
USACE / NAVFAC / AFCEA UFGS-03371 (September 2001)

Preparing Activity: USACE (CW)

Superseding
UFGS-03371 (May 1995)

UNIFIED FACILITIES GUIDE SPECIFICATIONS

References are in agreement with UMRL dated 25 June 2004

Latest change indicated by CHG tags

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DIVISION 03 - CONCRETE

SECTION 03371

SHOTCRETE

09/01

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SECTION 03371

SHOTCRETE
09/01

NOTE: This guide specification covers the requirements for materials, proportioning, application, and curing of shotcrete.

Comments and suggestions on this guide specification are welcome and should be directed to the technical proponent of the specification. A listing of technical proponents, including their organization designation and telephone number, is on the Internet.

Recommended changes to a UFGS should be submitted as a Criteria Change Request (CCR).

Use of electronic communication is encouraged.

Brackets are used in the text to indicate designer choices or locations where text must be supplied by the designer.

PART 1 GENERAL

NOTE: The content of this specification is such that guidance given in EM 1110-2-2005, STANDARD PRACTICE FOR SHOTCRETE, is applicable.

1.1 REFERENCES

NOTE: Issue (date) of references included in project specifications need not be more current than provided by the latest guide specification. Use of SpecsIntact automated reference checking is recommended for projects based on older guide specifications.

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

ACI INTERNATIONAL (ACI)

ACI 506.3R	(1991; R 1995) Guide to Certification of Shotcrete Nozzlemen
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ASTM INTERNATIONAL (ASTM)

ASTM A 820	(2001) Steel Fibers for Fiber-Reinforced Concrete
ASTM C 1018	(1997) Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)
ASTM C 1077	(2003) Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
ASTM C 1140	(2003a) Preparing and Testing Specimens from Shotcrete Test Panels
ASTM C 1141	(2001) Admixtures for Shotcrete
ASTM C 1240	(2003a) Silica Fume for Use as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar and Grout
ASTM C 136	(2001) Sieve Analysis of Fine and Coarse Aggregates
ASTM C 150	(2002ae1) Portland Cement
ASTM C 171	(2003) Sheet Materials for Curing Concrete
ASTM C 231	(2003) Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C 266	(1999) Time of Setting of Hydraulic-Cement Paste by Gillmore Needles
ASTM C 309	(2003) Liquid Membrane-Forming Compounds for Curing Concrete
ASTM C 33	(2003) Concrete Aggregates
ASTM C 42/C 42M	(2003) Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C 566	(1997) Total Evaporable Moisture Content of Aggregate by Drying
ASTM C 595	(2003) Blended Hydraulic Cements

ASTM C 595M	(1997) Blended Hydraulic Cements (Metric)
ASTM C 618	(2003) Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
ASTM C 685	(2000) Concrete Made by Volumetric Batching and Continuous Mixing
ASTM C 881	(1999) Epoxy-Resin-Base Bonding Systems for Concrete
ASTM C 94/C 94M	(2003a) Ready-Mixed Concrete
ASTM C 989	(1999) Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

U.S. ARMY CORPS OF ENGINEERS (USACE)

COE CRD-C 400	(1963) Requirements for Water for Use in Mixing or Curing Concrete
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1.2 SUBMITTALS

NOTE: Submittals must be limited to those necessary for adequate quality control. The importance of an item in the project should be one of the primary factors in determining if a submittal for the item should be required.

A "G" following a submittal item indicates that the submittal requires Government approval. Some submittals are already marked with a "G". Only delete an existing "G" if the submittal item is not complex and can be reviewed through the Contractor's Quality Control system. Only add a "G" if the submittal is sufficiently important or complex in context of the project.

For submittals requiring Government approval on Army projects, a code of up to three characters within the submittal tags may be used following the "G" designation to indicate the approving authority. Codes for Army projects using the Resident Management System (RMS) are: "AE" for Architect-Engineer; "DO" for District Office (Engineering Division or other organization in the District Office); "AO" for Area Office; "RO" for Resident Office; and "PO" for Project Office. Codes following the "G" typically are not used for Navy projects.

Submittal items not designated with a "G" are considered as being for information only for Army projects and for Contractor Quality Control approval for Navy projects.

Government approval is required for submittals with a "G" designation; submittals not having a "G" designation are [for Contractor Quality Control approval.][for information only. When used, a designation following the "G" designation identifies the office that will review the submittal for the Government.] The following shall be submitted in accordance with Section 01330 SUBMITTAL PROCEDURES:

SD-06 Test Reports

Mixture Proportions[; G][; G, [_____]]

The recommended mixture proportions, sources of materials, and all test results shall be submitted for approval.

Aggregates

Supplier's test reports for aggregates showing the materials meet the requirements of this specification.

Accelerator Compatibility[; G][; G, [_____]]

The Contractor shall establish the compatibility of the job cement and the proposed accelerators.

Preconstruction Test Panels

Cores and sawed concrete beams shall be taken from test panels and tested.

SD-07 Certificates

Portland Cement

Portland cement shall be certified for compliance with all specification requirements.

Pozzolans

Fly ash and other pozzolans shall be certified for compliance with all specification requirements.

Silica Fume

Silica fume shall be certified for compliance with all specification requirements.

Accelerating Admixtures

Accelerating admixtures shall be certified for compliance with all specification requirements.

Curing Materials

Curing materials shall be certified for compliance with all specification requirements.

Steel Fiber Reinforcement

Fiber reinforcement shall be certified for compliance with all

specification requirements.

Qualifications[; G][; G, [____]]

Qualifications of each nozzleman shall be certified.

1.3 UNIT PRICES

NOTE: If Section 01270 MEASUREMENT AND PAYMENT is included in the project specifications, this paragraph title (UNIT PRICES) should be deleted from this section and the remaining appropriately edited subparagraphs below should be inserted into Section 01270.

1.3.1 Shotcrete

1.3.1.1 Payment

Payment will be made for all costs associated with furnishing, delivering, and placing shotcrete.

1.3.1.2 Measurement

Shotcrete will be measured for payment based upon [the quantity in cubic meters yards of solid material gunned through the nozzles.] [the quantity per cubic meter, yard, based on [a unit length] [the area] shotcreted to the thickness shown on the contract drawings.]

1.3.1.3 Unit of Measure

Unit of measure: cubic meter. yard.

1.4 QUALITY ASSURANCE

The Contractor shall provide facilities and labor as may be necessary for obtaining and testing representative test samples. Shotcrete shall be sampled and tested by the method given in paragraph STRENGTH TESTING.

1.5 MIXTURE PROPORTIONS

NOTE: Consult the appropriate DM to fill in the blanks.

Mixture proportions and test data from prior experience within [____] years, if available, may be submitted for approval. If test data from experience are not available or accepted, specimens shall be made and tested from mixtures having three or more different proportions. The recommended mixture proportions, sources of materials, and all test results shall be submitted for acceptance. [Mixture proportions for nonfiber-reinforced shotcrete shall be selected on the basis of compressive strength tests of cores obtained from test panels fabricated in accordance with ASTM C 1140 and having minimum dimensions of 750 by 750 by 100 mm 30 by 30 by 4 inches. Cores shall be continuously moist cured until testing at [____] days age. For mixture acceptance purposes, the average

compressive strength of at least three cores shall be at least equal to 1.2 times the required compressive strength specified in paragraph COMPRESSIVE STRENGTH.] [Mixture proportions for fiber-reinforced shotcrete shall be selected on the basis of flexural strength [and toughness index] of 100 by 100 by 350 mm 4 by 4 by 14 inch beams sawed from test panels which are fabricated in accordance with ASTM C 1140 and having minimum dimensions of 750 by 750 by 100 mm. 30 by 30 by 4 inches. Beams shall be continuously moist cured until testing at [_____] days age. For mixture acceptance purposes, the average flexural strength [and toughness index] of at least three beams shall be not less than the flexural strength [and toughness index] specified in paragraph FLEXURAL STRENGTH [and TOUGHNESS INDEX].]

1.6 EVALUATION AND ACCEPTANCE

1.6.1 Strength

NOTE: Compressive strength should be specified for nonfiber-reinforced shotcrete and flexural strength should be specified for fiber-reinforced shotcrete. Consult EM 1110-2-2005 and the appropriate DM to fill in blanks.

If a flexural toughness index requirement is deemed necessary for fiber-reinforced shotcrete, the minimum toughness index necessary for anticipated service conditions should be specified. See EM 1110-2-2005 and ASTM C 1116 for guidance.

Final acceptance of the shotcrete will be based on [compressive] [flexural] strength results obtained from [cores] [beams].

1.6.1.1 [Compressive Strength]

The required compressive strength of cores shall not be less than [_____] MPa psi at [_____] days age when tested in accordance with ASTM C 42/C 42M.

The average compressive strength of cores taken from the [structure] [test panel], representing a shift or not more than 40 cubic meters 50 cubic yards of shotcrete tested at [_____] days of age, shall equal or exceed the required compressive strength specified with no individual core less than 85 percent of the required compressive strength. When the length of a core is less than 1.94 times the diameter, the correction factors given in ASTM C 42/C 42M will be applied to obtain the compressive strength of individual cores.]

1.6.1.2 [Flexural Strength]

Fiber-reinforced shotcrete beams shall be obtained and tested in accordance with ASTM C 1140 and shall have a flexural strength of not less than [_____] MPa psi at [_____] days age.]

1.6.1.3 [Toughness Index]

The toughness index, [I10] [I20], of fiber-reinforced shotcrete beams shall be [_____] at [_____] days age when tested in accordance with ASTM C 1018.]

1.7 QUALIFICATIONS

The Contractor shall submit a resume for each nozzleman certifying that each has not less than 1 year's experience for the particular type of shotcrete to be applied. The resume shall include company name, address, and telephone number, name of supervisor, and detailed description of work performed. All nozzlemen shall be certified in accordance with ACI 506.3R.

Qualifications of additional nozzlemen throughout the job shall be similarly submitted for approval.

1.8 PRECONSTRUCTION TEST PANELS

Specimens of the preconstruction test panels shall be made by each application crew using the equipment, materials, mixture proportions, and procedures for each mixture being considered, and for each shooting position to be encountered in the job. [The same reinforcement as in the structure shall be provided in at least one-half of the panel to test for proper embedment of reinforcing steel.] The test panels shall be fabricated to the same thickness as the structure, but not less than 100 mm 4 inches. [At least five 75 mm 3-inch diameter cores from each panel shall be taken for testing for compressive strength in accordance with ASTM C 1140 when nonfiber-reinforced shotcrete is used. The compressive strength of the cores shall meet the requirements specified in paragraph COMPRESSIVE STRENGTH.] [Three 100 by 100 by 350 mm 4 by 4 by 14 inch beams shall be obtained in accordance with ASTM C 1140 from the test panels when fiber-reinforced shotcrete is used. The flexural strength [and toughness index] of the fiber-reinforced shotcrete beams shall meet the requirements specified in paragraph FLEXURAL STRENGTH [and TOUGHNESS INDEX].]

PART 2 PRODUCTS

2.1 MATERIALS

2.1.1 Cementitious Materials

NOTE: See the appropriate DM to select the proper requirements for the Cementitious Materials Options. Other cementitious materials may be added if specifically recommended and approved in the concrete materials DM.

Cementitious materials shall be portland cement, blended hydraulic cement, portland cement in combination with pozzolan or ground granulated blast-furnace slag (GGBFS) [or [____]], or [or portland cement in combination with silica fume] and shall conform to appropriate specifications listed below.

2.1.1.1 Portland Cement

Portland cement shall meet the requirements of ASTM C 150 Type [I], [II], [III], [V] [low alkali] [with tricalcium aluminate limited to [5] [8] percent if Type III is used].

2.1.1.2 Blended Hydraulic Cement

ASTM C 595M ASTM C 595 Type IS, IP[(MS)].

2.1.1.3 Pozzolan Other Than Silica Fume

Pozzolans shall conform to ASTM C 618, Class [C], [F], with the optional requirements for [available alkalis from Table 1A] multiple factor, drying shrinkage, and uniformity of Table 2A.

2.1.1.4 [Ground Granulated Blast-Furnace Slag

Ground granulated blast-furnace slag shall conform to ASTM C 989, Grade [____].]

2.1.1.5 [Silica Fume

Silica may be furnished as a dry, densified material or as a slurry. Silica fume, unprocessed, or before processing into a slurry or a densified material, shall conform to ASTM C 1240.]

2.1.2 Aggregates

Aggregates shall conform to ASTM C 33 with the combined grading of coarse and fine aggregates conforming to the grading shown below.

SIEVE SIZE	PERCENT BY MASS PASSING INDIVIDUAL SIEVES		
	GRADING NO. 1	GRADING NO. 2	GRADING NO. 3*
19.0 mm (3/4 in.)	--	--	100
12.5 mm (1/2 in.)	--	100	80-95
9.5 mm (3/8 in.)	100	90-100	70-90
4.75 mm (No. 4)	95-100	75-85	50-70
2.36 mm (No. 8)	80-100	50-70	35-55
1.18 mm (No. 16)	50-85	35-55	20-40
600 µm (No. 30)	25-60	20-35	10-30
300 µm (No. 50)	10-30	8-20	5-17
150 µm (No. 100)	2-10	2-10	2-10

* Fine and coarse aggregates shall be batched separately to avoid segregation.

2.1.3 Water

Fresh, clean, potable mixing water or nonpotable water which meets the requirements of COE CRD-C 400 shall be used.

2.1.4 Admixtures

Admixtures to be used, when required or approved, shall comply with the appropriate sections of ASTM C 1141. Except as otherwise accepted, soluble admixtures shall be dissolved in water before introduction into the shotcrete mixture.

2.1.4.1 Accelerators

When accelerating admixtures complying with ASTM C 1141, Type II, Grade 1, are to be used, the Contractor shall establish the accelerator compatibility of the job cement and the proposed accelerators using ASTM C 266, except as modified herein. The powdered accelerator shall be blended with 50 grams of cement until uniform and 15 milliliters of water shall then be added. The liquid accelerator shall first be mixed with 15 milliliters of water

and then added to 50 grams of cement. Three percent of the proposed accelerator by mass of cement shall be used as a starting point. Mixing shall be accomplished within 15 seconds. The specimen shall be molded within 1 minute of adding the mixing water. If initial set is 2 minutes or less and a final set is 10 minutes or less, the accelerator is considered compatible. If these values are not achieved in the first test, additional tests shall be run using 2 percent and 4 percent of accelerator.

2.1.5 Curing Materials

Curing materials shall meet the following requirements.

2.1.5.1 Impervious Sheet Materials

ASTM C 171, type optional except polyethylene film, if used, shall be white opaque.

2.1.5.2 Membrane-Forming Curing Compound

ASTM C 309, Type 1-D or Type 2.

2.1.6 Reinforcement

2.1.6.1 Steel Fiber Reinforcement

Steel fiber reinforcement shall meet the requirements of ASTM A 820.

2.1.6.2 Other Types of Reinforcement

[Section [____]] [____] for all other types of reinforcement.

PART 3 EXECUTION

3.1 PRODUCTION OF SHOTCRETE

The shotcrete shall be produced by [wet-mix process] [dry-mix process].

3.1.1 Dry Mix Process

NOTE: Delete these three paragraphs if wet-mix process is specified.

3.1.1.1 Batching and Mixing

Aggregate and cementitious materials may be batched by mass or by volume. Equipment for batching by mass shall be capable of the accuracy specified in ASTM C 94/C 94M. Volumetric equipment shall be capable of batching with the accuracy specified in ASTM C 685. The mixing equipment shall be capable of thoroughly mixing the materials in sufficient quantity to maintain placing continuity and be capable of discharging all mixed material without any carryover from one batch to the next.

3.1.1.2 Delivery Equipment

The equipment shall be capable of discharging the aggregate-cement mixture into the delivery hose and delivering a continuous smooth stream of uniformly mixed material to the discharge nozzle. The discharge nozzle

shall be equipped with a manually operated water injection system (water ring) for directing an even distribution of water through the aggregate-cement mixture. The water valve shall be capable of ready adjustment to vary the quantity of water and shall be convenient to the nozzleman. The water pressure at the discharge nozzle shall be sufficiently greater than the operating air pressure to ensure that the water is completely mixed with the other materials. If the line water pressure is inadequate, a water pump shall be introduced into the line. The water pressure shall be steady (nonpulsating). The delivery equipment shall be thoroughly cleaned at the end of each shift. Equipment parts, especially the nozzle liner and water ring, shall be regularly inspected and replaced as required.

3.1.2 Wet Mix Process

NOTE: Delete these four paragraphs if dry-mix process is specified. See the appropriate DM to select the proper air content.

3.1.2.1 Batching and Mixing

Batching and mixing shall be accomplished in accordance with the applicable provisions of ASTM C 94/C 94M. If volumetric batching and mixing are used, the materials shall be batched and mixed in accordance with the applicable provisions of ASTM C 685. The mixing equipment shall be capable of thoroughly mixing the specified materials in sufficient quantity to maintain continuous placing. Ready-mix shotcrete complying with ASTM C 94/C 94M may be used.

3.1.2.2 Delivery Equipment

The equipment shall be capable of delivering the premixed materials accurately, uniformly, and continuously through the delivery hose. Recommendations of the equipment manufacturer shall be followed on the type and size of nozzle to be used and on cleaning, inspection, and maintenance of the equipment.

3.1.2.3 Air Content

Air-entraining admixture shall be used in such proportion that the air content of the shotcrete prior to gunning shall be [_____] plus or minus (\pm) 1.0 percent as determined by ASTM C 231.

3.1.3 Air Supply

The Contractor shall provide a supply of clean, dry air adequate for maintaining sufficient nozzle velocity for all parts of the work and, if required, for simultaneous operation of a suitable blowpipe for clearing away rebound.

3.2 PREPARATION OF SURFACES

3.2.1 Earth

Earth shall be compacted and trimmed to line and graded before placement of shotcrete. Surfaces to receive shotcrete shall be dampened.

3.2.2 Existing Concrete

All unsound and loose materials shall be removed by sandblasting, grinding, or high-pressure water jets before applying shotcrete. Any area to be repaired shall be chipped off or scarified to remove offsets which would cause an abrupt change in thickness without suitable reinforcement. Edges shall be tapered to leave no square shoulders at the perimeter of a cavity.

The surface shall be dampened but without visible free water.

3.2.3 Rock

Rock surfaces shall be cleaned to remove loose or drummy material, mud, running water, and other foreign matter that will prevent bond of the shotcrete. The rock surface shall be dampened prior to placement of shotcrete.

3.2.4 Shotcrete

When a layer of shotcrete is to be covered by a succeeding layer at a later time, it shall first be allowed to develop its initial set. Then all laitance, loose material, and rebound shall be removed by brooming or scraping. Hardened laitance set shall be removed by sandblasting and the surface thoroughly cleaned.

3.2.5 Construction Joints

Unless otherwise specified, construction joints shall be tapered to a shallow edge form, about 25 mm 1 inch thick. If nontapered joints are specified, special care shall be taken to avoid or remove trapped rebound at the joint. The entire joint shall be thoroughly cleaned and wetted prior to the application of additional shotcrete.

3.3 PLACEMENT OF SHOTCRETE

3.3.1 General

Shotcrete shall be placed using suitable delivery equipment and procedures.

The area to which shotcrete is to be applied shall be clean and free of rebound or overspray.

3.3.2 Placement Techniques

3.3.2.1 Placement Control

Thickness, method of support, air pressure, and water content of shotcrete shall be controlled to preclude sagging or sloughing off. Shotcreting shall be discontinued or suitable means shall be provided to screen the nozzle stream if wind or air currents cause separation of the nozzle stream during placement.

3.3.2.2 Corners

Horizontal and vertical corners and any area where rebound cannot escape or be blown free shall be filled first.

3.3.3 Placement Around Reinforcement

The nozzle shall be held at such distance and angle to place material behind reinforcement before any material is allowed to accumulate on the

face of the reinforcement. In the dry-mix process, additional water may be added to the mixture when encasing reinforcement to facilitate a smooth flow of material behind the bars. Shotcrete shall not be placed through more than one layer of reinforcing steel rods or mesh in one application unless demonstrated by preconstruction tests that steel is properly encased.

3.3.4 Cover of Reinforcement

NOTE: Use 19 mm (3/4 inch) if grading No. 1 in paragraph AGGREGATES is selected; otherwise, use 40 mm (1-1/2 inches).

The following minimum cover shall be provided.

- a. For shotcrete used as linings, coatings, slab, or wall: [19 mm 3/4 inch.] [40 mm. 1-1/2 inches.]
- b. For required structural reinforcement in beams, girders, and columns: 40 mm. 1-1/2 inches.

3.3.5 Placement Precautions

The following precautions shall be taken during placement.

- a. Placement shall be stopped if drying or stiffening of the mixture takes place at any time prior to delivery to the nozzle.
- b. Rebound or previously expended material shall not be used in the shotcrete mixture.

3.4 REPAIR OF DEFECTS

3.4.1 Defects

Defective areas larger than 31 000 square millimeters 48 square inches or 50 mm 2 inches deep shall be removed and replaced with fresh shotcrete. These defects include honeycombing, lamination, dry patches, voids, or sand pockets. Defective areas shall be removed in accordance with the procedures described in paragraph EXISTING CONCRETE and replaced with fresh shotcrete.

3.4.1.1 Repairs

All repairs shall be made within 1 week of the time the deficiency is discovered. All unacceptable materials shall be removed and repaired by the procedures described in the following two paragraphs. Voids and holes left by the removal of tie rods in all permanently exposed surfaces not to be backfilled and in surfaces to be exposed to water shall be reamed and completely filled with dry-patching mortar as specified below.

3.4.1.2 Minor Patching

Minor patching may be accomplished with a dry-pack mixture, or with materials as approved by the Contracting Officer. Patches that exceed 0.003 cubic meters 0.1 cubic foot in volume shall receive a brush coat of approved epoxy resin meeting ASTM C 881, Type II, as a prime coat. Care shall be taken not to spill epoxy or overcoat the repair surface so that

the epoxy runs or is squeezed out onto the surface which will remain exposed to view. Epoxy resin shall be used in strict conformance with manufacturer's recommendations with special attention paid to pot life, safety, and thin film tack time.

3.4.2 Core Holes

Core holes shall not be repaired with shotcrete. Instead, they shall be filled solid with a dry-pack mixture after being cleaned and thoroughly dampened.

3.5 FINISHING

NOTE: See the appropriate DM for type of finish required. The specified finishes should also be shown on the contract drawings. Delete the finishes not required.

3.5.1 Natural Gun Finish

Unless otherwise specified, undisturbed final layer of shotcrete as applied from nozzle without hand finishing shall be provided.

3.5.2 Cutting Screed

After the surface has taken its initial set (crumbling slightly when cut), excess material outside the forms and ground wires shall be sliced off with a downward cutting motion using a sharp-edged cutting screed.

3.5.3 Flash Coat

A thin coat of shotcrete containing finer sand applied from a distance greater than normal shall be applied to the surface as soon as possible after the screeding.

3.5.4 Float and Trowel Finish

Final surface finish shall be provided using [wood float] [rubber float] [steel trowel]. Troweling of thin sections of shotcrete shall be avoided unless both troweling and commencement of moisture curing take place within a relatively short period after placement of shotcrete.

3.5.5 Fiber-Reinforced Shotcrete

NOTE: Include this paragraph if the exposed steel fibers pose a safety hazard.

The Contractor shall finish the outer surface of the structure with a layer of nonfiber-reinforced shotcrete and provide an appropriate finish as denoted.

3.6 CURING AND PROTECTION

NOTE: See appropriate DM for protection durations

and EM 1110-2-2005 on the proper use of accelerating admixture.

3.6.1 Initial Curing

Immediately after finishing, shotcrete shall be kept continuously moist for at least 3 days. One of the following materials or methods shall be used:

- a. Ponding or continuous sprinkling.
- b. Absorptive mat or fabric, sand, or other covering kept continuously wet.
- c. Curing Compounds. On natural gun or flash finishes, use the coverage application requirement of 2.5 square meters per liter 100 square feet per gallon or twice the manufacturer's requirement, whichever is less. Curing compounds shall not be used on any surfaces against which additional shotcrete or other cementitious finishing materials are to be bonded unless positive measures, such as sandblasting, are taken to completely remove curing compounds prior to the application of such additional materials.

3.6.2 Final Curing

Additional curing shall be provided immediately following the initial curing and before the shotcrete has dried. One of the following materials or methods shall be used:

- a. Continue the method used in initial curing.
- b. Application of impervious sheet material conforming to ASTM C 171.

3.6.3 Formed Surface

If forms are to be removed during curing period, one of the curing materials or methods listed in paragraph INITIAL CURING shall be used immediately. Such curing shall be continued for the remainder of the curing period.

3.6.4 Duration of Curing

Curing shall be continued for the first 7 days after shotcreting or until the specified [compressive] [flexural] strength of the in-place shotcrete as determined by specimens obtained and tested in accordance with ASTM C 42/C 42M is achieved.

3.6.5 Temperature Considerations

The air temperature in contact with the shotcrete shall be continuously maintained at a temperature above 5 degrees C 40 degrees F for at least [3 days after placement.] [[_____] days after placement if an accelerator is used.] No shotcrete shall be applied when the concrete surface or air in contact with the concrete surface is below 5 degrees C 40 degrees F.

3.7 TESTS

3.7.1 Strength Testing

NOTE: See the appropriate DM for locations of test specimens and ages of tests. Air content tests should only be specified on shotcrete produced by the wet-mix process.

Test specimens shall be initially cured onsite, then shall be transported in an approved manner to an approved testing laboratory meeting the requirements of ASTM C 1077 within 48 hours of scheduled testing time.

3.7.1.1 Test Panel

One test panel shall be made for every 40 cubic meters 50 cubic yards of shotcrete placed but not less than one per each shift during which any shotcrete is placed. Panels shall have minimum dimensions of 450 by 450 by 100 mm 18 by 18 by 4 inches and shall be gunned in the same positions as the work represented during the course of the work by the Contractor's regular nozzleman. Panels shall be field cured in the same manner as in the job. [Three [_____] mm inch diameter cores shall be drilled from each panel at least 40 hours prior to testing and tested in accordance with ASTM C 1140.] [Two 100 by 100 by 350 mm 4 by 4 by 14 inch beams shall be saw cut from the test panels when fiber-reinforced shotcrete is used. The fiber-reinforced shotcrete beams shall be tested in accordance with ASTM C 1140 [ASTM C 1018.] If the quality of shotcrete is questionable, the Government may saw or core the panel specimens to determine the shotcrete quality and if remedial action is necessary.]

3.7.1.2 [Test Cores

Test cores shall be drilled from the structure at least 40 hours prior to testing and tested in accordance with ASTM C 1140. A set of three cores shall be taken not less than once each shift that shotcrete is placed nor less than once for each 40 cubic meters 50 cubic yards of shotcrete placed through the nozzle. The diameter of core specimens shall be determined in accordance with ASTM C 42/C 42M.]

3.7.1.3 [Compressive Strength

The compressive strength of the shotcrete shall be determined from the average of three cores obtained from [a test panel] [the structure] representing a specific volume of shotcrete and tested on the [_____] day after [panel fabrication] [placement in the structure.]]

3.7.1.4 [Flexural Strength

The flexural strength of the shotcrete shall be determined from the average of two test specimens obtained from a test panel and tested on the [_____] day after panel fabrication.]

3.7.1.5 [Toughness Index

The toughness index of the shotcrete shall be determined from the average of two test specimens obtained from a test panel and tested on the [_____] day after panel fabrication.]

3.7.2 Aggregate Moisture

Prior to batching the shotcrete and at least once during a shift in which shotcrete is being batched, the coarse and fine aggregate moisture content

shall be determined in accordance with ASTM C 566. The batch weights of both the aggregates and mixing water shall be appropriately adjusted to account for the available free moisture in the aggregates. The amount of free moisture in the aggregates, expressed as kilograms pounds of water per cubic meter, yard, shall be recorded on the batching ticket and delivered to the Contracting Officer prior to placement during the shift. The Contracting Officer will have the option to request additional aggregate moisture content tests for each of the required tests.

3.7.3 Grading

The grading of the coarse and fine aggregate shall be determined in accordance with ASTM C 136. The fine and coarse aggregate grading shall be determined prior to batching the shotcrete and at least once during a shift in which shotcrete is being batched. The Contracting Officer will have the option to require one additional sieve analysis test for aggregate type.

3.7.4 Thickness

The minimum shotcrete thickness shall be as shown in the drawings. The unhardened shotcrete shall be checked for thickness using a probe by the nozzleman or laborer at the time of placement. These thickness checks shall be at 15-minute intervals and all low or thin areas shall be corrected by applying additional shotcrete.

3.7.5 Mixture Proportions

Record and check mixture proportions at least once per shift for weigh batching. Record and check mixture proportions as recommended by ASTM C 685 at least once per shift for volumetric batching and continuous mixing plants.

3.7.6 Preparations

Prior to each placement of shotcrete, the Contractor's inspector shall certify in writing or by an approved checkout form that cleanup and preparations are in accordance with the plans and specifications.

3.7.7 [Air Content

Air content tests shall be conducted on wet-mix shotcrete according to ASTM C 231 with a frequency of not less than once each shift nor less than once for each 40 cubic meters 50 cubic yards of shotcrete placed through the nozzle. Tests shall be conducted on samples taken as the wet shotcrete mixture is placed in the delivery equipment.]

-- End of Section --