Chapter 7
Quality Control

7-1. General Considerations

Shotcrete is a unique concrete material with many unusual applications that require careful attention to details. It is essential that quality control procedures be established to assure that the final product functions as designed and that it has the desired life expectancy. The contract specifications should clearly call out the Contractor's responsibilities for verifying that the proposed materials, equipment, methods, etc. will meet the requirements of the contract specifications. Required submittals and test reports should be clearly stated in the specifications. ER 1180-1-6 should be followed in regard to the format and details of a contractor quality control (QC) program. The following discussions pertain to technical aspects of shotcrete and should be considered when preparing contractor QC specification requirements and when reviewing the Contractor's QC plan.

7-2. Preproduction Phase

Prior to start of production of shotcrete for any permanent work, the following submittals and test reports should be furnished and the following testing performed by the Contractor to verify that his materials, methods, equipment, and procedures meet the contract requirements.

a. Submittals.

(1) Cementitious materials. Manufacturer's certified test results should be furnished to verify that the cement and pozzolan meet the contract requirements. Appropriate test results should be furnished to verify that silica fume meets the contract requirements.

(2) Aggregates. Test data should be furnished to verify that the fine and coarse aggregates meet the quality and grading requirements of the contract.

(3) Admixtures and curing compound. A manufacturer's certificate of compliance should be furnished to verify that the air-entraining admixture, retarding admixture, water-reducing admixture, accelerating admixture, and curing compound meet the contract requirements.

(4) Fibers and reinforcement. A manufacturer's certificate should be furnished to verify that the proposed fibers and reinforcement meet the requirements of the specifications.

(5) Mixture proportions. Test data should be furnished to verify that the Contractor's proposed mixture proportions will produce shotcrete that meets the quality requirements of the specifications. Test specimens should contain the materials proposed for the project and should be obtained from test panels shot with the equipment and by a nozzleman that will be used for the permanent work.

(6) Accelerator compatibility test. When an accelerator is proposed to be used in the shotcrete, test data per CRD-C 625 (ASTM C 1141) should be furnished to verify that the combination of cement and accelerator meet the contract requirements for initial and final set times.

(7) Nozzleman certification. ACI certifies shotcrete nozzlemen. If required by the specifications, a current certification for each nozzleman who will be placing shotcrete in permanent work should be submitted.

(8) Equipment. If determined to be necessary by the designer and so stated in the contract, the equipment and layout of the proposed plant for producing, conveying, and placing the shotcrete should be furnished to verify conformance with the requirements of the specifications.

(9) Curing and protection. The method of providing the required curing and protection of the in-place shotcrete should be submitted. Hot weather and cold weather protection plans should be submitted.

b. Test panel fabrication, testing, and evaluation. Test panels must be scheduled to be shot early in a project to allow sufficient time for evaluation of the panels prior to start of production of shotcrete for the permanent work. Test panel sizes and configurations are detailed in Chapter 5. Test panels are necessary for evaluation of the proposed shotcrete mixture and to evaluate the qualifications of the proposed nozzleman. Specimens should be sawn or cored from the test panel to verify the contract requirement for strength. The specimens and the test panel should be visually examined for signs of laminations, sand streaks, aggregate pockets, reinforcing steel not completely surrounded by shotcrete,

and any other indications of either mixture proportion problems or nozzleman workmanship.

7-3. Production Phase

An ongoing program of testing should be performed by the Contractor to verify that the materials, methods, and in-place shotcrete meet the requirements of the contract documents. The specifications should clearly state the minimum types of tests that are required, the minimum frequency of performing each test, a procedure for reporting the results of the tests, and a procedure for correcting any deficiencies (Table 7-1).

a. Materials.

(1) Cementitious materials. Manufacturer's certified test results for the cement, pozzolan, and appropriate test data for silica fume should be furnished at the interval specified and whenever a change in the appearance or performance of the material is suspected.

(2) Aggregates.

(a) Quality. Test data should be furnished to verify that the quality of the aggregates meets the requirements of the specifications. Test data should be submitted at established intervals and whenever a change in the appearance or performance of the material is suspected.

(b) Grading. The grading of each aggregate group should be verified by testing according to CRD-C 103 (ASTM C 136) at established intervals and whenever a change in the appearance or performance of the material is suspected. Changes in the grading of an aggregate will cause a change in the water requirements of the mixture with attendant changes in the strength and placing characteristics of the shotcrete.

(c) Moisture content. The moisture content of each aggregate group must be known to calculate the amount of free water to be added to each batch of shotcrete. The moisture contents should be established prior to start of each shift and whenever a change is made in stockpile sources.

(3) Admixtures and curing compound. Manufacturers' certificates of compliance for the air-entraining admixture, retarding admixture, water-reducing admixture, accelerating admixture, and curing compound should be furnished at an established interval and whenever a change in the appearance or performance of the material is suspected.

b. Surface preparation. The Contractor's ability to prepare surfaces according to the requirements of the specifications should be verified during each shift. No shotcrete should be placed until surface preparations are completed. Bonding of the shotcrete layer to the underlying stratum is essential for proper performance and longevity.

c. Shotcrete.

(1) Strength. The strength of the shotcrete should be verified at established intervals. The method of obtaining samples, the method of testing, the frequency of testing, and the required strength should be clearly stated in the contract specifications.

(a) Test panels. A test panel should be shot at least once a shift. The panel should be shot by a nozzleman who is placing shotcrete in permanent work shotcrete. The panel should be at least 18 by 18 by 3 inches. The test panel should be cured at the project site in accordance with the contract requirements until it has attained sufficient strength to allow movement to the testing laboratory. Curing should continue in the test laboratory until specimens are obtained from the panel. Cores or beams should be taken from the panel in accordance with the provisions of CRD-C 27 (ASTM C 42). Cores are used to verify the compressive strength of nonfiber reinforced shotcrete, and beams are used to verify the flexural strength of fiber-reinforced shotcrete.

(b) In-place samples. At established intervals and whenever deemed necessary by the Contracting Officer, cores or beams should be obtained from the in-place shotcrete to verify the strength. The samples should be cured and tested in a manner similar to that of test panel samples.

(2) Mixture proportions. The mixture proportions of the shotcrete should be checked regularly to verify that the original proportions are being maintained. This is generally accomplished by verifying that the batch weights, especially the cementitious materials and water weights, are as required.

(3) Air content. Wet-mix shotcrete is generally required to have a specified air content as determined by CRD-C 41 (ASTM C 231). The air content should be determined at regular intervals and at locations as specified. The air content specified in the contract documents is higher than required for durable conventional concrete and allows for about 50 percent of

Table 7-1
Quality Control Testing Requirements

Guide to Testing Frequency*			
Property/Activity	Test Procedure	Frequency	Comment
Cementious Materials	Mill Test	per 400 tons of cement	
Aggregate Quality			
Quality	CRD-C 133 (ASTM C 33)	Initial	Increase if necessary
Grading	CRD-C 133 (ASTM C 33)	Per shift	
Particle Shape	CRD-C 119 (ASTM D 4791)	Initial	
Moisture Content	CRD-C 113 (ASTM C 566)	Daily	
Unhardened Properties			
Air Content	CRD-C 41 (ASTM C 231)	Per batch	Wet-mix only
Slump	CRD-C 5 (ASTM C 143)	Per batch	Wet-mix only
Mix Proportions		Per shift	
Rebound	per specs	Daily	
Thickness	per specs	Per 50 ft^2	Probe shotcrete or check gauge wires
Hardened Properties			
Fabricate Test Panels	per specs	Per shift	
Drill In-situ Cores	CRD-C 27 (ASTM C 42)	3 per 2,500 ft^2	
Compression Stength	CRD-C 14 (ASTM C 42/C 39)	3 per 2,500 ft^2	
Flexural Strength	CRD-C 16 (ASTM C 42/C 78)	2 per 5,000 ft^2	
Toughness	CRD-C 65 (ASTM C 1018)	3 per 5,000 ft^2	Fiber-reinforced shotcrete only
Surface Roughness	per specs	2 per 1,000 ft^2	
Delaminations	per specs	1 per 25 ft^2	

* Table values are only a guide. Testing frequency must be based on an evaluation of testing costs, criticality of performance, and the nature of the application.

the air to be lost during the delivery and shooting of the shotcrete. The specification must detail how air content is to be determined. If sampled at the pump, the test is performed as detailed in CRD-C 41 (ASTM C 231).

(4) In-place thickness. Gauge wires or studs should be set prior to placing shotcrete to facilitate placing of the required thickness. It is best to verify thickness by measuring the offset of the gauge wires since later probing of the in-place shotcrete may be very difficult. The in-place thickness of the shotcrete may be verified by probing the fresh shotcrete with a sharp tool. Thin areas should be corrected by immediate application of additional material. Cores of hardened shotcrete may be directed to be taken by the Contracting Officer to verify areas of suspect thickness.

(5) Rebound testing. It is advantageous to periodically determine the amount of shotcrete that is rebounding from the placement surfaces. This can be done by designating a placement area and collecting all the rebound material after the placement is complete. The percent of rebound can be calculated by determining the volume of material shot and the volume of material collected.

(6) Curing and protection. The contractor should verify that the required curing and protection of the shotcrete is being furnished. Proper curing is important due to the generally low water content of shotcrete. Any premature drying could impair the hydration process. Proper protection during hot or cold weather is essential to proper hydration of shotcrete.

(7) Nondestructive testing. The uniformity and quality of in-place shotcrete may be assessed by nondestructive testing devices such as impact hammers or probes (CRD-C 22 (ASTM C 805) and CRD-C 59 (ASTM C 803)), ultrasonic equipment (CRD-C 51 (ASTM C 597)), and pull out devices (CRD-C 78 (ASTM C 900)). The use of such devices should be at the direction of the Contracting Officer and should be used to identify areas of suspect quality and relative strength, not for actual strength determination.

(8) Delamination testing. Where appropriate, complete shotcrete coatings should be checked for complete bond to the substrate and bond between each shotcrete layer. This can be done using a small hammer on the surface. The contract should require that all delaminated areas be removed and shotcrete reapplied.

(9) Surface tolerances. Some applications may require that exacting surface variation tolerances be met. Verifying that a surface meets a tolerance is best done using the specified length straight-edge and measuring the gap below the edge. The specification should be clear that this method will be the verification method.

(10) Visual inspection. The quality of the shotcrete should be thoroughly evaluated by visual inspection. Surfaces should be inspected for uniformity, voids at the surfaces, varying finish conditions, dry conditions, seepage of water, cracking, and damaged sections.

7-4. Corrective Actions

When a submittal or test report indicates that a material or product fails to meet the contract requirements, the corrective actions specified in the contract documents should be initiated immediately.