Section 2424. Shotcrete

2424.01 DESCRIPTION.

A. Remove unsound concrete, prepare concrete surfaces, and apply and cure shotcrete where indicated in the contract documents and where directed by the Engineer.

B. Shotcrete is mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface. Apply Shotcrete using the Dry Mix Process. This is a process in which the dry cement aggregate mixture is carried by compressed air to the nozzle where water is interjected and the resulting mixture is jetted from the nozzle onto the surface to be shotcreted.

1. Shotcrete Mortar.
Shotcrete mortar is a top or surface layer in which the aggregate is limited to sand with a maximum nominal particle size of 1/4 inch (6.3 mm).

2. Shotcrete Concrete.
Shotcrete concrete contains fine aggregate and coarse aggregate with particle sizes in excess of 1/4 inch (6.3 mm). Procedures and quality of work are, in general, to comply with provisions of the current edition of ACI Standard 506, "Recommended Practice for Shotcreting," subject to approval of the Engineer.

2424.02 MATERIALS.

Use materials for shotcreting that meet the following requirements:

A. Portland Cement.
Meet the requirements of Section 4101, Type I.

B. Water.
Apply Section 4102.

C. Fine Aggregate.
Use natural sand meeting the requirements of Section 4110 or 4111.

D. Coarse Aggregate for Concrete.
Meet requirements of Section 4115 and the gradation requirements of Table 2424.02-1:

Table 2424.02-1: Gradation

Sieve No.	Percent Passing
3/4" (19 mm)	100
1/2" (12.5 mm)	97-100
3/8" (9.5 mm)	40-90
No. 4 (4.75 mm)	0-30
No. 200 (75 µm)	0-1.5
The maximum percent passing the No. 200 (75 µm) sieve may be increased to 2.5%, provided the agreed documented production limit is maintained at 1.0% or less, and any increase up to 2.5% is due to degradation of the parent material and not to contamination by other material.	

E. Wire Mesh.
Apply Article 4151.04. Use mesh that is 3 inches by 3 inches or 4 inches by 4 inches (75 mm by 75 mm or 100 mm by 100 mm) with nominal area of wire between 0.014 and 0.030 square inches (9 mm^2 and 19 mm^2), inclusive. Use mesh that is galvanized with a coating (minimum of 0.15 ounces per square foot (45 g/m^2)) recognized in the industry as a "regular" coating.

F. Concrete Anchors.
Furnish concrete anchors designed for use with 1/4 inch (6.4 mm) anchor bolts. Furnish 1/4 inch (6.4 mm) diameter, galvanized, hooked anchor bolts in lengths suitable for anchoring wire mesh to existing concrete.

G. Burlap.

For curing concrete use burlap that meets the requirements of Section 4104.

2424.03 CONSTRUCTION.

A. Equipment.

1. Power Driven Hand Tools.

Power driven hand tools are allowed, with the following restrictions:

a. Jack Hammers.

1) Do not use jack hammers heavier than a nominal 30 pound (14 kg) class.

2) Do not operate jack hammers or mechanical chipping tools at an angle in excess of 45 degrees measured from the surface of the concrete.

b. Chipping Hammers.

Do not use chipping hammers heavier than a nominal 15 pound (7 kg) class.

2. Hand Tools.

Provide hand tools, such as hammers and chisels, to remove final unsound concrete particles or to achieve the required depth.

3. Sand Blasting Equipment.

Use sand blasting equipment capable of removing rust, oil, and concrete laitance from the existing surface.

4. Proportioning and Mixing Equipment.

Use proportioning and mixing equipment that meets requirements of Articles 2001.20 and 2001.21, C. Use mixing equipment capable of thoroughly mixing the materials in sufficient quantity to maintain placing continuity.

5. Air Supply.

Use a compressor of adequate capacity to maintain a sufficient, constant nozzle velocity for all parts of the work while simultaneously operating a blow pipe for cleaning away rebound. Equip the air hose with a filter to prevent any oil or grease from entering the air stream.

6. Delivery Equipment.

Use delivery equipment capable of delivering a continuous, smooth supply of uniformly mixed material. Equip the nozzle with a water ring and valve to permit adjustment of the water. Maintain the water pressure at the nozzle at least 15 psi (100 kPa) greater than the air pressure. Use a nozzle capable of delivering a conical discharge stream.

B. Qualification of Operators.

1. Certification of Training and Experience.

Provide the Engineer a certified statement of training and experience in shotcreting for each of the individuals proposed to occupy the position of supervisor, shotcrete nozzle operator, and shotcrete gun operator.

2. Qualification Test.

a. Each nozzle operator, working with a certified gun operator, must pass a qualification test prior to undertaking the shotcrete application in the project work. This test serves to qualify the shotcrete operator and is to be performed prior to beginning work. The test measures the percent by weight (mass) of rebound. If the rebound is over the allowable percentage, the operator will be disqualified. Replace with an operator who can pass this test.

b. The Engineer may require additional qualification tests during the progress of the work if the quality of the shotcrete operation declines.

c. The test is as follows:

1) Erect 30 inch by 30 inch (750 mm by 750 mm) plywood board test panels horizontally, vertically, overhead, or any combination of positions depending on the anticipated corresponding shooting positions.

2) Arrange drop cloths around and over the test panel to collect the rebound.

3) The shotcrete operator is to fill the middle 18 inch by 18 inch (450 mm by 450 mm) area of the test panel with shotcrete mortar to a minimum depth of 4 inches (100 mm).

4) Determine the quantities of rebound and applied shotcrete. Compute the percent of rebound by dividing the weight (mass) of rebound by the combined weight (mass) of rebound plus the weight (mass) of the applied shotcrete.

5) The allowable percentage of rebound depends on the position of the surface and is specified in the Table 2424.03-1:

Table 2424.03-1: Maximum Rebound

Position of Surface	Maximum Allowable Percentage of Rebound by Weight (Mass)
Horizontal	15
Vertical	30
Overhead	50

d. Furnish the drop cloths, plywood, and all other material necessary for these tests.

C. Preparation of Surface for Shotcrete Repair.

1. Removals.

a. Remove concrete from each area the Engineer designates. Areas as shown in the contract documents are based on the best information available. The Engineer will determine actual areas.

b. Concrete may be removed with power or hand tools. Use only hand tools for final cleanup.

c. Extend removal at least to the level of reinforcing bars and deeper, as necessary, to remove all unsound concrete. Ensure removal allows for a minimum replacement depth of 2 inches (50 mm). Cut boundaries of removal areas to a 45 degree bevel, with no feather edges or square corners.

2. Cleaning Existing Reinforcement.

a. Use hand methods to remove pack rust.

b. Sandblast to sound metal.

c. Do not damage the reinforcement with tools. To ensure concrete will bond around the periphery of a reinforcing bar, excavate the existing concrete 3/4 inch (20 mm) clear around the bar when:

- More than one-half of an existing reinforcing bar circumference is exposed, or
- A reinforcing bar is loose and unbonded.

3. Anchorage.

The principal anchorage of shotcrete to the existing structure is to be the bond of the shotcrete to the old concrete and to exposed existing reinforcement. Provide supplemental anchorage as follows:

a. Where reinforcement has been exposed and clearance around the periphery of the bar is provided, do not add supplemental reinforcement unless existing reinforcement density and pattern are such that individual open spaces between bars are of 1.5 square foot (0.14 m^2) area or larger. For this situation, install 1/4 inch (6.4 mm) diameter hooked anchor bolts at the rate of one anchor bolt per each 1.5 square feet (0.14 m^2) of area within each open space.

b. Where existing reinforcement is not exposed to provide clearance around the bar periphery, install 1/4 inch (6.4 mm) diameter hooked anchor bolts on an approximate 1 foot by 1 foot (300 mm by 300 mm) grid spacing. For individual areas of 1 square foot (0.1 m^2) or less, install at least one anchor, although mesh will not be required.

4. Reinforcement.

For areas described in Article 2424.03, C, 3 above:

a. Ensure wire mesh is clean and free from coatings which will prevent adequate bond.

b. Fasten mesh to each anchor or to any existing exposed reinforcement, or both. Ensure wire mesh has a minimum of 3/4 inch (20 mm) clearance from the prepared surface.

c. Lap adjacent sheets of mesh at least 1.5 times the spacing of the mesh. Align laps so that parallel wires are staggered, not placed adjacent to each other.

d. Tie sheets together at 1 foot (300 mm) intervals.

e. Bend mesh extending around outside corners or re-entrant corners to template before securing to the anchorage.

f. Position all wire mesh, hook bolts, and existing reinforcement so that they will be covered by the application of at least 3/4 inch (20 mm) of shotcrete.

5. Final Preparation.
Give repair areas a final cleaning by sandblasting followed by air cleaning.

D. Proportioning and Mixing.

1. Storage and Handling.
Store and handle cement and aggregates and measure materials according to Article 2403.02, D.

2. Mix Proportions.
Determine the exact proportions of ingredients on the basis of design mix proportions and a trial application of the design mix. Once the Engineer approves, use the field determined mix in the actual application of shotcrete. Do not vary the mix without the Engineer's written approval.

3. Field Test of Design Mixes.

a. Field test design mixes by shooting one or more test panels. Shoot the first panel in the vertical position. If the first panel is satisfactory, shoot a second panel in the overhead position, if such position is applicable to the work.

b. Conduct a test for percentage of rebound with each test panel. The Engineer will:

1) Observe production of the test panel.

2) Approve or reject the mix based on observation of the placement characteristics and appearance of the completed panels.

3) Direct the testing of a new trial mix if one is necessary.

c. Use 30 inch by 30 inch (750 mm by 750 mm) plain plywood boards for test panels. Install one No. 5 (No. 15) reinforcing bar 1 inch (25 mm) from the surface of the backing board. Place this bar parallel to and 6 inches (150 mm) from one side of the panel.

d. Cover the middle 18 inch by 18 inch (450 mm by 450 mm) area with shotcrete to a minimum depth of 4 inches (100 mm), and finish.

e. Cure the test panels according to Article 2424.03, F.

f. The operator qualification tests specified in Article 2424.03, B may be conducted coincidentally with the field determination of mix for shotcrete.

4. Proportions for Shotcrete Concrete.
Set the design mix proportions for shotcrete concrete at 1 part cement to 3.5 parts aggregate. Proportion the aggregate fraction to be 40% coarse and 60% fine by volume.

5. Proportions for Shotcrete Mortar.
Set the design mix proportions for shotcrete mortar at 1 part cement to 3.5 parts fine aggregate.

6. Proportioning.

a. Proportion dry materials by weight (mass).

b. Ensure the moisture content of fine aggregates is in the range of 3% to 6% by weight (mass) and does not vary more than ± 0.5% during a day's production.

7. Mixing.

a. Do not reuse rebound materials.

b. Mix each batch for at least 1.5 minutes.

c. Clean the mixer as needed to remove all adherent material from the mixing vanes and from the drum.

d. Do not use batches in which the ingredients have been in contact with each other for 45 minutes or more.

8. Admixtures.

a. Admixtures will not be specified.

b. The Contractor may propose specific admixtures for either reducing rebound or improving the workability during finishing.

c. The Engineer may approve such admixtures provided they are incorporated in the field determination of mix.

d. Do not use admixtures containing calcium chloride or polyvinyl acetate.

E. Placing and Finishing.

1. Prewetting.
Saturate the placement area at least 1 hour before the placement of shotcrete, and keep the area damp. However, do not place shotcrete in standing water.

2. Concrete Placement.
- **a.** Apply shotcrete concrete in one or more layers to the total thickness required to restore the repair areas to original lines and section, or to construct a modified section as shown in the contract documents. Ensure each layer is 1 1/2 to 2 inches (40 mm to 50 mm) in thickness.
- **b.** Use ground lines or other suitable devices as necessary to establish true lines and section.
- **c.** Apply a wood float or broom finish to the final surface, subject to the Engineer's approval.
- **d.** The Contractor may use the following procedure in place of surface finishing shotcrete concrete as described above:
  - **1)** Follow the procedure described in 1 and 2 above, except stop the concrete filling and strike off the new concrete at about 1/2 inch (15 mm) below the final surface.
  - **2)** Change to shotcrete mortar and complete the repair, finishing the surface as described above.

3. Application Sequence.
When shotcreting a vertical face, apply all layers from bottom to top with adequate attention to preventing incorporation of rebound.

F. Curing.

1. Use wet burlap or other approved curing blankets to cover repair areas restored with shotcrete. Apply this cover immediately following finishing and leave in place for at least 7 calendar days. Maintain curing covers in a moist condition throughout this period.

2. The Contractor may submit, for the Engineer's approval, an alternate procedure to provide a wet cure through the minimum period stipulated above. Submit this procedure, together with the schedule for application, to the Engineer for approval before beginning the work.

G. Limitations of Operations.

1. Temperature.
- **a.** Apply shotcrete only when the ambient temperature is at least 40°F (4°C).
- **b.** Do not apply shotcrete to any frozen or frosted surface.
- **c.** Protect shotcrete in place from freezing throughout the curing period.

2. Rain.
- **a.** Do not apply shotcrete during periods of rain without shielding the work, the materials, and the batching and mixing facilities from the weather.
- **b.** Shield shotcrete in place from rain until the curing blankets are in place.

3. Wind.
- **a.** Provide sufficient screening or protection from wind to prevent the cement or fines from being blown out of the jet.
- **b.** Protect fresh shotcrete in place from rapid cooling or drying out by shielding from the wind or application of fog mist, or both, until curing blankets are in place.

4. Containment.
Screen the work area to:
- **a.** Contain dust and rebound materials.
- **b.** Protect nearby structures and vegetation.

5. Protection of Traffic.
Place screening between the work area and nearby traffic, as directed by the Engineer.

2424.04 METHOD OF MEASUREMENT.

Measurement of areas will be based on final surface dimensions to the nearest 0.1 foot (0.1 m). The Engineer will calculate the quantity to the nearest square foot (0.1 m^2) for each area.

2424.05 BASIS OF PAYMENT.

A. Payment for Shotcrete will be the contract unit price per square foot (square meter) for the number of square feet (square meters) placed in a satisfactory manner.

B. Payment is full compensation for:

- Preparing the surface,
- Installing anchors and reinforcement,
- Testing,
- Placing the concrete and mortar,
- Curing and protection, and
- Furnishing all materials, equipment, tools, labor, and incidentals necessary to complete the repair of the areas.