## 4.2 Supplementary Cementing Materials

4.2.1 *Engineer shall specify* which supplementary cementing materials, if any, are permitted or required for use on project.

4.2.2 Fly ash pozzolan shall conform to the requirements of ASTM C 618.

4.2.3 Granulated slag shall conform to the requirements of ASTM C 989, Grade 100 or 120, ground granulated blast furnace slag.

4.2.4 Silica fume shall conform to the requirements of ASTM C 1240.

## 4.3 Water

4.3.1 All water used in shotcrete production shall be of drinking water standard and free of oil and chemical or organic impurities.

4.3.2 Similarly, all water used for high-pressure water blasting, predampening of concrete surfaces prior to application of shotcrete, in blowpipes for removal of rebound and overspray, and for shotcrete curing shall be of drinking water standards and free of oil and chemical or organic impurities.

## 4.4 Aggregates

4.4.1 Aggregates shall be normal weight aggregates conforming to the requirements of AASHTO M 6 for fine aggregate and AASHTO M 80 for coarse aggregate. Gradation of aggregates shall be as required in the Contract Documents or as approved by the Engineer.

## 4.5 Admixtures

4.5.1 No admixtures shall be added to the shotcrete *without approval of the Engineer.* In particular any admixtures containing chlorides shall not be used. Shotcrete accelerators shall not be used *without written authorization by the Engineer.*

4.5.2 Air-entraining admixtures shall be added to the mix water *if specified in the Contract Documents.* Air-entraining admixtures shall conform to the requirements of ASTM C 260.

4.5.3 Chemical admixtures, if used, such as water reducing and set-retarding admixtures, shall conform to the requirements of

ASTM C 494. Superplasticizing admixtures, if used, shall conform to the requirements of ASTM C 1017.

## 4.6 Reinforcement

4.6.1 Welded wire mesh fabric shall be welded galvanized steel of dimensions and mass specified in drawings and shall conform to ASTM A 185.

4.6.2 New or replacement reinforcing bars shall be installed *as detailed in the Contract Documents.* Reinforcing bars shall conform to ASTM A 615, A 706, A 767, or A 775.

4.6.3 Inserts for attachment of welded wire mesh fabric to existing concrete shall be galvanized in accordance with ASTM A 385 and A 641, and be of adequate length and strength to resist a 10-kN pull-out force.

4.6.4 Fibers shall conform to the requirements of ASTM C 1116. Fiber type, length and addition rate shall be as *specified in the Contract Documents.*

## 4.7 Materials Handling and Storage

4.7.1 Portland cement and supplementary cementing materials shall be stored so as to be protected from exposure to moisture and temperatures below 5 degrees C and above 30 degrees C.

4.7.2 All admixtures shall be maintained at temperatures above 5 degrees C and below 30 degrees C at all times.

4.7.3 Aggregates used in site batching of shotcrete shall be stockpiled and handled so as to prevent segregation, and shall be tested to determine percent moisture for use in mix design and calculation of water-cement ratio. Shelters or tarpaulins shall be used to protect the aggregate stockpiles during periods of wet weather.

4.7.4 Fiber shall be stored in dry, sealed containers until ready for batching and shall be free from corrosion, oil, grease or other contaminants.

## 5.0 SHOTCRETE PROPORTIONING

### 5.1 Mixture Design

5.1.1 The Contractor shall be responsible for shotcrete mixture proportioning and shall submit the proposed shotcrete mixture proportions *to the Engineer for review and approval* 10 working days prior to application of production shotcrete. As a minimum, for each shotcrete mixture design the following information shall be submitted:

(a) An easily identifiable mix designation, number or code;

(b) Batch quantities of fine aggregate, coarse aggregate, cement, supplementary cementing material, expected water demand (to include all water from moisture in aggregates, and water added at the batch site and on site) and all other shotcrete ingredients, in $kg/m^3$, based on saturated surface dry aggregates; and

(c) Aggregate source, gradation, relative bulk density (specific gravity) and absorption.

5.1.2 Allowance shall be made for the shooting orientation and rebound in shotcrete mixture proportioning.

5.1.3 Shotcrete shall be proportioned to meet the performance requirements detailed in the project drawings and Section 5.3.

5.1.4 The Contractor shall submit performance test data from previous experience, if available, along with the shotcrete mixture proportions *for review by the Engineer.*

5.1.5 In the absence of suitable shotcrete mixture proportioning experience, the Contractor shall use the nominal trial mixture proportions detailed in Section 5 of the Commentary section of this Guide Specification. Adoption of these nominal trial mixture proportions shall not relieve the Contractor of responsibility for meeting the performance requirements detailed in the Contract Documents.

## 5.2 Silica Fume Shotcrete

5.2.1 The silica fume content of silica fume shotcrete shall be between 5 and 15 percent by mass of cement content or *as specified in the Contract Documents*.

5.2.2 Silica fume shall be supplied and added to the mixture in either a slurry; loose, uncompacted; or partially compacted form. Densely compacted silica fume shall not be used.

5.2.3 Silica fume shall be used in conjunction with the addition of sufficient superplasticizing and water reducing admixture to control water demand of the mixture. The water demand of wet-mix silica fume shotcrete shall not exceed the water demand of a comparable Portland cement shotcrete mixture without silica fume.

## 5.3 Performance Requirements

5.3.1 Shotcrete shall conform to the performance requirements in Table 1.

**TABLE 1**
**Wet-Mix Shotcrete Performance Requirements**

| Test Description | Test Method | Age (Days) | Specified Requirement |
|---|---|---|---|
| Max. Water–Cementitious Materials Ratio | | – | 0.42 |
| Air Content–As Shot, % | ASTM C 231 | – | 5 ± 1½ |
| Slump at Discharge into Pump, mm | ASTM C 143 | – | 60 ± 20 |
| Min. Compressive Strength, MPa ($f'_c$) | ASTM C 39<br>ASTM C 42 | 7<br>28 | 28<br>35 |
| Max. Boiled Absorption, %<br>Max. Vol. of Permeable Voids, % | ASTM C 642 | 7<br>7 | 8<br>17 |
| Max. Rapid Chloride Permeability, Silica-Fume Shotcrete, Coulombs | ASTM C 1202 | 7 | 1500 |

5.3.2 For wet-mix shotcrete other than silica-fume shotcrete, *the Contract Documents shall establish* maximum permissible rapid chloride permeability coulomb limits.

5.3.3 The air content shall be determined on shotcrete shot into an air pressure meter base.

## 6.0 SUPPLY AND EQUIPMENT

### 6.1 Batching, Mixing and Supply

6.1.1 Wet-mix shotcrete shall be batched, mixed and supplied by one of the following methods:

(a) Central mixing with transit mix delivery,

(b) Transit mixing and delivery,

(c) Volumetric batching, mobile mixer unit, or

(d) Dry-bagged premix materials with water added at site.

6.1.2 Central Mixing and Supply

(a) Aggregate, cement and silica fume shall be mass batched in a central mix plant and delivered in a transit mixer in accordance with the requirements of AASHTO M 157. Water and chemical admixtures shall be volumetrically batched. Weighing equipment shall be capable of batching to the accuracy specified in ASTM C 685.

(b) Shotcrete materials shall be added in any sequence which provides uniform mixing and dispersion except that all water reducing admixtures and superplasticizers shall be in the mixer at the time of addition of silica fume powder.

(c) Transit mixers shall be free of excessive accumulations of hardened shotcrete or concrete in the drum or on the blades. Blades shall be free of excessive wear. Transit delivery shall conform to the requirements of AASHTO M 157, Section 10.

(d) One retempering with superplasticizer added directly to the transit mixture during the period of discharge

shall be permitted in order to maintain workability (slump) of shotcrete within the specified range of 60 ± 20 mm. Mixing shall continue for a minimum period of five minutes at rated mixing speed after all additions of superplasticizer to the transit mixer.

(e) All shotcrete shall be shot within 90 minutes after addition of mix water to the batch. Shotcrete loads shall be of such batch size that this requirement is met.

6.1.3 Transit Mixing and Supply

(a) The same requirements shall apply as for central mixing except that all ingredients shall be added directly to the transit mixer, instead of the central mixer. Transit mixers shall be charged to not more than 70 percent of their rated capacity, to enable efficient mixing action.

6.1.4 Volumetric Site Batching

(a) The mobile mixer unit for volumetric batching shall conform to the requirements of ASTM C 685. The equipment shall proportion materials to the tolerances specified in ASTM C 685.

(b) The equipment shall be capable of thoroughly mixing materials in sufficient quantity to maintain shotcreting continuity.

(c) The equipment shall be calibrated in accordance with the requirement of ASTM C 685 at the start of every shift or every 30 cubic meters of shotcrete batched, whichever is more frequent, using a mass batch check of the volumetric proportioning.

(d) Feed systems for all materials (cement, silica fume, aggregates, admixtures) shall be interconnected so that if one feed stops, they all stop.

(e) The equipment shall be cleaned thoroughly at least once per shift to prevent accumulation of aged material.

(f) All wet-mix shotcrete shall be applied within 90 minutes of mixing. Aged material shall be discarded and not applied in the work.

6.1.5 Dry-Bagged Premix Supply

(a) The use of dry-bagged premix supply with water addition at the site shall be permitted, provided the Contractor can demonstrate uniform mixing of the shotcrete and satisfactory conformance to all the proper performance requirements.

## 6.2 Shotcrete Placing Equipment

6.2.1 The shotcrete delivery equipment shall conform to the requirements of Sections 3.3, 3.6, and 3.7 of ACI 506R and shall be capable of delivering a steady stream of uniformly mixed material to the discharge nozzle at the proper velocity and rate of discharge.

6.2.2 The use of positive displacement pumps equipped with hydraulic or mechanically powered pistons (e.g., similar to conventional concrete piston pumps), with compressed air added at the discharge nozzle, is the preferred type of wet-mix shotcrete delivery system. Pneumatic feed guns, rotary type feed guns (similar to dry-mix guns) and peristaltic squeeze-type pumps shall only be used if the Contractor can demonstrate that they produce shotcrete meeting all the performance requirements in this document.

6.2.3 The air ring at the nozzle shall be carefully monitored for any signs of blockage of individual air holes. If non-uniform discharge of shotcrete becomes apparent, shooting shall be stopped, and the air ring cleaned or other appropriate corrective actions taken.

6.2.4 The delivery equipment shall be thoroughly cleaned at the end of each shift. Any build-up of coatings in the delivery hose and nozzle liner shall be removed. The air ring and nozzle shall be regularly inspected and replaced as required.

## 6.3 Auxiliary Shotcrete Equipment

6.3.1 The Contractor shall supply a clean, dry air supply, capable of maintaining sufficient nozzle velocity for all parts of the work and simultaneous operation of a blowpipe.

6.3.2 The air supply system shall contain a moisture and oil trap to prevent contamination of the shotcrete.

6.3.3 Auxiliary shotcrete equipment such as delivery hose, water hose, water booster pumps, blowpipes, couplings, admixture dispensers and fiber feeders shall conform to the recommendations in Section 3.8 of ACI 506R.

## 7.0 PREPARATION FOR SHOTCRETING

### 7.1 Concrete Removal and Preparation

7.1.1 The Contractor, at the *direction of the Engineer,* shall locate and remove all loose, spalled, deteriorated and delaminated concrete. Sounding shall be used to locate delaminated areas. Care shall be exercised not to damage areas of sound concrete or reinforcing steel during concrete removal operations. Unless specifically *directed by the Engineer*, depth of removal shall not exceed 150 mm. Concrete removal shall be in accordance with a sequence approved by the Engineer.

7.1.2 Concrete removal shall be accomplished using one or more of the following methods:

a) Chipping with hand picks, chisels or light-duty pneumatic or electric chipping hammers (not to exceed 7 kg mass);

b) Scarifiers, scabblers or other suitable mechanical means; and/or

c) High-pressure (100 to 275 MPa) water jetting.

7.1.3 If sound concrete is encountered before existing reinforcing steel is exposed, the surface shall be prepared and repaired without further removal of the concrete. When corroded reinforcing steel is exposed, concrete removal shall continue until there is a minimum 20-mm clearance around the exposed, corroded reinforcing bar. Care shall be taken to not damage bond to adjacent non-exposed reinforcing steel during concrete removal processes.

7.1.4 The perimeter of all areas where concrete is removed shall be tapered at an approximately 45-degree angle, except that the outer edges of all chipped areas shall be sawcut to minimum depth of 15 mm to prevent featheredging unless otherwise approved by the Engineer.

7.1.5 After all deteriorated concrete has been removed, the repair surface to receive shotcrete shall be prepared by abrasive blast cleaning or high-pressure (100 to 275 MPa) water jetting. The repair surface shall have an adequate surface roughness determined as three peak-to-valley measurements of 5 mm within 150 mm.

7.1.6 Abrasive blast cleaning or high-pressure water jetting shall remove all fractured surface concrete and all traces of any unsound material or contaminants such as oil, grease, dirt, slurry, or any materials which could interfere with the bond of freshly placed shotcrete. Cleaned areas shall have shotcrete applied within 48 hours or shall be reblasted.

7.1.7 The requirement for abrasive blast cleaning or high-pressure water jetting may be waived by *the Engineer* where concrete removal has been performed with high-pressure water blasting and the prepared surface is free of any residual slurry or other material detrimental to adequate shotcrete bond.

7.1.8 Unless otherwise *specified in the Contract Documents*, all material removed shall become the property of the Contractor and shall be disposed of as approved by the Engineer.

## 7.2 Reinforcement

7.2.1 All corroded reinforcing steel exposed during concrete removal shall have corrosion products removed by abrasive grit blasting. The exposed reinforcing steel surface that is facing away from the sandblast nozzle shall be cleaned to remove all dust and loose particles.

7.2.2 Reinforcing steel displaying deep pitting or loss of more than 20 percent of cross-sectional area or as *specified in the Contract Documents* shall be removed and replaced or augmented with additional reinforcement, *as detailed in the Contract Documents.*

7.2.3 In cases of isolated pitting, the existing reinforcing steel need not be cut, but shall be reinforced by addition of appropriately placed reinforcing bar of suitable length *as detailed in the Contract Documents.*

7.2.4 The minimum lap splice length of all replacement and new reinforcing steel shall be as *detailed in the Contract Documents.* Such bars shall be placed in accordance with the recommendations of ACI 506R, Sections 5.4 and 5.5. In

particular, bars shall not be bundled in lapped splices, but shall be placed such that the minimum spacing around each bar is three times the maximum aggregate size or 20 mm, whichever is larger, to allow for proper encapsulation with shotcrete.

7.2.5 Intersecting reinforcing bars shall be tightly secured to each other using 1.6-mm or heavier gauge tie wire, and adequately supported to minimize vibration during shotcrete placement.

7.2.6 As an alternative to lapped splices, replacement reinforcing steel shall be welded to existing reinforcing, subject to verification of weldability of both existing and new reinforcing steel and as *specified in the Contract Documents.*

7.2.7 Welded wire mesh fabric reinforcement shall conform to the requirements of ASTM A 185 and shall be galvanized.

7.2.8 Welded wire mesh fabric shall be provided as *detailed in the Contract Documents* and at each repair area larger than 0.1 square meter if the depth of the repair exceeds 70 mm from the original dimension of the repaired member. Sheets of adjoining mesh shall be lapped by at least one and one-half spaces at all intersections, in both directions, and be securely fastened. Welded wire mesh fabric shall have a minimum shotcrete cover of 50 mm.

7.2.9 Mesh shall be fastened to preset anchors or existing reinforcing using 1.6-mm or heavier gauge tie wire, on a grid not more than 300 mm square. Large knots of tie wire which could result in sand pockets and voids during shotcreting shall be avoided.

7.2.10 The minimum clearance between installed reinforcing steel or mesh and existing concrete shall be 20 mm.

7.2.11 As an alternative to welded wire mesh fabric, steel or synthetic fiber reinforced shotcrete may be used, as *specified in the Contract Documents.* Fiber reinforced shotcrete shall only be used in conjunction with appropriate anchor and tie-back systems, as *specified by the Contract Documents.*

## 7.3 Anchors

7.3.1 Anchors shall be positioned at the spacing *detailed in the Contract Documents.* Any given area shall have a minimum of four anchors. The reinforcing shall not vibrate or deform excessively during shotcreting. Unless otherwise specified, the