested. Except for the concentric circles described below, the bearing faces shall not depart from a plane by more than 0.001 in. [0.02 mm] in any 6 in. [150 mm] of blocks 6 in. [150 mm] in diameter or larger, or by more than 0.001 in. [0.02 mm] in the diameter of any smaller block; and new blocks shall be manufactured within one half of this tolerance. When the diameter of the bearing face of the spherically seated block exceeds the diameter of the specimen by more than 0.5 in. [13 mm], concentric circles not more than 0.03 in. [0.8 mm] deep and not more than 0.04 in. [1 mm] wide shall be inscribed to facilitate proper centering.

NOTE 3—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than 55 HRC.

5.2.1 Bottom bearing blocks shall conform to the following requirements:

5.2.1.1 The bottom bearing block is specified for the purpose of providing a readily machinable surface for maintenance of the specified surface conditions (Note 4). The top and bottom surfaces shall be parallel to each other. If the testing machine is so designed that the platen itself is readily maintained in the specified surface condition, a bottom block is not required. Its least horizontal dimension shall be at least 3 % greater than the diameter of the specimen to be tested. Concentric circles as described in 5.2 are optional on the bottom block.

NOTE 4—The block may be fastened to the platen of the testing machine.

5.2.1.2 Final centering must be made with reference to the upper spherical block. When the lower bearing block is used to assist in centering the specimen, the center of the concentric rings, when provided, or the center of the block itself must be directly below the center of the spherical head. Provision shall be made on the platen of the machine to assure such a position.

5.2.1.3 The bottom bearing block shall be at least 1 in. [25 mm] thick when new, and at least 0.9 in. [22.5 mm] thick after any resurfacing operations.

5.2.2 The spherically seated bearing block shall conform to the following requirements:

5.2.2.1 The maximum diameter of the bearing face of the suspended spherically seated block shall not exceed the values given below:

Diameter of Test Specimens, in. [mm]	Maximum Diameter of Bearing Face, in. [mm]
2 [50]	4 [105]
3 [75]	5 [130]
4 [100]	6.5 [165]
6 [150]	10 [255]
8 [200]	11 [280]

NOTE 5—Square bearing faces are permissible, provided the diameter of the largest possible inscribed circle does not exceed the above diameter.

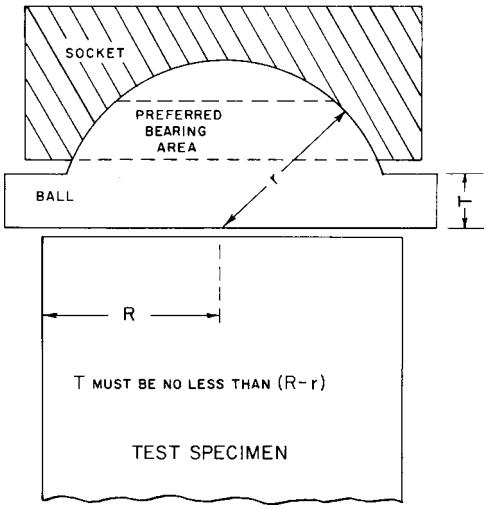
5.2.2.2 The center of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5 % of the radius of the sphere. The diameter of the sphere shall be at least 75 % of the diameter of the specimen to be tested.

5.2.2.3 The ball and the socket shall be designed so that the steel in the contact area does not permanently deform when loaded to the capacity of the testing machine.

NOTE 6—The preferred contact area is in the form of a ring (described as preferred "bearing" area) as shown on Fig. 1.

5.2.2.4 The curved surfaces of the socket and of the spherical portion shall be kept clean and shall be lubricated with a petroleum-type oil such as conventional motor oil, not with a pressure type grease. After contacting the specimen and application of small initial load, further tilting of the spherically seated block is not intended and is undesirable.

5.2.2.5 If the radius of the sphere is smaller than the radius of the largest specimen to be tested, the portion of the bearing face extending beyond the sphere shall have a thickness not less than the difference between the radius of the sphere and radius of the specimen. The least dimension of the bearing face shall be at least as great as the diameter of the sphere (see Fig. 1).



NOTE—Provision shall be made for holding the ball in the socket and for holding the entire unit in the testing machine.

FIG. 1 Schematic Sketch of a Typical Spherical Bearing Block

5.2.2.6 The movable portion of the bearing block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted at least 4° in any direction.

5.2.2.7 If the ball portion of the upper bearing block is a two-piece design composed of a spherical portion and a bearing plate, a mechanical means shall be provided to ensure that the spherical portion is fixed and centered on the bearing plate.

5.3 *Load Indication*:

5.3.1 If the load of a compression machine used in concrete testing is registered on a dial, the dial shall be provided with a graduated scale that is readable to at least the nearest 0.1 % of the full scale load (Note 7). The dial shall be readable within 1 % of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks; the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment located outside the dialcase and easily accessible from the front of the machine while observing the zero mark and dial pointer. Each dial shall be equipped with a suitable device that at all times, until reset, will indicate to within 1 % accuracy the maximum load applied to the specimen.

NOTE 7—Readability is considered to be 0.02 in. [0.5 mm] along the arc described by the end of the pointer. Also, one half of a scale interval is readable with reasonable certainty when the spacing on the load indicating mechanism is between 0.04 in. [1 mm] and 0.06 in. [2 mm]. When the spacing is between 0.06 and 0.12 in. [2 and 3 mm], one third of a scale interval is readable with reasonable certainty. When the spacing is 0.12 in. [3 mm] or more, one fourth of a scale interval is readable with reasonable certainty.

5.3.2 If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read.

The numerical increment must be equal to or less than 0.10 % of the full scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 % for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times until reset will indicate within 1 % system accuracy the maximum load applied to the specimen.

6. Specimens

6.1 Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 %.

NOTE 8—This may occur when single use molds are damaged or deformed during shipment, when flexible single use molds are deformed during molding, or when a core drill deflects or shifts during drilling.

6.2 Prior to testing, neither end of test specimens shall depart from perpendicularity to the axis by more than 0.5° (approximately equivalent to 0.12 in. in 12 in. [1 mm in 100 mm]). The ends of compression test specimens that are not plane within 0.002 in. [0.050 mm] shall be sawed or ground to meet that tolerance, or capped in accordance with either Practice C 617 or, when permitted, Practice C 1231/C 1231M. The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.01 in. [0.25 mm] by averaging two diameters measured at right angles to each other at about midheight of the specimen.

6.3 The number of individual cylinders measured for determination of average diameter is not prohibited from being reduced to one for each ten specimens or three specimens per day, whichever is greater, 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 0.02 in. [0.5 mm]. When the average diameters do not fall within the range of 0.02 in. [0.5 mm] or when the cylinders are not made from a single lot of molds, each cylinder tested must be measured and the value used in calculation of the unit compressive strength of that specimen. When the diameters are measured at the reduced frequency, the cross-sectional areas of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

6.4 If the purchaser of the testing services requests measurement of density of test specimens, determine the mass of specimens before capping. Remove any surface moisture with a towel and measure the mass of the specimen using a balance or scale that is accurate to within 0.3 % of the mass being measured. Measure the length of the specimen to the nearest 0.05 in. [1 mm] at three locations spaced evenly around the circumference. Compute the average length and record to the nearest 0.05 in. [1 mm]. Alternatively, determine the cylinder density by weighing the cylinder in air and then submerged under water at 73.5 ± 3.5 °F (23.0 ±2.0 °C), and computing the volume according to 8.3.1.

6.5 When density determination is not required and the length to diameter ratio is less than 1.8 or more than 2.2, measure the length of the specimen to the nearest 0.05 D.

7. Procedure

7.1 Compression tests of moist-cured specimens shall be made as soon as practicable after removal from moist storage.

7.2 Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition.

7.3 All test specimens for a given test age shall be broken within the permissible time tolerances prescribed as follows:

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

7.4 *Placing the Specimen*—Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen and place the test specimen on the lower bearing block. Carefully align the axis of the specimen with the center of thrust of the spherically seated block.

7.4.1 *Zero Verification and Block Seating*—Prior to testing the specimen, verify that the load indicator is set to zero. In cases where the indicator is not properly set to zero, adjust the indicator (Note 9). As the spherically seated block is brought to bear on the specimen, rotate its movable portion gently by hand so that uniform seating is obtained.

NOTE 9—The technique used to verify and adjust load indicator to zero will vary depending on the machine manufacturer. Consult your owner's manual or compression machine calibrator for the proper technique.

7.5 *Rate of Loading*—Apply the load continuously and without shock.

7.5.1 The load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a stress rate on the specimen of 35 ± 7 psi/s [0.25 ± 0.05 MPa/s] (See Note 10). The designated rate of movement shall be maintained at least during the latter half of the anticipated loading phase.

NOTE 10—For a screw-driven or displacement-controlled testing machine, preliminary testing will be necessary to establish the required rate of movement to achieve the specified stress rate. The required rate of movement will depend on the size of the test specimen, the elastic modulus of the concrete, and the stiffness of the testing machine.

7.5.2 During application of the first half of the anticipated loading phase, a higher rate of loading shall be permitted. The higher loading rate shall be applied in a controlled manner so that the specimen is not subjected to shock loading.

7.5.3 Make no adjustment in the rate of movement (platen to crosshead) as the ultimate load is being approached and the stress rate decreases due to cracking in the specimen.

7.6 Apply the compressive load until the load indicator shows that the load is decreasing steadily and the specimen displays a well-defined fracture pattern (Types 1 to 4 in Fig. 2). For a testing machine equipped with a specimen break detector,

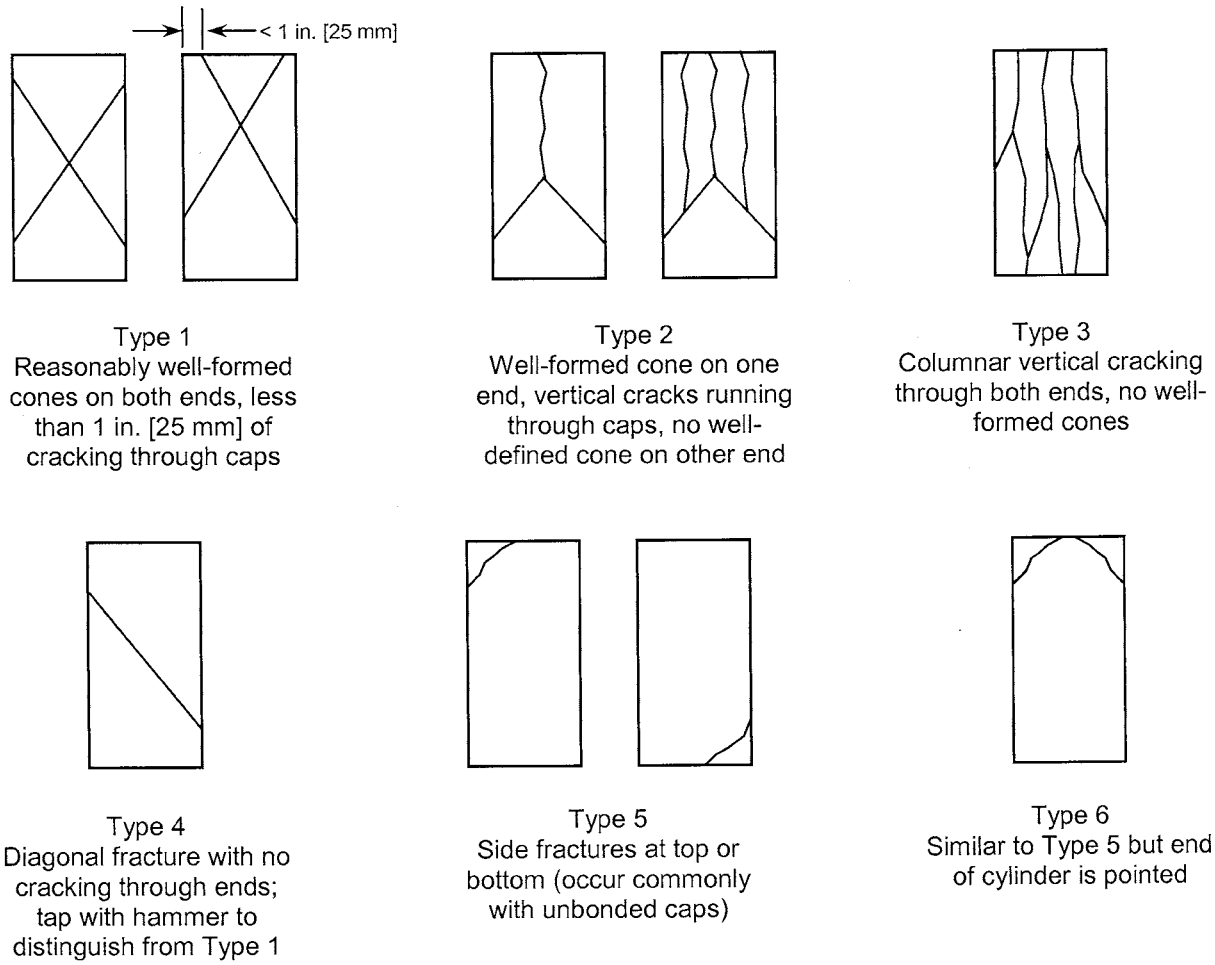


FIG. 2 Schematic of Typical Fracture Patterns

automatic shut-off of the testing machine is prohibited until the load has dropped to a value that is less than 95 % of the peak load. When testing with unbonded caps, a corner fracture similar to a Type 5 or 6 pattern shown in Fig. 2 may occur before the ultimate capacity of the specimen has been attained. Continue compressing the specimen until the user is certain that the ultimate capacity has been attained. Record the maximum load carried by the specimen during the test, and note the type of fracture pattern according to Fig. 2. If the fracture pattern is not one of the typical patterns shown in Fig. 2, sketch and describe briefly the fracture pattern. If the measured strength is lower than expected, examine the fractured concrete and note the presence of large air voids, evidence of segregation, whether fractures pass predominantly around or through the coarse aggregate particles, and verify end preparations were in accordance with Practice C 617 or Practice C 1231/C 1231M.

8. Calculation

8.1 Calculate the compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described in Section 6 and express the result to the nearest 10 psi [0.1 MPa].

8.2 If the specimen length to diameter ratio is 1.75 or less, correct the result obtained in 8.1 by multiplying by the appropriate correction factor shown in the following table Note 11:

L/D:	1.75	1.50	1.25	1.00
Factor:	0.98	0.96	0.93	0.87

Use interpolation to determine correction factors for L/D values between those given in the table.

NOTE 11—Correction factors depend on various conditions such as moisture condition, strength level, and elastic modulus. Average values are given in the table. These correction factors apply to low-density concrete weighing between 100 and 120 lb/ft^3 [1600 and 1920 kg/m^3] and to normal-density concrete. They are applicable to concrete dry or soaked at the time of loading and for nominal concrete strengths from 2000 to 6000 psi [14 to 42 MPa]. For strengths higher than 6000 psi [42 MPa] correction factors may be larger than the values listed above[3].

8.3 When required, calculate the density of the specimen to the nearest 1 lb/ft^3 [10 kg/m^3] as follows:

$$Density = \frac{W}{V} \tag{2}$$

[3] Bartlett, F.M. and MacGregor, J.G., "Effect of Core Length-to-Diameter Ratio on Concrete Core Strength," ACI Materials Journal, Vol 91, No. 4, July-August, 1994, pp. 339-348.

where:
W = mass of specimen, lb [kg], and
V = volume of specimen computed from the average diameter and average length or from weighing the cylinder in air and submerged, ft^3 [m^3]

8.3.1 When the volume is determined from submerged weighing, calculate the volume as follows:

$$V = \frac{W - W_s}{\gamma_w} \quad (3)$$

where:
W_s = apparent mass of submerged specimen, lb [kg], and
γ_w = density of water at 73.5 °F [23 °C] = 62.27 lbs/ft^3 [997.5 kg/m^3].

9. Report

9.1 Report the following information:

9.1.1 Identification number,

9.1.2 Diameter (and length, if outside the range of 1.8 *D* to 2.2 *D*), in inches [millimetres],

9.1.3 Cross-sectional area, in square inches [square millimetres],

9.1.4 Maximum load, in pounds-force [kilonewtons],

9.1.5 Compressive strength calculated to the nearest 10 psi [0.1 MPa],

9.1.6 Type of fracture, if other than the usual cone (see Fig. 2),

9.1.7 Defects in either specimen or caps, and,

9.1.8 Age of specimen.

9.1.9 When determined, the density to the nearest 1 lb/ft^3 [10 kg/m^3].

10. Precision and Bias

10.1 *Precision*

10.1.1 *Within-Test Precision*—The following table provides the within-test precision of tests of 6 by 12 in. [150 by 300 mm] and 4 by 8 in. [100 by 200 mm] cylinders made from a well-mixed sample of concrete under laboratory conditions and under field conditions (see 10.1.2).

	Coefficient of Variation[4]	Acceptable Range[4] of Individual Cylinder Strengths	
		2 cylinders	3 cylinders
6 by 12 in. [150 by 300 mm]			
Laboratory conditions	2.4 %	6.6 %	7.8 %
Field conditions	2.9 %	8.0 %	9.5 %
4 by 8 in. [100 by 200 mm]			
Laboratory conditions	3.2 %	9.0 %	10.6 %

[4] These numbers represent respectively the (1s %) and (d2s %) limits as described in Practice C 670.

10.1.2 The within-test coefficient of variation represents the expected variation of measured strength of companion cylinders prepared from the same sample of concrete and tested by one laboratory at the same age. The values given for the within-test coefficient of variation of 6 by 12 in. [150 by 300 mm] cylinders are applicable for compressive strengths between 2000 and 8000 psi [15 to 55 MPa] and those for 4 by 8 in. [100 by 200 mm] cylinders are applicable for compressive strengths between 2500 and 4700 psi [17 to 32 MPa]. The within-test coefficients of variation for 6 by 12 in. [150 by 300 mm] cylinders are derived from CCRL concrete proficiency sample data for laboratory conditions and a collection of 1265 test reports from 225 commercial testing laboratories in 1978.[5] The within-test coefficient of variation of 4 by 8 in. [100 by 200 mm] cylinders are derived from CCRL concrete proficiency sample data for laboratory conditions.[6]

10.1.3 *Multilaboratory Precision*—The multi-laboratory coefficient of variation for compressive strength test results of 6 by 12 in. [150 by 300 mm] cylinders has been found to be 5.0 %[4]; therefore, the results of properly conducted tests by two laboratories on specimens prepared from the same sample of concrete are not expected to differ by more than 14 %[4] of the average (See Note 12). A strength test result is the average of two cylinders tested at the same age.

NOTE 12—The multilaboratory precision does not include variations associated with different operators preparing test specimens from split or independent samples of concrete. These variations are expected to increase the multilaboratory coefficient of variation.

10.1.4 The multilaboratory data were obtained from six separate organized strength testing round robin programs[6] where 6 x 12 in [150 x 300 mm] cylindrical specimens were prepared at a single location and tested by different laboratories. The range of average strength from these programs was 2500 to 13 000 psi [17.0 to 90 MPa].

NOTE 13—Subcommittee C09.61 will continue to examine recent concrete proficiency sample data and field test data and make revisions to precisions statements when data indicate that they can be extended to cover a wider range of strengths and specimen sizes.

10.2 *Bias*—Since there is no accepted reference material, no statement on bias is being made.

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: C09-1006.

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C09–1027 .

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Designation: C 42/C 42M – 04

American Association State
Highway and Transportation Officials Standard
AASHTO No.: T24

Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[1]

This standard is issued under the fixed designation C 42/C 42M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers obtaining, preparing, and testing (*1*) cores drilled from concrete for length or compressive strength or splitting tensile strength determinations and (*2*) beams sawed from concrete for flexural strength determinations.

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

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

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 39/C 39M Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

C 174/C 174M Test Method for Measuring Length of Drilled Concrete Cores

C 496 Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

C 617 Practice for Capping Cylindrical Concrete Specimens

C 642 Test Method for Density, Absorption, and Voids in Hardened Concrete

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C 823 Practice for Examination and Sampling of Hardened Concrete in Constructions

C 1231/C 1231M Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

2.2 *ACI Standards:*

318 Building Code Requirements for Structural Concrete[3]

3. Significance and Use

3.1 This test method provides standardized procedures for obtaining and testing specimens to determine the compressive, splitting tensile, and flexural strength of in-place concrete.

3.2 Generally, test specimens are obtained when doubt exists about the in-place concrete quality due either to low strength test results during construction or signs of distress in the structure. Another use of this method is to provide strength information on older structures.

3.3 Concrete strength is affected by the location of the concrete in a structural element, with the concrete at the bottom tending to be stronger than the concrete at the top. Core strength is also affected by core orientation relative to the horizontal plane of the concrete as placed, with strength tending to be lower when measured parallel to the horizontal plane.[4] These factors shall be considered in planning the locations for obtaining concrete samples and in comparing strength test results.

3.4 The strength of concrete measured by tests of cores and beams is affected by the amount and distribution of moisture in the specimen at the time of test. There is no standard procedure to condition a specimen that will ensure that, at the time of test,

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing for Strength.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

[4] Neville, A., "Core Tests: Easy to Perform, Not Easy to Interpret," *Concrete International*, Vol. 23, No. 11, November 2001, pp. 59-68.

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

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it will be in the identical moisture condition as concrete in the structure. The moisture conditioning procedures in this test method are intended to provide reproducible moisture conditions that minimize within-laboratory and between-laboratory variations and to reduce the effects of moisture introduced during specimen preparation.

3.5 There is no universal relationship between the compressive strength of a core and the corresponding compressive strength of standard-cured molded cylinders. The relationship is affected by many factors such as the strength level of the concrete, the in-place temperature and moisture history, and the strength gain characteristics of the concrete. Historically, it has been assumed that core strengths are generally 85 % of the corresponding standard-cured cylinder strengths, but this is not applicable to all situations. The acceptance criteria for core strength are to be established by the specifier of the tests. ACI 318 provides core strength acceptance criteria for new construction.

4. Apparatus

4.1 *Core Drill*, for obtaining cylindrical core specimens with diamond impregnated bits attached to a core barrel.

4.2 *Saw*, for cutting beam specimens to size for flexural strength tests and to trim ends of cores. The saw shall have a diamond or silicon-carbide cutting edge and shall be capable of cutting specimens that conform to the prescribed dimensions, without excessive heating or shock.

5. Sampling

5.1 *General*:

5.1.1 Samples of hardened concrete for use in the preparation of strength test specimens shall not be taken until the concrete is strong enough to permit sample removal without disturbing the bond between the mortar and the coarse aggregate (see Note 1 and Note 2). When preparing strength test specimens from samples of hardened concrete, samples that have been damaged during removal shall not be used unless the damaged portion(s) are removed and the resulting test specimen is of suitable length (see 7.2). Samples of defective or damaged concrete that cannot be tested shall be reported along with the reason that prohibits use of the sample for preparing strength test specimens.

NOTE 1—Practice C 823 provides guidance on the development of a sampling plan for concrete in constructions.

NOTE 2—It is not possible to specify a minimum age when concrete is strong enough to withstand damage during removal, because the strength at any age depends on the curing history and strength grade of the concrete. If time permits, the concrete should not be removed before it is 14 days old. If this is not practical, removal of concrete can proceed if the cut surfaces do not display erosion of the mortar and the exposed coarse aggregate particles are embedded firmly in the mortar. In-place test methods may be used to estimate the level of strength development prior to attempting removal of concrete samples.

5.1.2 Specimens containing embedded reinforcement shall not be used for determining compressive, splitting tensile, or flexural strength.

5.2 *Core Drilling*—A core specimen shall be drilled perpendicular to the surface and not near formed joints or obvious edges of a unit of deposit. Record and report the approximate angle between the longitudinal axis of the drilled core and the horizontal plane of the concrete as placed. A specimen drilled perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit when possible.

5.3 *Slab Removal*—Remove a slab sufficiently large to secure the desired test specimens without the inclusion of any concrete that has been cracked, spalled, undercut, or otherwise damaged.

DRILLED CORES

6. Measuring the Length of Drilled Cores

6.1 Cores for determining the thickness of pavements, slabs, walls or other structural elements shall have a diameter of at least 3.75 in. [95 mm] when the lengths of such cores are stipulated to be measured in accordance with Test Method C 174/C 174M.

6.2 For cores that are not intended for determining structural dimensions, measure the longest and shortest lengths on the cut surface along lines parallel to the core axis. Record the average length to the nearest ¼ in. [5 mm].

7. Cores for Compressive Strength

7.1 *Diameter*—The diameter of core specimens for the determination of compressive strength in load bearing structural members shall be at least 3.70 in. [94 mm]. For non-load bearing structural members or when it is impossible to obtain cores with length-diameter ratio (L/D) greater than or equal to 1, core diameters less than 3.70 in. [94 mm] are not prohibited (see Note 3). For concrete with nominal maximum aggregate size greater than or equal to 1½ in. [37.5 mm], the core diameters shall be as directed by the specifier of the tests (see Note 4).

NOTE 3—The compressive strengths of nominal 2-in. [50-mm] diameter cores are known to be somewhat lower and more variable than those of nominal 4-in. [100-mm] diameter cores. In addition, smaller diameter cores appear to be more sensitive to the effect of the length-diameter ratio.[5]

NOTE 4—The preferred minimum core diameter is three times the nominal maximum size of the coarse aggregate, but it should be at least two times the nominal maximum size of the coarse aggregate.

7.2 *Length*—The preferred length of the capped or ground specimen is between 1.9 and 2.1 times the diameter. If the ratio of the length to the diameter (L/D) of the core exceeds 2.1, reduce the length of the core so that the ratio of the capped or ground specimen is between 1.9 and 2.1. Core specimens with length-diameter ratios equal to or less than 1.75 require corrections to the measured compressive strength (see 7.9.1). A strength correction factor is not required for L/D greater than 1.75. A core having a maximum length of less than 95 % of its diameter before capping or a length less than its diameter after capping or end grinding shall not be tested.

7.3 *Moisture Conditioning*—Test cores after moisture conditioning as specified in this test method or as directed by the

[5] Bartlett, F.M. and MacGregor, J.G., "Effect of Core Diameter on Concrete Core Strengths," *ACI Materials Journal*, Vol. 91, No. 5, September-October 1994, pp. 460-470.

specifier of the tests. The moisture conditioning procedures specified in this test method are intended to preserve the moisture of the drilled core and to provide a reproducible moisture condition that minimizes the effects of moisture gradients introduced by wetting during drilling and specimen preparation.

7.3.1 After cores have been drilled, wipe off surface drill water and allow remaining surface moisture to evaporate. When surfaces appear dry, but not later than 1 h after drilling, place cores in separate plastic bags or nonabsorbent containers and seal to prevent moisture loss. Maintain cores at ambient temperature, and protect cores from exposure to direct sunlight. Transport the cores to the testing laboratory as soon as possible. Keep cores in the sealed plastic bags or nonabsorbent containers at all times except during end preparation and for a maximum time of 2 h to permit capping before testing.

7.3.2 If water is used during sawing or grinding of core ends, complete these operations as soon as possible, but no later than 2 days after drilling of cores unless stipulated otherwise by the specifier of tests. After completing end preparation, wipe off surface moisture, allow the surfaces to dry, and place the cores in sealed plastic bags or nonabsorbent containers. Minimize the duration of exposure to water during end preparation.

7.3.3 Allow the cores to remain in the sealed plastic bags or nonabsorbent containers for at least 5 days after last being wetted and before testing, unless stipulated otherwise by the specifier of tests.

NOTE 5—The waiting period of at least 5 days is intended to reduce moisture gradients introduced when the core is drilled or wetted during sawing or grinding.

7.3.4 When direction is given to test cores in a moisture condition other than achieved by conditioning according to 7.3.1, 7.3.2, and 7.3.3, report the alternative procedure.

7.4 *Sawing of Ends*—The ends of core specimens to be tested in compression shall be flat, and perpendicular to the longitudinal axis in accordance with Test Method C 39/C 39M. If necessary, saw the ends of cores that will be capped so that prior to capping, the following requirements are met:

7.4.1 Projections, if any, shall not extend more than 0.2 in. [5 mm] above the end surfaces.

7.4.2 The end surfaces shall not depart from perpendicularity to the longitudinal axis by a slope of more than 1:8*d* or [1:0.3*d*] where *d* is the average core diameter in inches [or mm].

7.5 *Density*—When required by the specifier of the tests, determine the density by weighing the core before capping and dividing the mass by the volume of the core calculated from the average diameter and length. Alternatively, determine the density from the mass in air and submerged mass in accordance with Test Method C 642. After submerged weighing, dry cores in accordance with 7.3.2 and store in sealed plastic bags or nonabsorbent containers for at least 5 days before testing.

7.6 *Capping*—If the ends of the cores do not conform to the perpendicularity and planeness requirements of Test Method C 39/C 39M, they shall be sawed or ground to meet those requirements or capped in accordance with Practice C 617. If cores are capped in accordance with Practice C 617, the capping device shall accommodate actual core diameters and produce caps that are concentric with the core ends. Measure core lengths to the nearest 0.1 in. [2 mm] before capping. Unbonded caps in accordance with Practice C 1231/C 1231M are not permitted.

7.7 *Measurement*—Before testing, measure the length of the capped or ground specimen to the nearest 0.1 in. [2 mm] and use this length to compute the length-diameter (L/D) ratio. Determine the average diameter by averaging two measurements taken at right angles to each other at the mid-height of the specimen. Measure core diameters to the nearest 0.01 in. [0.2 mm] when the difference in core diameters does not exceed 2 % of their average, otherwise measure to the nearest 0.1 in. [2 mm]. Do not test cores if the difference between the largest and smallest diameter exceeds 5 % of their average.

7.8 *Testing*—Test the specimens in accordance with Test Method C 39/C 39M. Test the specimens within 7 days after coring, unless specified otherwise.

7.9 *Calculation*—Calculate the compressive strength of each specimen using the computed cross-sectional area based on the average diameter of the specimen.

7.9.1 If the ratio of length to diameter (L/D) of the specimen is 1.75 or less, correct the result obtained in 7.9 by multiplying by the appropriate correction factor shown in the following table (see Note 6):

Ratio of Length to Diameter (L/D)	Strength Correction Factor
1.75	0.98
1.50	0.96
1.25	0.93
1.00	0.87

Use interpolation to determine correction factors for L/D values not given in the table.

NOTE 6—Correction factors depend on various conditions such as moisture condition, strength level, and elastic modulus. Average values for corrections due to length-diameter ratio are given in the table. These correction factors apply to low-density concrete having a density between 100 and 120 lb/ft^3 [1600 and 1920 kg/m^3] and to normal density concrete. They are applicable to both dry and wet concrete for strengths between 2000 psi and 6000 psi [14 MPa to 42 MPa]. For strengths above 10 000 psi [70 MPa], test data on cores show that the correction factors may be larger than the values listed above.[6]

7.10 *Report*—Report the results as required by Test Method C 39/C 39M with the addition of the following information:

7.10.1 Length of core as drilled to the nearest ¼ in. [5 mm],

7.10.2 Length of test specimen before and after capping or end grinding to the nearest 0.1 in. [2 mm], and average diameter of core to the nearest 0.01 in. [0.2 mm] or 0.1 in. [2 mm],

7.10.3 Compressive strength to the nearest 10 psi [0.1 MPa] when the diameter is measured to the nearest 0.01 in. [0.2 mm] and to the nearest 50 psi [0.5 MPa] when the diameter is measured to the nearest 0.1 in. [2 mm], after correction for length-diameter ratio when required,

[6] Bartlett, F.M. and MacGregor, J.G, "Effect of Core Length-to-Diameter Ratio on Concrete Core Strengths," *ACI Materials Journal*, Vol. 91, No. 4, July-August 1994, pp. 339-348.

7.10.4 Direction of application of the load on the specimen with respect to the horizontal plane of the concrete as placed,

7.10.5 The moisture conditioning history:

7.10.5.1 The date and time core was obtained and first placed in sealed bag or nonabsorbent container,

7.10.5.2 If water was used during end preparation, the date and time end preparation was completed and core placed in sealed bag or nonabsorbent container,

7.10.6 The date and time when tested,

7.10.7 Nominal maximum size of concrete aggregate.

7.10.8 If determined, the density,

7.10.9 If applicable, description of defects in cores that could not be tested, and

7.10.10 If any deviation from this test method was required, describe the deviation and explain why it was necessary.

7.11 *Precision:*[7]

7.11.1 The single-operator coefficient of variation on cores has been found to be 3.2 %[8] for a range of compressive strength between 4500 psi [32.0 MPa] and 7000 psi [48.3 MPa]. Therefore, results of two properly conducted tests of single cores by the same operator on the same sample of material should not differ from each other by more than 9 %[8] of their average.

7.11.2 The multi-laboratory coefficient of variation on cores has been found to be 4.7 %[8] for a range of compressive strength between 4500 psi [32.0 MPa] and 7000 psi [48.3 MPa]. Therefore, results of two properly conducted tests on cores sampled from the same hardened concrete (where a single test is defined as the average of two observations (cores), each made on separate adjacent drilled 4 in. [100 mm] diameter cores), and tested by two different laboratories should not differ from each other by more than 13 %[8] of their average.

7.12 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

8. Cores for Splitting Tensile Strength

8.1 *Test Specimens*—The specimens shall conform to the dimensional requirements in 7.1, 7.2, 7.4.1, and 7.4.2. Ends are not to be capped.

8.2 *Moisture Conditioning*—Condition the specimens as described in 7.3, or as directed by the specifier of tests.

8.3 *Bearing Surfaces*—The line of contact between the specimen and each bearing strip shall be straight and free of any projections or depressions higher or deeper than 0.01 in. [0.2 mm]. When the line of contact is not straight or contains projections or depressions having heights or depths greater than 0.01 in., grind or cap the specimen so as to produce bearing lines meeting these requirements. Do not test specimens with projections or depressions greater than 0.1 in. [2.0 mm]. When capping is employed, the caps shall be as thin as practicable and shall be formed of high-strength gypsum plaster.

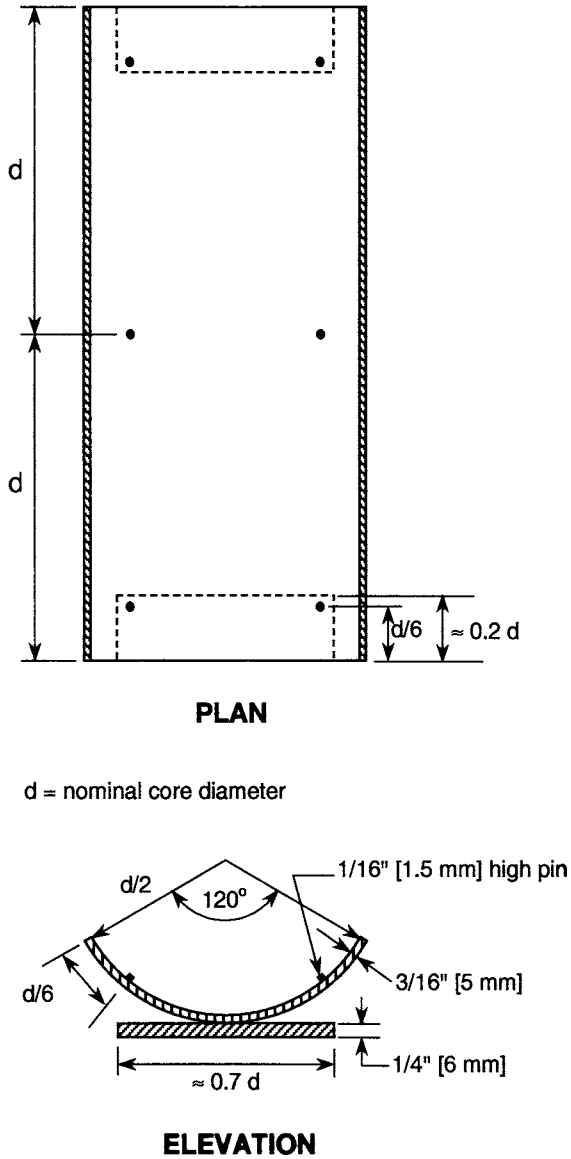

FIG. 1 Suitable Capping Device for Splitting Tensile Strength Test

NOTE 7—Fig. 1 illustrates a device suitable for applying caps to the bearing surfaces of core specimens.

8.4 *Testing*—Test the specimens in accordance with Test Method C 496.

8.5 *Calculation and Report*—Calculate the splitting tensile strength and report the results as required in Test Method C 496. When grinding or capping of the bearing surfaces is required, measure the diameter between the finished surfaces. Indicate that the specimen was a core and provide the moisture conditioning history as in 7.10.5.

8.6 *Precision:*[9]

8.6.1 The within laboratory single operator coefficient of variation for splitting tensile strength between 520 psi [3.6 MPa] and 590 psi [4.1 MPa] of cores has been found to be

[7] Bollin, G. E., "Development of Precision and Bias Statements for Testing Drilled Cores in Accordance with ASTM C 42," *ASTM Journal of Cement, Concrete, and Aggregates*, Vol 15, No. 1, 1993.

[8] These numbers represent, respectively, the (1s %) and (d2s %) limits as described in Practice C 670.

[9] Steele, G.W., "Portland Cement Concrete Core Proficiency Sample Program," Strategic Highway Research Program, SHRP-P-636, National Research Council, Washington, D.C., 1993.

5.3 %.[8] Therefore, results of two properly conducted tests by the same operator in the same laboratory on the same sample of material should not differ by more than 14.9 %[8] of their average.

8.6.2 The multi-laboratory coefficient of variation for splitting tensile strength between 520 psi [3.6 MPa] and 590 psi [4.1 MPa] of cores has been found to be 15.0 %.[8] Therefore, results of two properly conducted tests on the same sample of material of hardened concrete and tested by two different laboratories should not differ from each other by more than 42.3 %[8] of their average.

8.7 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

BEAMS FOR FLEXURAL TESTING

9. Flexural Strength

9.1 *Test Specimens*—Unless otherwise specified, a beam specimen for the determination of flexural strength shall have a nominal cross section of 6 by 6 in. [150 by 150 mm] (Note 8). The specimen shall be at least 21 in. [530 mm] in length, but when two tests for flexural strength are to be made in one beam specimen, it shall be at least 33 in. [840 mm] in length. Perform the sawing operation so that the concrete will not be weakened by shock or by heating. The sawed surfaces shall be smooth, plane, parallel, and free from steps, ridges, and grooves. Take care in handling sawed beam specimens to avoid chipping or cracking.

NOTE 8—In many cases, particularly with prisms cut from pavement slabs, the width will be governed by the size of the coarse aggregate and the depth by the thickness of the slab.

9.2 *Moisture Conditioning*—Protect the surfaces of sawed specimens from evaporation by covering them with wet burlap and plastic sheeting during transportation and storage. Test the specimens within 7 days of sawing. Submerge the test specimens in lime-saturated water at 73.5 ± 3.5°F [23.0 ± 2.0°C] for at least 40 h immediately prior to the flexure test. Test the specimens promptly after removal from water storage. During the period between removal from water storage and testing, keep the specimens moist by covering with a wet blanket of burlap or other suitable absorbent fabric.

9.2.1 When the specifier of tests so directs, beams shall be tested in a moisture condition other than that achieved by conditioning in accordance with 9.2.

NOTE 9—Relatively small amounts of drying of the surface of flexural specimens induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

9.3 *Testing*—Test the specimens in accordance with the applicable provisions of Test Method C 78.

NOTE 10—Sawing may greatly reduce the indicated flexural strength; beams shall, therefore, be tested with a molded surface in tension whenever possible. The location of the tension face with respect to the position of the concrete as placed and the position of the sawed surfaces should be reported.

9.4 *Report*—Report the results in accordance with the applicable provisions of Test Method C 78 and the requirements of this test method, including the moisture condition at the time of testing. Identify orientation of the specimen's finished, sawed, and tension faces with respect to their positions in the test apparatus.

10. Precision and Bias

10.1 *Precision*—Data are not available for preparing a statement on the precision of flexural strength measured on sawed beams.

NOTE 11—Users of this method who have replicate test data that may be appropriate for a statement on repeatability are encouraged to contact the chairman of the subcommittee.

10.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

11. Keywords

11.1 compressive strength; concrete coring; concrete sawing; concrete strength; flexural strength; splitting tensile strength

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this test method since the last issue (C 42/C 42M – 03) that may impact its use (Approved July 1, 2004).

(1) The wording in 7.4 was clarified and the requirements in 7.4.2 were revised.

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