M-47

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# STANDARD SPECIFICATIONS

# FOR

# REPAIR OF CONCRETE

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United States
Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver Federal Center
Denver, Colorado 80225-0007

**Contents**

HOW TO USE THIS MANUAL

This manual is divided into 3 sections. The general requirements contained in section 1 and the concrete preparation requirements contained in section 2 always apply to each and every Reclamation concrete repair project. Section 3 consists of a number of paragraphs containing the special requirements of the various repair materials and techniques. Once a repair material/technique has been properly selected from section 3 (see "Step 4. Choose An Appropriate System" below) it should be sufficient in preparing a job specific specification to simply require that the repairs be performed in accordance with the provisions of section 1, section 2, and section 3.X of this manual. Assistance in using this manual or with any other phase of concrete repair of Reclamation structures can be obtained by contacting:

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The standard concrete repair materials and techniques described in this manual have been developed and evaluated by the Bureau of Reclamation over a period of some 90 years. Unfortunately, during this time many repair failures have occurred on Reclamation concrete structures even though very durable repair materials were specified and used. In evaluating the causes of these failures it has been learned that it is essential to consistently use a systematic approach to repairing concrete. Many such such repair systems exist and this manual will not attempt to discuss or evaluate which of these systems is best for any set of field conditions. Rather, the following repair system has been used by Reclamation over a long period of time and has been found to result in successful concrete repairs. This system, known as "The Seven Steps of Concrete Repair", is suitable for repairing both construction defects in new concrete as well as old concrete damaged by long exposure to field conditions. In using this system it is necessary to take the steps in numerical order. Quite often the first questions asked when damaged concrete is detected is "What should be used to repair this?" or "How much will the repair cost?". These are not wrong questions. Rather they are asked at the wrong time. With a systematic approach these questions are asked only when sufficient information is available to provide correct answers.

The Seven Steps of Concrete Repair

1. Determine the cause of damage
2. Evaluate the extent of damage
3. Determine the need to repair
4. Choose an appropriate repair system
5. Prepare the old concrete

6. Apply the repair system

7. Cure the repair properly

Step 1. Determine the cause of damage - It is essential to correctly determine the causes(s) of the damage to the concrete. If this is not done, or if the determination is incorrect, the cause of damage will most likely attack and deteriorate the repair. The money spent for such repairs is, thus, totally lost and larger replacement repairs become necessary at much higher cost.

Step 2. Evaluate the extent of damage - The objective of this step is to determine how much of the structure is damaged and how extensive the damage is.

Step 3. Determine the need to repair - Not all damage to concrete requires repair. Repairs should be undertaken only if they will result in longer or more economical service life, a safer structure, or necessary cosmetic improvements in the structure. This step also includes determination of when the structure can be taken out of service for repairs, an estimate of how long the repairs will take, and how to budget the costs of the repairs.

These first 3 steps are the major components of a condition survey. Only after they have properly been performed should one proceed with selecting and installing the repair materials.

Step 4. Choose an appropriate repair system - Upon completion of the first 3 steps, an appropriate repair system can be selected that takes into consideration the many factors essential to a successful repair. In a majority of the repair situations, the standard materials and methods in this specification will fully meet all repair needs. It should be recognized, however, that service conditions or special repair situations will occur where these "standard materials" will not meet the special requirements and it will be necessary to resort to "non-standard" repair materials or methods. Such materials are continually being tested and evaluated by Reclamation laboratory and field offices. They include materials that may have performed quite well in laboratory tests but have not yet been applied in the field, materials not yet having long or sufficient field service to determine service life expectancy, or newly developed commercial materials not yet tested or evaluated by Reclamation. It is appropriate to use such repair materials and techniques only when it has been determined that none of the standard repair materials will properly serve, and when it is fully understood and agreed by all involved parties that the risks associated with the use of unproven materials are justified by the expected benefits of repair success and are acceptable.

Step 5. Prepare the old concrete - The most common cause of repair failure is improper or inadequate preparation of the old concrete prior to application of the repair material. Even the best of repair materials will give poor service life if bonded to weakened or deteriorated old concrete. The provisions of section 2 of this manual provide only the minimum preparation requirements. It should be noted that each of the standard repair materials has special preparation requirements and that these requirements are listed under paragraphs f of section 3. That is, for example, the special preparation requirements for replacement concrete will

be listed under paragraphs 3.6.f while those of epoxy bonded concrete will be listed under paragraphs 3.8.f.

Step 6. Apply the repair system - Each standard and non-standard repair material has application procedures specific for that material. For example, the procedures used with replacement concrete are vastly different from those necessary for polymer concrete or epoxy bonded concrete. It is essential that proper application techniques as listed in the section 3 paragraphs g for each material be followed exactly.

Step 7. Cure the repair properly - The second most common cause of repair failures is improper or inadequate curing. Each repair material has specific curing requirements. As an example, replacement concrete benefits from long periods of water curing while latex modified concrete, currently a non-standard material, requires 24 hours water curing followed by drying to allow formation of the latex film. Polymer concrete has essentially no curing requirements while those of silica fume concrete are are exceedingly exact. Failure to achieve proper cure for the proper duration, as listed in section 3 paragraphs f, will result in loss of the repair at the final step of the process.

## SECTION 1 - GENERAL REQUIREMENTS

### 1.1 GENERAL

Concrete that is damaged from any cause; structural concrete that has cracked; concrete that is honeycombed, fractured, or otherwise defective; and concrete that, because of excessive surface depressions, must be excavated and built up to bring the surfaces to the prescribed lines, shall be repaired or replaced in accordance with these specifications and contract requirements.

The method of repair or replacement (procedure) shall be as determined and directed by the Contracting Officer.

Contract, as used herein, shall mean the contract which, by reference, these specifications are included in and made a part. Contracting Officer, as used herein, shall mean the person executing the contract on behalf of the Government, and shall include duly authorized representatives. Contractor, as used herein, shall mean the party entering into the contract with the

Government, and shall include subcontractors, suppliers, manufacturers, and agents at all tiers.

1.2 DESIGNS

Concrete mixture proportions, compressive strengths, and other design requirements shall be as specified in these specifications. Designs by the Contractor shall be subject to the approval of the Contracting Officer.

1.3 SUBMITTALS

Submittals shall be in accordance with these specifications and the contract requirements entitled "Submittal Requirements." The Contractor shall submit MSDS (Material Safety Data Sheets), approval drawings and data, repair plans, certifications, material samples, test data and samples, and other submittals as required in these specifications. The Contractor shall be responsible for the accuracy of all submittals.

Unless specified otherwise submittals shall include the original and 2 copies.

1.4 QUALITY ASSURANCE

Quality assurance shall be in accordance with the requirements of the contract entitled "Quality Assurance," and with the requirements of these specifications.

All concrete shall be repaired as necessary to produce surfaces conforming to the specified tolerances and finish requirements of the contract in which these specifications are incorporated by reference and as outlined in section 3.

If, in the opinion of the Contracting Officer, the results of concrete repair indicate that proper quality control procedures are not being consistently utilized, further repair work may be suspended in whole or in part at the discretion of the Contracting Officer. Such suspension will be effective until the Contractor demonstrates substantial improvement in quality control procedures and repair results.

a. Contractor's quality control. - In accordance with the clause in the contract entitled "Inspection of Construction," the Contractor shall be responsible for providing quality control measures to ensure compliance of the repair with these specifications. The Contractor shall implement necessary and appropriate quality control procedures to ensure that all concrete repairs conform to the requirements of these specifications.

b. Government inspection and tests. - Government inspection and tests will be in accordance with the clause in the contract entitled "Inspection of Construction," and with these specifications.

Not less than 24 hours in advance of any concrete repair, the Contractor shall inform the Contracting Officer when the concrete repairs will be performed and, unless inspection is specifically waived, the repairs shall be performed only in the presence of an authorized representative of the Contracting Officer.

c. Testing. - Except as specified in paragraphs 3.5 and 3.12 of the specifications the Contractor shall perform all tests. The Contractor shall provide all materials, equipment, and labor necessary for performing the tests at no additional cost to the Government.

d. Approval. - Approval of the repairs will be based on the inspection and testing requirements of these specifications.

e. Rejection. - Repairs that fail to meet the requirements of these specifications will be rejected.

1.5 MATERIALS AND WORKMANSHIP

a. Materials. - The Contractor shall furnish all materials for repair or maintenance of concrete and shall furnish all materials for forming, curing, and protection of the repairs, as required. All materials shall meet materials specifications as specified in section 3, and all equipment used and methods of operation for the repair or maintenance of concrete shall be subject to approval of the Contracting Officer.

The references to materials in the specifications, wherein manufacturer's products or brands are specified by "brand name or equal" purchase descriptions, are made as standards of comparison only as to type, design, character, or quality of the article required, and do not restrict the Contractor to the manufacturer's products or to the specific brands named. It shall be the responsibility of the Contractor to prove equality of materials and products to those referenced and to provide all descriptive information, test results, and other evidence as may be necessary to prove the equality of materials or products which the Contractor offers as being equal to those referenced.

b. Workmanship. - Concrete shall be repaired by skilled workmen as outlined in section 3.

1.6 SAFETY

All work shall be performed in accordance with the applicable safety and health standards, the requirements of Reclamation's "Health and Safety Standards," the contract, and these specifications. Certain additional safety precautions shall be employed to prevent skin and eye contact with chemicals, resins, or monomeric materials. Protective glasses and clothing, including rubber or plastic gloves shall be worn by all persons handling monomeric materials. All exposed skin areas shall be protected with a protective barrier cream formulated for that purpose. Barrier cream for skin protection shall be specified for the materials used and approved by a physician. Adequate ventilation shall be provided and maintained at all times during use of monomeric materials and solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. All contaminated materials such as wipes, empty containers, and waste material shall be continually deposited in containers that are protected from spillage. Spillage shall be immediately and thoroughly cleaned up and disposed of in accordance with applicable regulations.

Federal Standard No. 313, as amended, for the preparation and submission of material safety data sheets is hereby incorporated and made a part of these specifications.

In accordance with the clause in the contract entitled "Hazardous Material Identification and Material Safety Data," the Contractor shall submit a completed MSDS (Material Safety Data Sheet), Department of Labor Form OSHA-174, or GSA-approved Alternate Form A for each hazardous material as required by Federal Standard No. 313, as amended. The information in this MSDS shall be followed to assure safe use, handling, storage, and an environmentally acceptable disposal of the commodity used on the job site.

The Contractor shall submit to the Contracting Officer, not less than 30 days prior to job site delivery of each hazardous material, completed MSDS and identification and certification for the material.

1.7 REPAIR PROCEDURES

All repair or maintenance procedures shall be performed in accordance with the applicable specifications of section 3, including surface preparation, forming, finishing, and curing.

**SECTION 2 - CONCRETE PREPARATION FOR REPAIR**

Concrete to be repaired shall be prepared in accordance with the requirements of this paragraph and with the special requirements of section 3.

2.1 REMOVAL AND CLEANING

All damaged, deteriorated, loosened, or unbonded portions of existing concrete shall first be removed by water blasting, bush hammering, jack hammering, or any other approved method, with approved equipment, after which the surfaces of existing concrete shall be prepared by contained shotblasting, wet sandblasting, or water blasting to remove any microfractured surfaces resulting from the initial removal process. The surfaces shall then be cleaned and allowed to dry thoroughly, unless the specific repair technique requires application of materials to a saturated surface. Concrete removal processes involving the use of jack hammers in excess of 30 pounds, dry sandblasting, or scrabblers shall not be used without approval by the Contracting Officer. The use of acids for cleaning or preparing concrete surfaces for repair will not be permitted.

2.2 SAW CUT EDGES

The perimeters of repairs to concrete that involve concrete removal and subsequent materials replacement shall be saw cut perpendicular to the repair surface to a minimum depth of 1 inch. Featheredge repairs to concrete shall not be used.

2.3 REINFORCING STEEL

All loose scale, rust, corrosion by products, or concrete shall be removed from exposed reinforcing steel. Reinforcing steel exposed for more than one-third of its perimeter circumference shall be completely exposed to provide 1-inch minimum clearance between the steel and the concrete. Damaged or

deteriorated reinforcing steel shall be removed and replaced as directed by the Contracting Officer.

2.4 MAINTENANCE OF PREPARED SURFACES

After the concrete has been prepared and cleaned, it shall be kept in a clean, dry condition until the repair has been completed. Any contamination, including oil, solvent, dirt accumulation, or foreign material shall be removed by additional wet sandblasting and air-water jet cleanup followed by drying.

**SECTION 3 - SPECIFICATIONS FOR REPAIRING CONCRETE**

3.1 SURFACE GRINDING

Where bulges, offsets, and other irregularities exceed the specified tolerances, the protrusions shall be repaired so that the surfaces are within the specified limits. Surface grinding techniques may be used for this purpose subject to the following limitations:

a. Grinding of surfaces subject to cavitation erosion (hydraulic surfaces subject to flow velocities exceeding 40 feet per second) shall be limited in depth so that no aggregate particles are exposed more than 1/16 inch in cross section at the finished surface.

b. Grinding of surfaces exposed to public view shall be limited in depth so that no aggregate particles are exposed more than 1/4 inch in cross section at the finished surface.

c. Grinding of all other surfaces shall be as directed by the Contracting Officer. In no event shall surface grinding result in exposure of more than one-half the diameter of the maximum-size aggregate.

d. Where surface grinding has caused or will cause exposure of aggregate particles greater than the limits of subparagraph 3.1.a. or b., the concrete shall be repaired by excavating and replacing the concrete in accordance with paragraph 3.6 or 3.8. as directed by the Contracting Officer.

3.2 PORTLAND CEMENT MORTAR

a. General. - Repairs with portland cement mortar shall be made only if specifically approved by the Contracting Officer. Approval for hand-applied cement mortar repairs will be given only for very small repair areas not associated with critical performance of the structure. When approved, portland cement mortar may be used for repairing defects on exposed, new concrete surfaces if the defects are small and are too wide for dry pack and too shallow for concrete replacement and only if the repairs can be completed within 24 hours of removing the forms. Portland cement mortar shall not be used for repairs to old or existing concrete or for repairs that extend to or below the first layer of reinforcing steel.

b. Submittals. - Before beginning any repair work, the Contractor shall submit a detailed list of the equipment, procedures, and materials the Contractor proposes to use for cement mortar repair to the Contracting Officer for approval.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - Portland cement mortar shall consist of type I or type II portland cement, clean water, and clean, well-graded sand passing a 1.18-mm (No. 16) sieve. All mortar materials, including curing compound shall meet the requirements of subparagraph 3.6.d.

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6.

f. Concrete preparation. - After damaged or defective concrete has been removed as specified in section 2, the surface on which mortar is to be placed shall be prepared by being thoroughly cleaned of all micro fractured, loose, or deteriorated materials and surface-dried.

g. Application and Mixture Proportioning. - Portland cement mortar shall be composed of portland cement, sand, and water, all well mixed and brought to proper consistency. Mortar mixtures and application techniques shall be in accordance with the requirements for mortar replacement method as described in Reclamation's "Concrete Manual", Eighth Edition, revised, chapter VII. Cement mortar shall not be applied until approval of all submittals has been received from the Contracting Officer.

h. Curing. - All cement mortar repairs shall be water cured for 7 days following application. At no time during this initial curing period shall the mortar be allowed to dry. If drying occurs, the repair shall be removed and replaced. If the repair is removed and the original concrete is older than the maximum specified in subparagraph 3.2.a., another repair method shall be used in accordance with these specifications. Following the 7-day curing period and while the repair is still saturated, the surface of the repair shall receive two coats of wax-base (type I) or water-emulsified resin base (type II) curing compound meeting the requirements of subparagraph 3.6.d.

3.3 DRY PACK AND EPOXY BONDED DRY PACK

a. General. - The dry pack concrete repair technique shall be limited to areas that are small in width and relatively deep, such as core holes, holes left by the removal of form ties, cone-bolt and she-bolt holes, and narrow slots cut for repair of cracks. Epoxy bonded dry pack shall be used for critical repairs or for repairs expected to be exposed to severe service conditions. Dry pack shall not be used for shallow depressions where lateral restraint cannot be obtained, nor for filling behind steel reinforcement.

b. Submittals. - Before beginning any repair work, the Contractor shall submit to the Contracting Officer for approval, data for the mortar materials and as provided by paragraph 3.8.b.(2).

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - Dry pack mortar shall consist of type I or II portland cement, clean sand that will pass a 1.18-mm (No. 16) sieve, and clean water. All dry pack materials, including curing compound, shall meet the

requirements of subparagraph 3.6.d. Epoxy bonding resin shall meet the requirements of paragraph 3.8.d.(2).

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6.

f. Concrete preparation. - Holes for dry pack shall have a minimum depth of 1 inch and shall be square at the surface edge. A careful inspection shall be made to ensure that the hole is thoroughly clean and is in sound concrete. The interior surfaces of the hole shall be presoaked prior to application of the dry pack. If epoxy bonded dry pack is to be used presoaking the repair area prior to application of the dry pack shall not be performed.

g. Application. - A mortar bond coat or epoxy resin bond coat shall be applied to the concrete hole surface prior to placing dry pack. The mortar bond coat shall consist of 1 part portland cement to 1 part sand mixed with water to give a fluid paste consistency. The mortar bond coat shall be thoroughly brushed onto the hole surfaces. The epoxy resin bond coat shall consist of materials and be applied in accordance with the provisions of paragraph 3.8.g.(3). Dry pack mortar shall consist of 1 part portland cement to 2.5 parts sand (by weight) and shall be mixed with just enough water so that the mortar will stick together when molded by hand and not exude water when squeezed.

The dry-pack mortar shall be immediately packed into place in 3/8-inch compacted layers before the bond coat has dried or cured.

Each layer shall be compacted over the entire surface by tamping with a hardwood dowel and hammer. Hardwood dowels are used in preference to metal bars because the bars tend to polish the surface of each layer. The final layer shall be finished immediately after compaction by laying the flat side of a hardwood board against the fill and striking the board firmly with a hammer.

h. Curing. - Proper curing is essential for a successful dry-pack repair. The surface of the repair area shall be protected from drying and shall be kept continuously moist for 7 days. The surface of the repair shall be protected from surface drying by using burlap kept wet, wet sand, or plastic sheeting over a water soaker hose, or other methods approved by the Contracting Officer. After 7 days and while the surface is still damp, two coats of curing compound shall be applied to prevent moisture loss. The dry-pack repair area shall not be exposed to freezing temperatures for 3 days after application of the curing compound.

## 3.4 PREPLACED AGGREGATE CONCRETE

a. General. -

(1) Preplaced aggregate concrete (PAC) is concrete that has been made by forcing a grout into the voids of a mass of clean, graded, coarse aggregate. As a repair method, PAC is used where placing conventional concrete is extremely difficult, such as in underwater repairs, concrete and masonry repairs, or where shrinkage of concrete must be kept to a minimum. In underwater repairs, injection of grout at the bottom of the

PAC displaces water, leaving a homogeneous mass of concrete with a minimum of paste washout.

For the purpose of this repair method, grout is defined as a mixture of water, cementitious materials, sand, and admixtures.

(2) Reference standards and specifications for PAC. - Reference standards and specifications for materials, testing, and proportioning PAC shall be the standards listed below. Standards and specifications for testing concrete and concrete materials shall be in accordance with applicable ASTM and ACI standards.

(a) ASTM C 937 - Standard Specification for Grout Fluidifier for Preplaced-Aggregate Concrete.

(b) ASTM C 938 - Standard Practice for Proportioning Grout Mixtures for Preplaced-Aggregate Concrete.

(c) ASTM C 939 - Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method).

(d) ASTM C 940 - Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory.

(e) ASTM C 941 - Standard Test Method for Water Retentivity of Grout Mixtures for Preplaced-Aggregate Concrete in the Laboratory.

(f) ASTM C 942 - Standard Test Method for Compressive Strength of Grouts for Preplaced-Aggregate Concrete in the Laboratory.

(g) ASTM C 943 - Standard Practice for Making Test Cylinders and Prisms for Determining Strength and Density of Preplaced-Aggregate Concrete in the Laboratory.

(h) ASTM C 953 - Standard Test Method for Time of Setting of Grouts for Preplaced-Aggregate Concrete in the Laboratory.

(i) American Concrete Institute Standard (ACI-304), Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete.

b. Submittals. -

(1) At least 60 days prior to beginning repair work, the Contractor shall submit for approval a repair plan for PAC construction. The repair plan shall include detailed drawings of formwork construction, the grout injection system including sequence of injecting grout into insert pipes, location and spacing of injection tubes, sounding wells, and pipes; a description of all equipment including pumps, sizes and diameters of pipes, hoses, and connections; the planned operating procedures and pumping rates for grout; methods of placing coarse aggregate; methods of consolidating aggregates and PAC during grouting; and communication facilities between the grout mixing and pumping plant and PAC placement.

The proportions of grout mixtures and fresh properties of grout shall be submitted with the repair plan. Included with the grout proportions, shall be the voids content and compacted density of aggregates before injection of grout, the density of hardened PAC, and the compressive strengths of PAC at 7 and 28 days' age.

(2) The Contractor shall submit for approval to the Contracting Officer's representative a proposed specific operating procedure including a hazard analysis for all preplaced aggregate concreting and grout injecting operations. The specific operating procedure shall include such things as engineering controls, protective clothing, eye protection, respiratory protection, and air sampling as necessary to check the effectiveness of the control program.

(3) Pump rating curves and complete mixer details, including photographs or drawings of the proposed mixing equipment, shall be submitted to the Contracting Officer for approval 30 days prior to use. The Contracting Officer shall have the right to require the Contractor to make changes in the equipment which the Contracting Officer determines necessary to make the equipment perform satisfactorily during the grouting operations without additional cost to the Government

(4) The Contractor shall submit test results from testing of cylinders in accordance with the requirements of subparagraph c. below.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. Unless otherwise directed, grout mixtures shall be proportioned in accordance with ASTM C 938.

For normal structural work, the ratio of cementitious materials (cement plus pozzolan) to sand shall be 1:1. If leaner mixes are required (generally for low heat generation), the ratio may be adjusted, but shall not exceed 1:2.

The ratio of cement to pozzolan, by weight, shall be between 2:1 and 4:1 as directed by the Contracting Officer.

The ratio of water to cementitious materials

$$\frac{W}{P+C}$$

where:
W = weight of water
P = weight of pozzolan
C = weight of concrete

shall not exceed 0.50 by weight. For severe exposure conditions, the W/P+C ratio shall be in accordance with Reclamation's "Concrete Manual," Eighth Edition, revised, chapter III, table 15.

The pumpability of grout containing fine sand (grading 1, table 2 of ASTM C 637) shall be controlled by the consistency test using the flow cone in accordance with ASTM C 939. The flow time shall be between 20 and 30 seconds unless it can be demonstrated that grout can be effectively pumped at a different flow time.

Compressive strength cylinders shall be cast in accordance with ASTM C 943 and tested at 7 and 28 days' age with a minimum of two cylinders tested for each age. The design compressive strength of PAC shall be 4,000 pounds per square inch at 28 days' age. The required average strength for PAC is that which will ensure that 80 percent of all test cylinders exceed the design strength.

The quality of the top of formed PAC placements shall be ensured by venting air, water, and low-quality grout from the uppermost location in the placement.

For unformed surfaces where a screeded or troweled finish is required, the grout level shall flood the top surface above any aggregate, and any diluted grout shall be removed by brooming. A thin layer of pea gravel having a maximum-size aggregate (MSA) of 3/8 inch shall be worked into the surface by raking and tamping or internal vibration. The surface shall be finished in accordance with conventional concrete procedures to resemble the finish of the surrounding concrete. Care shall be taken when topping off the unformed surface to avoid lifting or loosening of the surface aggregate.

d. Materials. - Materials for PAC shall be in accordance with the requirements of ASTM C 938 and the following additional requirements:

(1) Pozzolan. - Pozzolan shall meet the requirements of ASTM C 618 for class F pozzolan.

(2) Admixtures. -

(a) Air-entraining admixture. - Air-entraining admixture (AEA) shall meet the requirements of ASTM C 260.

The amount of AEA used for injecting mortar shall be that amount necessary to effect a total air content in the mortar, prior to injection, of 9 percent, plus or minus 1 percent, by volume of mortar.

(b) Grout fluidifier. - Grout fluidifier shall meet the requirements of ASTM C 937.

(c) Chemical admixtures. - Chemical admixtures, if permitted, shall meet the requirements of ASTM C 494 for types A, D, F, or G admixtures. Chemical admixtures shall not be used without prior approval from the Contracting Officer.

(3) Sand. - Sand shall consist of natural particles which may be supplemented by limited quantities of crushed sand to make up for deficiencies in the natural materials. Natural sand is required due to its favorable particle shape for pumping grout. Sand for PAC differs from sand used for conventional concrete, primarily in its finer grading.

Sand shall meet the quality requirements of subparagraph 3.6.d.; and the grading requirements of ASTM C 938.

(4) Coarse aggregate . - Coarse aggregate shall be clean and well-graded. Unless otherwise directed, the MSA shall be 1-1/2 inches, and after compaction in the forms, shall have a voids content from 35 to 45 percent.

Coarse aggregate shall meet the quality requirements of subparagraph 3.6.d.; and, the grading requirements of ASTM C 637, table 2, grading 1 for coarse aggregate.

For larger placements, the largest size aggregate that can economically be placed shall be used. The MSA and grading of coarse aggregate for these placements should follow the guidelines of ACI 304.

e. Safety. - All work shall be performed in accordance with requirements of paragraph 1.6 and these specifications.

The Contractor shall comply with Reclamation's "Construction Safety Standards" as well as all other applicable safety and health standards and regulations. In the event of conflict, the more stringent standard shall apply.

f. Concrete preparation. - The Contractor shall prepare all concrete surfaces and foundations for PAC application. Concrete surface preparation shall be in accordance with subparagraph 3.6.f.

For underwater repairs, high-pressure water jetting shall be the normal method for concrete removal and surface scarification. Low-pressure water jetting will be allowed for cleanup immediately before placing PAC.

In underwater construction where contamination is known or suspected to exist, the water shall be sampled and tested to determine the degree of contamination and its possible influence on the quality of concrete. Where moderate contamination is present, concrete surfaces shall be cleaned within 2 days prior to placing aggregate and grouting. If contaminants are present in such quantity or are of such character that harmful effects cannot be eliminated or controlled, preplaced aggregate concrete shall not be used.

All loose, fine material shall be removed from the placement insofar as possible before placement of coarse aggregate to prevent subsequent coating of the aggregate or filling of voids.

g. Application. -

(1) General. - Application of PAC shall include construction and placement of formwork and the grout injection system, placement of aggregate, injection of grout, finishing, and curing of PAC.

(2) Equipment. - The grout mixing, pumping, and injection system shall be furnished by the Contractor.

The grout injection system shall be designed to deliver and inject grout into the preplaced aggregate, to provide a means for determining the grout elevations within the aggregate mass, and to provide vents in enclosed forms for water and air to escape. The injection system shall have a bypass for returning grout to an agitating tank.

Pumps shall be of a positive displacement type and be equipped with a pressure gauge on the outlet line to indicate any incipient line blockage. At least one extra pump shall be on standby to maintain continuous pumping operations. The pumps shall have quick-disconnecting fittings to the grout supply line.

Mixing and agitating equipment shall be sized to maintain a continuous, uninterrupted flow of grouting mortar for the duration of the PAC placement. The mixing plant shall be a high-speed centrifugal type and shall be equipped with an accurate water meter, reading cubic feet to tenths of a cubic foot. In addition to the grout mixer, a holdover mechanical agitator tank of similar volume as the mixer shall be provided. Suitable provisions shall be made for passing the grout through a U.S. Standard 2.36-mm (No. 8) sieve as it is discharged from the mixer.

The batching and mixing plant equipment shall accurately measure the amounts of cement, pozzolan, sand, admixtures, and water batched for grout. Inaccuracies in feeding and measuring during operation shall not exceed by individual weight plus or minus 1 percent for water; plus or minus 2 percent for cement, pozzolan, or sand; and plus or minus 3 percent for admixtures.

The length of delivery line shall be kept to a practicable minimum. Pipe sizes shall be designed so that during operation, the grout velocity ranges between 2 and 4 feet per second for delivery lines up to 300 feet, or at a pumping rate of about 1 cubic foot of grout per minute through a 1-inch-diameter pipe. Pipe sizes shall be approximately 1 inch in diameter, but may need to be increased in size for delivery lines longer than 300 feet to reduce pressures.

Grout insert pipes shall have a diameter of 3/4 to 1 inch and shall be placed vertically, horizontally, or at angles to inject grout at the proper location. Grout insert pipes shall be in sections about 5-1/2 feet in length for ease of withdrawal. For depths greater than 15 feet, grout insert pipes shall be flushed coupled. For depths less than 15 feet, standard pipe couplings may be used.

Connections between grout delivery lines and insert pipes shall have quick-disconnect fittings. Quick-disconnect fittings which reduce the cross section of the flow area shall not be used. Each insert pipe, or the end of the delivery line where it attaches to the insert pipe, shall be equipped with an individual valve to control or stop the flow of grout. Valves shall be of a quick-opening, plug type which can readily be cleaned.

For vertical and angled injection tube placements, sounding wells shall be used to determine the level of grout in the placement. Sounding wells shall consist of slotted pipe with a diameter of about 2 inches. A 1-inch-diameter float, weighted so that it will float on grout and sink in water (for underwater placements), shall be attached to a sounding line and float freely in the sounding well.

(3) Formwork. - Forms for PAC may be of wood, steel, or other materials suitable for conventional concrete. Wood forms or other materials which

may swell or become damaged by submergence in water shall not be used for underwater repairs.

Joints and any entry holes for bolts, reinforcement, injection ports, vents, or injection wells shall be caulked to eliminate grout leakage.

Forms shall be designed to resist the lateral pressure exerted by aggregates during and after placing, and to resist full hydraulic pressure of the concrete throughout placing until initial setting has begun.

Form vibrators for consolidation shall be mounted so that vibration does not loosen bolts and joints which may lead to grout leakage or failure. Form vibrators shall be mounted on ribs or stiffeners attached to the sheathing to effectively transmit vibration to the concrete.

All forms shall be coated with a suitable bond breaker for ease of removal without damaging concrete. For underwater repairs, the bond breaker shall be selected so that it does not wash off the forms during submergence. Formwork, injection tubing, inspection wells, and other equipment shall be protected from damage by aggregates during placing.

Reinforcing steel shall be installed during construction of formwork and securely held in place during placement of aggregate and injection of grout.

(4) Grout pipe system. - The grout pipe system shall be furnished by the Contractor and shall consist of a series of regularly spaced injection tubes with outlets beginning at the bottom and continuing to the top of the compacted aggregates. Observation wells shall be spaced at regular intervals between the injection tubes. Vent pipes shall be used in forms that contain restricted or irregular spaces where water or air may be entrapped by the rising grout surface, such as blockouts or embedment work.

The grout pipe system shall be designed to inject grout beginning at the lowest point in the PAC placement and continue to raise the grout level within the mass by selectively withdrawing the pipes and switching to other pipes to maintain the grout at a gently sloping to nearly horizontal level. The grout pipe system shall be coded to clearly identify the location of the outlet of the pipe supplying grout and the order of supplying grout to the pipes.

The spacing of grout insert pipes shall be between 4 and 12 feet and should average approximately 6 feet. The outlet of grout insert pipes shall begin not more than 6 inches above the bottom of the aggregate mass. Rows of horizontal pipes should be not more than 6 inches above the next lower row of pipes.

As a guide for layout of insert pipes, it can be assumed that the grout surface will have a 1:4 (vertical to horizontal) slope in the dry and a l:6 slope under water.

For vertical and inclined injection systems, sounding wells shall be spaced to observe the level of grout. The ratio of number of sounding

wells to insert pipes shall be between 1:4 and not less than 1:10. Sounding wells shall be placed vertically or near vertically.

The delivery line shall consist of a single pipeline extending from the pump to the insert pipe equipped with a valve, or to a wye branching to two insert pipes equipped with valves at the beginning of the wye and at both outlets. A manifold system in which more than one grout insert is operative at the same time shall not be used.

(5) Aggregate preparation and placement. - Coarse aggregate shall be washed and screened immediately before placing in the forms. If more than one size of coarse aggregate is used, the aggregate shall be batched and mixed in the proper proportions or discharged at proportional rates onto a vibrating deck or revolving wash screens.

Coarse aggregate shall be transported to the forms by buckets, conveyors, or other approved methods. Coarse aggregates shall be dumped as close as possible to their final location. A flexible rubber elephant trunk (tremie) shall be used to limit free fall to less than 5 feet to minimize segregation and breakage of aggregate. For large placements, a gated pipe with a diameter at least four times the MSA shall be used. The pipe shall be gradually filled and lowered toward the point of placement, and after the pipe is completely filled at the upper end, aggregate shall be discharged from the lower gate. Aggregate shall not be discharged through an unfilled or partially filled pipe.

Coarse aggregate shall be dumped and spread in nearly horizontal lifts, each lift not to exceed 1 foot in height. Around closely spaced embedded items, such as reinforcing steel, conduits, and blockouts, and in more difficult placements where high density and exceptional homogeneity of concrete are desired, the lift height shall be limited to no more than 4 inches and may have to be placed by hand. Vehicular traffic shall not be permitted on top of preplaced coarse aggregate, with the exception of small skips or loaders and only with approval of the Contracting Officer. This equipment shall have rubber tires and be cleaned of any loose debris or substances that may contaminate aggregates or interfere with grout travel during injection.

Although coarse aggregate shall be completely washed prior to placing it shall not be flushed with water in the forms for the purpose of washing.

If water is used for the purpose of precooling aggregate or to provide lubrication for grout, the water shall be injected through the preplaced grout insert pipes rather than on top of the aggregates.

(6) Grout injection. - Injection shall begin at the lowest insert pipe point within the form and continue to raise the level of grout evenly to the top of the mass of aggregate. The injection process shall raise the level of grout approximately 18 to 24 inches above the outlet of the insert pipe before withdrawing of that pipe begins. Thereafter, the level of grout shall remain a minimum of 12 inches above the outlet of the insert pipe until the injection is completed.

Grouting shall proceed at only one insert pipe at a time. If a wye or manifold system is used, the system shall be equipped with individual valves to control the flow to each insert pipe.

Before the insert pipe is withdrawn, the valve at the pipe inlet shall be shut off. The delivery pipe may then be disconnected to inject at other locations.

When injection insert pipes are placed horizontally, the process shall begin at the lowest insert pipe. Adjacent insert pipes shall have valves opened both alongside and above the pipe being injected. When grout begins to flow out of these pipes, they shall be shut off and grouting continued so that the adjacent pipes are completely submerged. The initial pipe shall then be shut and the process shall be repeated, traveling in a horizontal direction before proceeding to the upper row.

Grout shall not be allowed to set up in the insert pipes between injections. If the injection process is expected to continue for an extended period, a suitable retarding admixture shall be used in the grout. Vertical insert pipes may be rodded to remove grout prior to reinjection; however, insert pipes shall not be cleaned by injecting water through them.

The rate of grout rise and rate of grout injection shall be controlled within the form so that excessive form pressures are not created and so that grout does not cascade within the mass. This is particularly important when grouting under water to avoid sand streaks and honeycombing within the mass.

When grouting around embedded items and particularly under flat surfaces or recessed areas, the grout shall be injected until good quality grout is forced from vent pipes. Good quality grout shall be grout that is not diluted and free from sand, silt, trash, and other items. The rate of flow of grout and grout injection pressures shall be closely monitored in enclosed locations to avoid form failure.

Form vibration shall be used to consolidate grout and remove entrapped air pockets adjacent to form surfaces. Excessive form vibration which causes sand streaking shall not be done. Internal vibration shall not be used for consolidation of the aggregate-grout mixture, but may be used for topping off unformed surfaces.

Unplanned construction joints shall not be used without approval from the Contracting Officer. If a breakdown occurs that stops placement, the grout insert tubes shall be withdrawn, and the grout surface shall be considered a cold joint. Cold joints shall be treated by first removing coarse aggregate down to the joint surface, removing aggregate and poor-quality mortar, and then cleaning the joint surface by approved methods, taking care not to undercut exposed aggregates.

h. Curing. - Curing and protection of PAC shall be in accordance with subparagraph 3.6.h.

## 3.5 SHOTCRETE

a. General. - Shotcrete is defined as pneumatically applied concrete or mortar placed directly onto a surface. The shotcrete shall be composed of water, cementitious materials, sand, coarse aggregate, steel fibers (if specified), and admixtures, and shall be placed by either the dry-mix or wet-mix process as specified herein.

The dry-mix process shall consist of thoroughly mixing the solid materials; feeding these materials into a mechanical feeder or gun; carrying the materials by compressed air through a hose to a special nozzle; introducing the water and intimately mixing it with the other ingredients at the nozzle; and then jetting the mixture from the nozzle at high velocity onto the surface to receive the shotcrete.

The wet-mix process shall consist of thoroughly mixing all the ingredients with the exception of the accelerating admixture, if used; feeding the mixture into the delivery equipment; delivering the mixture by positive displacement or compressed air to the nozzle; and then jetting the mixture from the nozzle at high velocity onto the surface to receive the shotcrete.

The equipment used by the Contractor for mixing and applying shotcrete shall be capable of handling and applying shotcrete containing the specified maximum-size coarse aggregate. All equipment, including mixers, hoses, nozzles, nozzle liners, air- and water-pressure gauges, and gaskets, shall be maintained in clean and proper operating condition satisfactory to the Contracting Officer.

b. Submittals. - The Contractor shall submit for approval to the Contracting Officer a proposed specific operating procedure including a hazard analysis for all shotcrete operations. The specific operating procedure shall include such things as engineering controls, protective clothing, eye protection, respiratory protection, and air sampling as necessary to check the effectiveness of the control program.

The Contractor shall submit the specimens extracted from panels fabricated for preapplication testing.

The Contractor shall submit test specimens of fresh and hardened concrete from locations directed by the Contracting Officer.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. The Government will perform all testing of fresh and hardened shotcrete. The Contractor shall obtain specimens from locations specified by the Government. The compressive strength of the shotcrete will be determined through the medium of tests of 3- by 3-inch cores or 3-inch cubes. The average compressive strength of specimens taken from a shotcrete application shall be not less than:

(1) Four thousand pounds per square inch at 28 days' age.

(2) Six hundred pounds per square inch at 8 hours' age. This will be determined from 3-inch cubes extracted from test panels.

Adjustments shall be made as directed by the Contracting Officer to obtain shotcrete having suitable impermeability, strength, density, and durability. Suitable strength is that which will ensure that 80 percent of all test specimens exceed or equal the average strength as specified above.

(3) Preapplication testing of shotcrete and nozzlemen. - No shotcrete shall be applied to the work until preapplication testing indicates that the nozzleman is qualified and the proposed shotcrete mixture meets the specified compressive strength. The Contractor shall allow adequate lead time for fabricating of test panels and testing shotcrete

specimens. Furthermore, the Contractor is encouraged to fabricate panels for several mixtures since failure of a single mixture to meet specified strength requirements could delay accomplishment of other work.

(a) Shotcrete mixture. - At least 30 days prior to application of shotcrete to the work, the Contractor shall fabricate two test panels for each mixture to be used for vertical and overhead positions of application.

Application of shotcrete to test panels may be accomplished at locations other than the construction site provided:

(aa) Equipment used for fabricating test panels is identical to that to be used in application.

(bb) The materials used in fabricating test panels are from the same sources as those to be used in application and meet all specifications requirements.

(cc) Application is made in the presence of the Contracting Officer by a nozzleman who will later apply the shotcrete to the work.

Test panels shall be fabricated by applying shotcrete in one application not less than 4 inches thick to a panel form made of plywood or other suitable material.

The panel form to be used for vertical and overhead applications shall be either of two types as follows:

(dd) Open ended on at least two sides with 90E edges on enclosed sides. The minimum size of this open-ended panel shall be 18 inches square.

(ee) Enclosed on all four sides with members that taper outward in a manner that prevents the accumulation of rebound at edges and corners while allowing a shotcrete thickness of not less than 4 inches over the entire flat area of the panel. The minimum size of the center flat area of panels enclosed by tapered edges shall be 15 inches square.

Panels should be stiffened and weighted sufficiently to provide rigid surfaces against which the shotcrete can be applied. The panels shall contain the same type of reinforcement as to be used in construction to indicate whether sound shotcrete is obtained without shadowing behind the reinforcement.

After fabrication, the panel shall, except when test specimens are being obtained, be covered and sealed with polyethylene sheeting or shall be cured by any other approved method that will prevent loss of moisture.

The Contractor shall provide all necessary equipment and shall obtain 3-inch cubes from the test panels for testing the compressive strength at 8 hours' age and shall obtain 3-inch cubes or 3-inch-diameter cores from test panels for testing the compressive strength at 28 days' age.

All core drilling and saw cutting of cubes shall be performed in a workmanlike manner by competent and experienced workmen. Test specimens shall be extracted at the latest time, satisfactory to the Contracting Officer, that the specimens can be delivered by the Contractor to the Government for testing at the specified age. At least five specimens shall be obtained from each of the panels for each mixture being verified. Extreme care shall be taken in drilling cores or cutting cubes to obtain specimens satisfactory to the Contracting Officer.

Cores shall be 3 inches in diameter, drilled the full depth of the shotcrete; they shall be straight, sound, of uniform diameter, and of sufficient length for subsequent trimming by the Contractor to produce a right cylinder with an L/D ratio of 1.0 plus or minus 0.03.

Cubes shall be cut full depth of the shotcrete, shall be sound, and shall have six uniform square sides of 3-inch length plus or minus 0.05 inch.

Immediately after extraction, test specimens shall be individually wrapped and sealed in polyethylene bags or covered and sealed by any other approved means to prevent loss of moisture. Each test specimen shall be properly marked for identification.

Each set of test specimens shall be delivered without delay to the project laboratory, or other location approved by the Contracting Officer, for testing at the specified age.

(b) Shotcrete nozzleman. - The nozzleman who applies shotcrete shall be certified with the materials and equipment to be used for the work. Certification shall be in accordance with ACI 506.3R with the following limitations:

(aa) The certification examination will be conducted by authorized representative of the Contracting Officer.

(bb) The examination will consist of an oral test and a field workmanship demonstration test.

(cc) The test panels shall be a minimum of 18 inches square and 4 inches deep. The sides may have beveled edge forms (45E angle out to reduce the entrapment of rebound in the corners).

(dd) Test specimens shall be of the size and shape specified for quality control in these specifications.

d. Materials. -

(1) Portland cement. - The cementitious materials in shotcrete shall comply with subparagraph 3.6.d.(1), with the exception that type III cement may be approved for use if sulfate conditions do not exist.

(2) Water. - Water shall be in accordance with subparagraph 3.6.d.(4).

(3) Sand and coarse aggregate. - Except as hereinafter provided for coarse aggregate grading, the sand and coarse aggregate shall be in accordance with subparagraph 3.6.d.(5).

The maximum-size coarse aggregate shall be no larger than 3/8 inch. No material retained on the 3/8-inch sieve shall be permitted. Only 3 percent significant undersize aggregate material that will pass a 4.75-mm (No. 4) U.S. Standard sieve will be permitted.

(4) Admixtures. - Admixtures shall be in accordance with subparagraph 3.6.d.(3).

(a) Accelerator. - The Contractor may use an accelerating admixture in shotcrete.

(b) Air-entraining admixture. - The amount of air-entraining admixture used for the wet-mix process shall be that amount necessary to effect a total air content in the shotcrete, prior to application, of 7 percent plus or minus 1 percent by volume of shotcrete.

(5) Steel fibers. - Where directed by the Contracting Officer, the Contractor shall furnish steel fibers for reinforcement. The amount of steel fibers used shall be 90 pounds of fiber per cubic yard of shotcrete.

Steel fibers shall be carbon steel deformed type I (cold drawn wire) or type II (cut sheet) to conform to the requirements of ASTM A 820. Length of steel fiber shall be 3/4-inch minimum to 1-1/4-inch maximum. The length divided by diameter (or equivalent diameter), or aspect ratio, shall be 45 minimum and 100 maximum. The steel fiber shall have a minimum average tensile strength of 50,000 pound-force per square inch.

(6) Curing compounds. - Curing compounds shall meet the applicable requirements of subparagraph 3.6.d.(6).

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6.

f. Concrete preparation. - Concrete to be repaired with shotcrete shall be prepared in accordance with section 2.

g. Application. -

(1) Mixture proportions. - The proportions of water, cementitious materials, sand, coarse aggregate, and admixture and fibers, if used, shall be determined by the Contractor subject to approval by the Contracting Officer to obtain the specified compressive strength and bond. The shotcrete shall have a minimum cementitious materials content of 658 pounds per cubic yard, as discharged from the nozzle. Furthermore, the amount of cementitious materials will be increased by the Contracting Officer as necessary to obtain the specified compressive strengths and bond.

(2) Consistency. - The consistency of the dry-mix process shotcrete shall be regulated by the amount of water introduced at the nozzle and shall be adjusted so that the in-place shotcrete is adequately compacted and neither sags nor shows excessive rebound.

The consistency of the wet-mix process shotcrete at the delivery point shall not exceed a 3-inch slump.

(3) Batching. - Batching for the dry-mix process shall be as specified in this paragraph. Water, cementitious materials, sand, coarse aggregate, admixture, and fibers shall be volume proportioned by controlled, calibrated, screw conveyor, or other methods of feed, provided uniform proportions are obtained. The equipment shall be capable of controlling the delivery of material so that inaccuracies do not exceed 1 percent for water; 1-1/2 percent for cementitious materials; 2 percent for sand and coarse aggregate; and 3 percent for admixture and fibers. If these limits cannot be consistently met, then batching shall be by direct weighing.

To ensure accurate, consistent proportioning of aggregate, augers used in dry-mix process shotcrete delivery equipment shall be constructed of abrasion-resistant material to prevent rapid and excessive wear. Auger feed shall be recalibrated as necessary to keep them within the prescribed batching accuracy percent.

The percentage of surface moisture in the sand (ASTM C 566) shall be 3 to 6 percent, by weight, and shall be controlled within this range as may be necessary to maintain uniform feed and to avoid choking the delivery equipment.

Shotcrete batches containing cementitious materials that have been in contact with damp aggregate or other moisture for more than 2 hours shall be wasted at the Contractor's expense.

Batching for the wet-mix process shall be in accordance with the requirements for concrete batching under subparagraph 3.6.g.

When batching with fibers the Contractor shall obtain a good blend of fibers throughout the shotcrete. The Contractor shall furnish appropriate equipment or develop a suitable technique for dispersing the fibers in the mixer free of fiber clumps. A suggested guide is ACI 544.3R.

(4) Mixing. - Mixing for the wet-mix and the dry-mix process shall be as specified in this paragraph. Cementitious materials, sand, coarse aggregate, admixtures, and steel fibers shall be uniformly added and thoroughly mixed by machine before being fed into the delivery equipment.

Mixers used to mix dry ingredients shall discharge the batch without segregation. Mixers shall be tested for uniformity of coarse aggregate content from front to back of the mixer. The maximum permissible difference in percentage of coarse aggregate by weight of sample shall not exceed 6 percent within a batch.

The discharge nozzle for the dry-mix process shall be equipped with a manually operated water injection system of sufficient pressure to provide an even distribution of water into the dry shotcrete mixture at the nozzle. The water valve shall be capable of ready adjustment to vary the quantity of water and shall be convenient to the nozzleman.

(5) Placing. - Placing shotcrete shall be performed only by a nozzleman certified in accordance with subparagraph 3.5.c.(3) during preapplication testing.

An air compressor with ample capacity to provide clean, dry air and maintain a uniform nozzle velocity shall be used for applying shotcrete.

The shotcrete shall be applied by pneumatic pressure from a discharge nozzle held about 2 to 5 feet from the surface and in a stream as nearly normal as possible to the surface being covered. The nozzle shall also be rapidly gyrated while applying the shotcrete.

The shotcrete shall be applied in layers having a thickness that will ensure complete adherence of the shotcrete to the surface. Any shotcrete that shows evidence of sloughing or separation shall be removed and replaced by and at the expense of the Contractor and to the satisfaction of the Contracting Officer.

Care shall be taken to prevent the formation of sand pockets in the shotcrete. Any sand pockets formed shall be removed immediately and replaced with suitable shotcrete at the expense of the Contractor.

Use of rebound as shotcrete aggregate is not permitted, and rebound accumulations shall be removed and disposed of at the expense of the Contractor as approved by the Contracting Officer.

The temperature of shotcrete, as placed, shall be between 50 and 90 EF. Shotcrete shall not be applied to frozen surfaces. The applied shotcrete shall be kept at a temperature of at least 50 EF for a minimum of 3 days immediately following application. When cold weather conditions prevail at the job site and the temperature of aggregates and water is below 50 EF, it may be necessary to heat the aggregate and/or water prior to use in the shotcrete to obtain shotcrete meeting the specified 28-day compressive strength.

The Contractor shall provide and maintain sufficient standby equipment to assure continuous production and application of shotcrete.

If, in the Contracting Officer's opinion, the shotcreting system selected by the Contractor fails to provide satisfactory in-place shotcrete in accordance with these specifications, the Contractor shall change to another system of either of the two processes, provide a redemonstration of the nozzleman's proficiency, or provide a new qualified nozzleman.

If, in the Contracting Officer's opinion, the projection of steel fibers (when used) on the face of the finished shotcrete creates a hazard to personnel, a sacrificial coating of no less than 1/2-inch thickness of shotcrete without the steel fibers shall be applied.

h. Curing. - Shotcrete that is applied where the ambient relative humidity is 85 percent or above will not require measures to control the evaporation of water during curing. However, the Contractor shall substantiate that the relative humidity level in the area of application is above 85 percent by furnishing, installing, and maintaining equipment capable of continuously recording relative humidity.

When the relative humidity is less than 85 percent, the Contractor shall initiate an approved curing method immediately after application of the shotcrete.

Curing shall be accomplished by either:

(1) Raising and maintaining the ambient relative humidity above 85 percent, or

(2) Applying a membrane curing compound as specified in subparagraph 3.6.d.(6).

Water curing. - Shotcrete cured with water shall meet the applicable requirements of subparagraph 3.6.h. except the 14-day requirement may be reduced to 7 days.

3.6 CONCRETE REPLACEMENT

a. General. - Concrete replacement shall be used on areas of damaged or unacceptable concrete greater than 1 square foot having a depth greater than 6 inches or a depth extending 1 inch below or behind the backside of reinforcement. Concrete replacement shall also be used for holes extending entirely through concrete sections and for large areas of repair greater than 4 inches in depth when the concrete to be repaired is less than 7 days old. Epoxy bonding agents, latex bonding agents, dry neat cement, cement paste, or cement and sand mortar shall not be used to bond fresh concrete to concrete being repaired by this method.

b. Submittals. - The Contractor shall submit certification of compliance for materials in accordance with subparagraph d. below.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - All concrete materials shall be obtained from previously tested and approved sources. Materials will be accepted on certificate of compliance with the following ASTM Standards:

(1) Portland cement. - Portland cement shall meet the requirements of ASTM C 150 for type I, II, or V cement. The specific cement type shall be as directed by the Contracting Officer and determined by the environment in which the repair is conducted.

(2) Pozzolan. - Pozzolan shall meet the requirements of ASTM C 618 for class F pozzolan.

(3) Admixtures. - The Contractor shall furnish air-entraining and chemical admixtures for use in concrete.

(a) Air-entraining admixture shall be used in all concrete and shall conform to ASTM C 260.

(b) Chemical admixtures. - The Contractor may use type A, D, F, or G chemical admixtures. If used, they shall conform to ASTM C 494.

(4) Water. - The water used in making and curing concrete shall be free from objectionable quantities of silt, organic matter, salts, and other impurities.

(5) Aggregate. - The term "sand" is used to designate aggregate in which the maximum size particle will pass a 4.75-mm (No. 4) sieve. The term "coarse aggregate" is used to designate all aggregate which can be retained on a 4.75-mm (No. 4) sieve. Sand and coarse aggregate meeting the requirements of ASTM C 33 shall be used in all concrete.

(6) Curing compound. - Wax-base (type I) and water-emulsified resin-base (type II) curing compounds shall conform to the requirements of Reclamation's "Specifications for Concrete Curing Compound" (M-30) dated October 1, 1980.

e. Safety. - All work shall be performed in accordance with paragraph 1.6.

f. Concrete preparation. - After damaged or unacceptable concrete has been removed as specified in section 2. the surface on which the replacement concrete will be placed shall be prepared. An acceptable surface shall have the appearance of freshly broken, properly cured concrete. The surface shall be free of any deleterious materials such as free moisture, ice, petroleum products, mud, dust, carbonation, and rust. The perimeters of the repair shall be saw cut to a minimum depth of 1 inch.

The clean surface is not ready to receive repair concrete until it has been brought to a saturated, surface-dry condition. This condition is attained by saturating the surface to a depth that no concrete mixture water may be absorbed from the fresh concrete. Then, just prior to placing concrete against the surface, all free moisture (moisture capable of reflecting light) shall be removed from the prepared surface.

g. Application. - Replacement concrete shall be composed of cement, coarse aggregate, sand, water, and approved admixtures, all well mixed and brought to the proper consistency. Concrete mixtures shall be proportioned in accordance with Reclamation's "Concrete Manual", Eighth Edition, revised, chapter III. The water-cement ratio of the concrete (exclusive of water absorbed by the aggregates) shall not exceed 0.47 by weight. Slump of the concrete, when placed, shall not exceed 2 inches for concrete in slabs that are horizontal or nearly horizontal and 3 inches for all other concrete. Concrete with less slump should be used when it is practicable to do so. The concrete ingredients shall be thoroughly mixed in a batch mixer. The concrete, as discharged from the mixer, shall be uniform in composition and consistency from batch to batch.

(1) Forms. - Forms shall be used for concrete whenever necessary to confine the concrete and shape it to the required lines. The forms shall be clean and free from encrustations of mortar, grout, or other foreign material. Before concrete is placed, the surfaces of the forms shall be coated with a form oil that will effectively prevent sticking and will not soften or stain the concrete surfaces or cause the surfaces to become chalky or dust producing.

(2) Placing. - Placing of concrete shall be performed only in the presence of an authorized representative of the Contracting Officer. Placement shall not begin until all preparations are complete and the

authorized representative of the Contracting Officer has approved the preparations. Concrete shall not be placed in standing or running water unless, as determined by the Contracting Officer, the structure under repair cannot be economically dewatered. If underwater concrete placement is required, special placing procedures shall be required. A suggested guide is ACI 394R.

When appropriate, concrete shall be placed in layers not greater than 20 inches thick. Each layer, regardless of the thickness, shall be adequately consolidated using immersion-type vibrators or form vibrators when approved. Adequate consolidation of concrete is obtained when all undesirable air voids, including the air voids trapped against forms and construction joints, have been removed from the concrete.

(3) Finishing. - The class of finish required shall be a finish closely resembling the finish of the surrounding concrete.

h. Curing and protection. - Concrete repairs shall be cured either by water curing or by use of wax-base (type I) or water-emulsified resin-base (type II) curing compound meeting the requirements of subparagraph 3.6.d.(6). Daily inspection by the Contractor shall be performed to ensure the maintenance of a continuous, water-retaining film over the repaired area. The water-retaining film shall be maintained for 28 days after the concrete has been placed.

Water curing shall commence when the concrete has attained sufficient set to prevent detrimental effects to the concrete surface. The concrete surface shall be kept continuously wet for 14 days.

The Contractor shall protect all concrete against damage until acceptance by the Government. Whenever freezing temperatures are imminent, the Contractor shall maintain the newly placed repair concrete at a temperature of not less than 50 EF for 72 hours. Water-cured concrete shall be protected from freezing for the duration of the curing cycle and an additional 72 hours after the water is removed.

## 3.7 EPOXY-BONDED EPOXY MORTAR

a. General. - Epoxy-bonded epoxy mortar is defined as freshly mixed epoxy mortar (sand with epoxy binder) that is placed over an epoxy resin bond coat on hardened existing concrete. Epoxy-bonded epoxy mortar repair may be used when the depth of repair is 1-1/2 inches or less. This method may also be used for repair of areas with a depth greater than 1-1/2 inches when those areas are small (less than 1 square foot) and few in number, and where it is impractical to use epoxy-bonded concrete.

Epoxy-bonded epoxy mortar may be used only when:

(1) Moisture in the structure will not collect behind the bond coat and cause damage upon freezing, and

(2) The repair will not be subjected to extremes of temperatures such as those caused by exposure to direct sunlight, extremes of climate, or extremes in water temperature.

All epoxy-bonded epoxy mortar repairs to new construction shall be performed after 7 days from the original placement.

b. Submittals. -

(1) When directed by the Contracting Officer, the Contractor shall submit samples of the epoxy-resin bonding system. The samples shall be submitted at least 30 days prior to use in the work to the Bureau of Reclamation, Attn D-8180, Building 56, Denver Federal Center, West Sixth Avenue and Kipling Street, Denver CO 80225.

(2) Certification of epoxy-bonding agent. - The Contractor shall furnish the Contracting Officer the manufacturer's certification of conformance of the epoxy-resin bonding system with these specifications. The certification shall identify the Reclamation solicitation/ specifications number(s) under which the epoxy is to be used and shall include the quantity represented, the batch numbers of the resin and curing agent, and the manufacturer's results of tests performed on the particular combination of resin and curing agent.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) Epoxy resin. - The same epoxy resin system shall be used for both the bond coat and the epoxy mortar. The epoxy resin shall meet the requirements of specifications ASTM C 881 for a type I , grade 2, class B or C or a type III, grade 2, class B or C epoxy system. In addition, it shall be a 100-percent solids system, and no unreactive diluents, wetting agents, or volatile solvents shall be incorporated.

(2) Sand. - The sand for epoxy mortar shall be clean, dry, well-graded sand composed of sound particles passing a 1.18-mm (No. 16) sieve and conform to the following limits:

| Sieve | Individual percent, by weight, retained on sieve |
|---|---|
| 600 µm (No. 30) | 26 to 36 |
| 300 µm (No. 50) | 18 to 28 |
| 150 µm (No. 100) | 11 to 21 |
| pan | [1]25 to 35 |

[1]Range shown is applicable when 60 to 100 percent of pan is retained on the 75 µm (No. 200) sieve. When 0 to 59 percent of pan is retained on the 75 µm (No. 200) sieve, the percent pan shall be within the range of 10 to 20 percent, and the individual percentages retained on the 600 µm, 300 µm, and 150 µm (Nos. 30, 50, and 100) sieves shall be increased proportionately.

Sand of this grading is not usually commercially available and may have to be produced by the Contractor. Starting with a concrete sand, the oversized particles shall be removed with a 1.18-mm (No. 16) sieve. Individual sieve sizes of sand can be purchased to mix with the remaining sand to meet the required grading. Most sands require at least the addition of more pan material to meet the required grading.

When directed, minor adjustments in sand grading shall be made to provide a suitable epoxy mortar. Other fillers or commercially available sand gradings prepared specifically for epoxy mortars may be used in epoxy mortar on approval by the Contracting Officer.

The sand shall be maintained in a dry area at no less than 60 EF temperature for 24 hours immediately prior to time of use.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 of these specifications. Certain additional safety precautions shall be employed when using uncured epoxy materials. Skin contact with uncured epoxy shall be avoided. Protective clothing, including rubber or plastic gloves, shall be worn by all persons handling epoxy materials. All exposed skin areas that may come in contact with the material shall be protected with a protective barrier cream formulated for that purpose. Adequate ventilation shall be provided and maintained at all times during use of epoxy and epoxy solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. If spray application is used, the operator shall wear a compressed air-fed hood, and no other personnel shall be closer than 100 feet if downwind of the operator when spraying is being performed. All epoxy-contaminated materials such as wipes, empty containers, and waste material shall be continually disposed of in containers which are protected from spillage. Epoxy spillage shall be immediately and thoroughly cleaned up. Appropriate solvents may be used to clean tools and spray guns, but in no case shall the solvents be incorporated in any epoxy resin or in the placing operation. Solvents shall not be used to remove epoxy materials from skin. Only soap, water, and rags shall be used for this purpose.

All tools shall be completely dried after cleaning and before reuse. All materials, tools, and containers contaminated with epoxy resin or epoxy curing agent shall be removed from the site for disposal in accordance with appropriate local or Federal regulations.

f. Concrete preparation. - Surface preparation and needed removal of existing concrete shall be as in section 2, except that the saw cut shall be 1 inch or equal to the depth of the repair, whichever is less. For repairs less than 1 square foot in area, the required vertical edge may be accomplished with a pneumatic tool or hydrodemolition equipment in lieu of saw cutting. For minor cosmetic repairs of surface defects less than 2 inches in diameter, surface preparation may be limited to cleaning with a small wire brush, removing dust, and heating in depth. Epoxy paste meeting the requirements of ASTM C 881, grade 3, may be used without a bond coat for minor cosmetic repairs of surface defects less than 2 inches in diameter in lieu of epoxy-bonded epoxy mortar when all of the conditions for use of epoxy mortar are met. Any overfilling of minor surface defects shall be removed by grinding after hardening is complete. Where repairs are exposed to public view, color matching of the repair material to the existing concrete shall be done.

The surfaces of the existing concrete to which epoxy mortar is to be epoxy bonded shall be prepared and maintained in a clean and dry condition. Unless epoxy mortar application to wet concrete surfaces is approved by the Contracting Officer. The existing concrete shall be preheated in depth. Preheating shall be sufficient to drive internal moisture from the repair surface and prevent its return until the bond coat is in place. Preheating shall not cause damage to or instant setting of the bond coat.

g. Application. -

(1) Forms. - Forms shall be used as necessary to prevent slumping or sagging of finished epoxy-bonded epoxy mortar. Such forms shall be covered with polyethylene film, and form oil shall not be used.

(2) Preparation of epoxy resin for bond coat. - The epoxy resin is a two-component material which requires combination of components and mixing prior to use. Once mixed, the material has a limited pot life and must be used immediately. The bonding system shall be prepared by adding the curing component to the resin component in the proportions recommended by the manufacturer, followed by thorough mixing. Since the working life of the mixture depends on the temperature (longer at lower temperature, much shorter at higher temperature), the quantity to be mixed at one time shall be applied and topped within approximately 30 minutes. The addition of thinners or diluents to the resin mixture shall not be done. Both components of class C epoxy shall be stored above 60 EF prior to use.

(3) Application of epoxy resin bond coat for epoxy-bonded epoxy mortar. - Immediately after the epoxy resin is mixed, it shall be applied to the prepared, dry existing concrete at a coverage of not more than 80 square feet per gallon, depending on surface conditions. The area of coverage per gallon of agent depends on the roughness of the surface to be covered and may be considerably less than the maximum specified. The epoxy resin may be applied by any convenient, safe method such as squeegee, brushes, or rollers, which will yield an

effective coverage, except that spraying of the materials will be permitted only if an efficient airless spray is used and when the concrete surfaces to receive the agent are 70 EF or warmer, which spray shall be demonstrated as providing an adequate job with minimum overspray prior to approval of its use.

Care shall be exercised to confine the epoxy resin to the area being bonded and to avoid contamination of adjacent surfaces. However, the epoxy bond coat shall extend slightly beyond the edges of the repair area.

Steel to be embedded in epoxy mortar shall be coated with epoxy resin. The steel shall be prepared in accordance with the requirements of section 2 and by removing all loose rust either with a wire brush or by wet sandblasting. The exposed steel shall be completely coated with epoxy resin at the time it is being applied to the concrete surfaces of the repair area.

The applied epoxy resin film shall be in a fluid condition at the time the epoxy mortar is placed. The epoxy resin may be allowed to stiffen to a very tacky condition rather than a fluid condition before epoxy mortar is placed on steep sloping or vertical surfaces, in which case special care shall be taken to thoroughly compact the epoxy mortar against the stiffening bond coat. In the event the bond coat is curing too quickly to meet the placement requirements, a second bond coat shall be applied over the first while the first bond coat is still tacky. If any bond coat has cured beyond the tacky state, it shall be completely removed by sandblasting, and proper cleanup, heating, and drying shall be accomplished and a new bond coat applied.

(4) Placing and finishing. - The epoxy mortar shall be composed of sand and epoxy resin suitably blended to provide a stiff, workable mixture. The epoxy components shall be mixed thoroughly prior to the application of the bond coat and prior to the addition of the sand. The mixture proportions shall be established, batched, and reported on a weight basis, provided that the dry sand and mixed epoxy may be batched by volume using suitable measuring containers that have been calibrated on a weight basis. If equivalent volume proportions are being used, care shall be taken to prevent confusing them with weight proportions. Epoxy mortar will require approximately 5-1/2 to 6 parts of graded sand to 1 part epoxy, by weight. The Contracting Officer will determine, and adjust where necessary, the mix proportions for the particular epoxy and sand being used. The epoxy mortar shall be thoroughly mixed with a slow-speed mechanical stirrer or other equipment producing equivalent results. The mortar shall be mixed in small-sized batches so that each batch will be completely mixed and placed within approximately 30 minutes from the time the two components for the epoxy resin are combined. The addition of thinners or diluents to the mortar mixture will not be permitted.

The prepared epoxy mortar shall be tamped, flattened, and smoothed into place in all areas while the epoxy bond coat is still in a fluid condition. The mortar shall be worked to grade and given a steel trowel finish. Special care shall be taken at the edges of the area being repaired to ensure complete filling and leveling and to prevent the mortar from being spread over surfaces not having the epoxy bond coat

application. Steel troweling shall be performed in a manner to best suit the prevailing conditions but, in general, shall be performed by applying slow, even strokes. Trowels may be heated to facilitate the finishing. The use of thinner, diluents, water, or other lubricant on placing or finishing tools will not be permitted, except for final cleanup of tools. After leveling of the epoxy mortar to the finished grade where precision surfaces are required, the mortar shall be covered with plywood panels smoothly lined with polyethylene sheeting and weighted with sandbags or otherwise braced, or by other means acceptable to the Contracting Officer, until danger from slumping has passed. When polyethylene sheeting is used, no attempt shall be made to remove it from the epoxy mortar repair before final hardening.

Epoxy-bonded epoxy mortar repairs shall be finished to the plane of the surfaces adjoining the repair areas. The final finished surfaces shall match the texture of the surfaces adjoining the repair areas.

h. Curing and protection. - Epoxy-mortar repairs shall be cured immediately after completion of each repair area at not less than 60 EF until the mortar is hard. Post curing shall then be initiated at elevated temperatures by heating, in depth, the epoxy mortar and the concrete beneath the repair. Post curing shall continue for a minimum of 4 hours at a surface temperature not less than 90 EF nor more than 110 EF, or for a minimum of 24 hours at a surface temperature not less than 60 EF nor more than 110 EF. The heat shall be supplied by using portable propane-fired heaters, infrared heat lamps, or other approved methods capable of producing the required temperature and positioned so that the required surface temperatures are obtained.

In no case shall epoxy-bonded epoxy mortar be subjected to moisture until after the specified post curing has been completed.

## 3.8 EPOXY-BONDED CONCRETE

a. General - Epoxy-bonded concrete is defined as freshly mixed portland cement concrete that is placed over a fluid epoxy resin bond coat on hardened existing concrete. Epoxy-bonded concrete repair may be used when the depth of repair is 1-1/2 inches or greater.

b. Submittals. -

(1) When directed by the Contracting Officer, the Contractor shall submit samples of the epoxy-resin bonding system. The samples shall be submitted at least 30 days prior to use in the work to the Bureau of Reclamation, Attn D-3731, Building 56, Denver Federal Center, West Sixth Avenue and Kipling Street, Denver CO 80225.

(2) Certification of epoxy-bonding agent. - The Contractor shall furnish the Contracting Officer the manufacturer's certification of conformance of the epoxy-resin bonding system with these specifications. The certification shall identify the Reclamation solicitation/ specifications number(s) under which the epoxy is to be used and shall include the quantity represented, the batch numbers of the resin and curing agent, and the manufacturer's results of tests performed on the particular combination of resin and curing agent.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) Concrete materials. - The materials and procedures used to prepare and mix concrete for epoxy-bonded concrete repair shall be as specified in subparagraph 3.6.d. except that slump of concrete, when placed, shall not exceed 1-1/2 inches.

(2) Epoxy resin. - The epoxy-resin bonding system shall meet the requirements of specification, ASTM C 881 for a type II, grade 2, class B or C epoxy system. In addition, it shall be a 100-percent solids system and shall not contain unreactive diluents or wetting agents. Volatile solvents shall not be incorporated into the epoxy system.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications. Certain additional safety precautions shall be employed when using uncured epoxy materials. Skin contact with uncured epoxy shall be avoided. Protective clothing, including rubber or plastic gloves, shall be worn by all persons handling epoxy materials. All exposed skin areas that may come in contact with the material shall be protected with a protective barrier cream formulated for that purpose. Adequate ventilation shall be provided and maintained at all times during use of epoxy and epoxy solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. All epoxy-contaminated materials such as wipes, empty containers, and waste material shall be continually disposed of in containers which are protected from spillage. Epoxy spillage shall be immediately and thoroughly cleaned up. Appropriate solvents may be used to clean tools and spray guns, but in no case shall the solvents be incorporated in any epoxy resin or in the placing operation. Solvents shall not be used to remove epoxy materials from skin. Only soap, water, and rags shall be used for this purpose.

All tools shall be completely dried after cleaning and before reuse.

All materials, tools, and containers contaminated with epoxy resin or epoxy curing agent shall be removed from the site for disposal in accordance with appropriate local or Federal regulations.

f. Concrete preparation. - Concrete to be repaired by epoxy-bonded concrete shall be prepared in accordance with the provisions of section 2, except that the perimeters of the repair shall be saw cut to a minimum depth of 1 inch. Epoxy-bonded concrete shall not be applied to concrete surfaces at a surface temperature less than 60 EF nor greater than 90 EF.

g. Application of epoxy-bonded concrete. -

(1) Forms. - Forms shall be used for epoxy-bonded concrete whenever necessary to confine the concrete and shape it to the required lines. The forms shall have sufficient strength to withstand the pressure resulting from placing operations, shall be maintained rigidly in position, and shall be sufficiently tight to prevent loss of mortar from the concrete.

(2) Preparation of epoxy resin. - The epoxy resin is a two-component material which requires combination of components and mixing prior to use. Once mixed, the material has a limited pot life and must be used immediately. The bonding system shall be prepared by adding the curing component to the resin component in the proportions recommended by the manufacturer, followed by thorough mixing. Since the working life of the mixture depends on the temperature (longer at lower temperature, much shorter at higher temperature), the quantity to be mixed at one time shall be applied and topped within approximately 30 minutes. The addition of thinners or diluents to the resin mixture will not be permitted. Both components of class C epoxy shall be at 60 EF prior to use.

(3) Application of epoxy resin bond coat for surface repairs. - Immediately after the epoxy resin is mixed, it shall be applied to the prepared, dry existing concrete at a coverage of not more than 80 square feet per gallon, depending on surface conditions. The area of coverage per gallon of agent depends on the roughness of the surface to be covered and may be considerably less than the maximum specified. The epoxy resin may be applied by any convenient, safe method such as squeegee, brushes, or rollers, which will yield an effective coverage, except that spraying of the materials will be permitted only if an efficient airless spray is used and when the concrete surfaces to receive the agent are 70 EF or warmer, which spray shall be demonstrated as providing an adequate job with minimum overspray prior to approval of its use. If spray application is used, the operator shall wear a compressed air-fed hood, and no other personnel shall be closer than 100 feet if downwind of the operator when spraying is being performed.

Care shall be exercised to confine the epoxy resin to the area being bonded and to avoid contamination of adjacent surfaces. However, the epoxy bond coat shall extend slightly beyond the edges of the repair area.

Steel to be embedded in epoxy-bonded concrete shall be coated with epoxy resin. The steel shall be prepared in accordance with the requirements of section 2 and in the same manner required for preparation of the concrete being repaired. The exposed steel shall be completely coated with epoxy resin at the time it is being applied to the concrete surfaces of the repair area.

The applied epoxy resin film shall be in a fluid condition at the time the concrete is placed, provided that the epoxy resin may be allowed to stiffen to a very tacky condition rather than a fluid condition before concrete is placed on steep sloping or vertical surfaces, in which case special care shall be taken to thoroughly compact the concrete against the stiffening bond coat. In the event that an applied film cures beyond the fluid condition, or a very tacky condition where permitted, before the concrete is placed, a second bond coat shall be applied while the first bond coat is still tacky. If any bond coat has cured beyond the tacky state, it shall be completely removed by sandblasting, and proper cleanup, heating, and drying shall be accomplished, and a new bond coat applied.

(4) Placing and finishing. - Use of epoxy-bonded concrete in repairs requiring forming, such as on steeply sloped or vertical surfaces, will

be permitted only when the forming required is such that the bond coat can be applied and the concrete properly placed within the time period necessary to ensure that the applied bond coat will still be fluid, or tacky where permitted.

Immediately after application of the epoxy bond coat, while the epoxy is still fluid, concrete shall be spread evenly to a level slightly above grade and compacted thoroughly by vibrating, tamping, or both. Vibrators shall not be permitted to penetrate through the fresh concrete to the level of the fluid epoxy bond coat. Such vibration can emulsify the epoxy and reduce the bond. Tampers shall be sufficiently heavy for thorough compaction. After being compacted and screeded, the concrete shall be given a wood float or steel trowel finish, as directed. Troweling, if required, shall result in a smooth, dense finish that is free from defects and blemishes. As the concrete continues to harden, the surface shall be given successive trowelings. The final troweling shall be performed after the surface has hardened to such an extent that no cement paste will adhere to the edge of the trowel. The number of trowelings and time at which trowelings are performed shall be subject to approval of the Contracting Officer.

The surfaces of epoxy-bonded concrete repairs shall be finished to the plane of the surfaces adjoining the repair areas. The final finished surfaces shall match the texture of the surfaces adjoining the repair areas.

h. Curing and protection. - The Contractor shall cure and protect all repairs from damage until acceptance by the Government. Concrete shall be protected against freezing for not less than 6 days from time of placement.

As soon as the epoxy-bonded concrete has hardened sufficiently to prevent damage, the surface shall be moistened by spraying lightly with water and then covering with sheet polyethylene, or by applying an approved curing compound, provided that curing compound shall be used for curing concrete whenever there is any possibility that freezing temperatures will prevail during the curing period. Sheet polyethylene, if used, shall be an airtight, nonstaining, waterproof covering which will effectively prevent loss of moisture from the concrete by evaporation. Edges of the polyethylene shall be lapped and sealed. The waterproof covering shall be left in place for not less than 14 days.

If a waterproof covering is used and the concrete is to be subjected to any use that might rupture or otherwise damage the covering during the curing period, the covering shall be protected by a suitable layer of clean wet sand or other cushioning material that will not stain concrete, as approved by the Contracting Officer. Application of curing compound, if used, shall be in accordance with Reclamation's "Specifications for Concrete Curing Compound, M-30." After the curing has been accomplished, the covering, except curing compound if used, and all foreign material shall be removed and disposed of as directed.

## 3.9 POLYMER CONCRETE SYSTEMS

a. General. - Polymer concrete repair systems for concrete may be either of two types: a methacrylate monomer system, or a vinyl ester resin system. These materials may be used for patches, overlays, grout pads, and

embedment of sills, gates, and similar structures in concrete members. Prior approval of the Contracting Officer is required for applications where the repair is exposed to the direct rays of the sun or subjected to rapid temperature changes in excess of 10 EF per hour for more than a 3-hour period. The materials may be supplied as a prepackaged system or as components for a system designed for use as polymer concrete.

The polymer concrete system shall consist of a 100-percent reactive monomer or resin system (no nonreactive diluents or solvents are permitted); an initiator for polymerization of the resin or monomer system, a promoter to activate the initiator; aggregate; and a primer system to be applied to the surface of the concrete to be repaired. The system shall be supplied with or without pigments to approximate the color of concrete, as directed by the Contracting Officer.

b. Submittals. - Before starting work, the Contractor shall submit to the Contracting Officer for approval the following documents:

(1) A safety plan.

(2) A statement of technical qualifications, training, and past experience in handling and applying polymer concrete materials.

(3) A manufacturer's affidavit that states the chemical constituents and proportions of the material, a Materials Data Safety Sheet for each component, the use for which the material is designed, instructions on storage and use of the materials, and typical mechanical and physical properties of the final product.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) Monomer and resin systems. -

(a) Methacrylate monomer systems. - The monomer system may be based on either methyl methacrylate monomer or on high molecular weight methacrylate monomer systems. The monomer system shall consist of 100-percent reactive components, and no nonreactive diluents or solvents shall be permitted. The initiator shall be an organic peroxide. The promoter shall be either a cobalt salt or an organic amine compound. Materials shall be used in the proportions recommended by the manufacturer for the temperature conditions at the job site to meet the pot life and curing time requirements of these specifications.

(b) Vinyl ester resin systems. - The vinyl ester resin shall be an elastomer-modified dimethacrylate diglycidyl ether of bisphenol A and shall be Dow Chemical Company Derakane 8084; or equal having the following salient characteristics:

| | |
|---|---|
| Liquid Resin Properties | |
| Styrene content | 45 percent by weight |
| Viscosity, Brookfield (cps), 77 EF | 1,200 |

Flash point, cc, (EF) 82

Clear Casting Properties

| | |
|---|---|
| Tensile strength, ($lb/in^2$) | 10,000 |
| Tensile modulus ($lb/in^2$) | 430,000 |
| Elongation, percent | 10 |
| Flexural strength, ($lb/in^2$) | 16,000 |
| Flexural modulus, ($lb/in^2$) | 420,000 |
| Heat distortion temperature (EF) | 170 |

The initiator shall be an organic peroxide and the promoter shall be cobalt napthenate or cobalt octoate. Materials shall be used in the proportions recommended by the manufacturer for the temperature conditions at the job site to meet the pot life and curing time requirements of these specifications.

(2) Aggregates. -

(a) Prepackaged systems. - Prepackaged systems normally contain a preblended fine aggregate. The use of additional fine aggregate shall not be permitted in these systems unless specifically authorized by the manufacturer. Prepackaged systems that do not contain a preblended fine aggregate shall use a fine aggregate meeting the requirements of subparagraph 3.9.d.(2)(b). Prepackaged polymer concrete systems may be extended by the addition of coarse aggregate. The maximum size of the coarse aggregate shall not exceed the lesser of either one-third of the depth of the repair or 1-1/2 inches. The coarse aggregate shall be composed of hard, dense, clean durable, well-graded rock particles.

(b) Separate component polymer concrete systems. - The aggregate shall be composed of hard, dense, clean, durable, well-graded rock particles. Not more than 2 percent by weight of the fine aggregate shall pass the 75 µm (No. 200) sieve, and the maximum aggregate size shall not be greater than one-third the depth of the repair. The grading shall be based on the following guide:

| Nominal size fraction | Aggregate grading percent retained by weight | | | | | |
|---|---|---|---|---|---|---|
| 9.5 - 19.0 mm (3/8 - 3/4 inch) | -- | -- | -- | -- | -- | 29 |
| 4.75 - 9.5 mm (No. 4 - 3/8 inch) | -- | -- | -- | -- | 29 | 20 |
| 2.36 - 4.75 mm (No. 8 - No. 4) | -- | -- | -- | 29 | 21 | 16 |
| 1.18 - 2.36 mm (No. 16 - No. 8) | -- | -- | 31 | 21 | 16 | 10 |
| 600 µm - 1.18 mm (No. 30 - No. 16) | -- | 31 | 22 | 15 | 10 | 7 |
| 300 - 600 µm (No. 50 - No. 30) | 50 | 23 | 16 | 10 | 7 | 5 |

| Nominal size fraction | Aggregate grading percent retained by weight | | | | | |
|---|---|---|---|---|---|---|
| 150 - 300 µm (No. 100 - No. 50) | 30 | 16 | 10 | 8 | 4 | |
| *Pan | 20 | 30 | 21 | 17 | 13 | 9 |

*NOTE: Pan material shall consist of:
1. Minus 75 µm (No. 200) sieve size ground silica, or
2. Minus 75 µm (No. 200) sieve size crushed hard, dense, durable, clean rock washed free of clay and organic impurities, or
3. A mixture of 1 or 2 above with 50% fly ash.

(3) Coupling agent. - The coupling agent incorporated into the monomer or resin system shall be an organosilane compound, Union Carbide A-174, or equal.

(4) Primer. - The polymer concrete shall be applied to a prepared and primed concrete surface. The primer shall consist of either a methyl methacrylate monomer system, a high molecular weight methacrylate monomer system, or an elastomer-modified vinyl ester resin system (Dow Chemical Company Derakane 8084, or equal). The same monomer or resin system used in the polymer concrete is acceptable as a primer. The polymer concrete shall be applied to a primed surface while the primer is still tacky and has not completely cured to a hard and dry finish, with the exception of methyl methacrylate polymer concrete systems applied to a methyl methacrylate primer system which does not contain cross-linking comonomers which may be applied to a cured and dry primed surface. The primer system shall be formulated according to the manufacturer's instructions to give adequate pot life for the job site temperature conditions for proper application of the polymer concrete.

(5) Polymer concrete properties. - The polymer concrete shall have the following properties:

(a) Curing time of 1 to 3 hours at ambient temperature (substrate and air) of 32 to 100 EF.

(b) Pot life of 15 to 30 minutes at ambient temperatures of 32 to 100 EF.

(c) Compressive strength of at least 7,000 lb/in$^2$. (ASTM C 39).

(d) Splitting tensile strength of at least 1,000 lb/in$^2$. (ASTM C 496).

(e) Linear shrinkage, less than 0.05%.

(f) Bond strength to concrete - at least equal to the splitting tensile strength of the base concrete.

e. Safety. - All work shall be performed in accordance with requirements of paragraph 1.6 and these specifications. The Contractor shall also:

(1) Hold a safety meeting at the job site conducted by an industrial hygienist or by a technically qualified professional staff member to acquaint and instruct all workers and supervisors on the job in the proper care and handling of the polymer concrete materials as specified by the manufacturer of the polymer concrete, safety precautions to be observed, personal protective gear, and protection of the environment.

(2) Require all workers, supervisors, inspectors, visitors, and other people at the job site to wear personal protective gear as directed by the Contracting Officer.

(3) Ensure that the polymer concrete materials are stored, handled, and applied in the manner specified by the manufacturer. In addition:

(a) Storage. - polymer concrete materials shall be stored in the shipping containers in a well-ventilated area and out of the direct rays of the sun. The storage temperature shall not exceed 80 EF (27 EC). Materials shall not be stored longer than 3 months.

(b) Mixing and application. - No smoking, flame, or other ignition sources shall be permitted during mixing and application. Type B or type ABC fire extinguishers shall be provided at the mixing and application sites. Electrical equipment in contact with the polymer concrete should be grounded for safe discharge of static electricity.
(c) Handling. - Workers shall be provided and required to wear rubber boots, disposable protective clothing, splash-type safety goggles, rubber gloves, and organic vapor respirators as directed by the Contracting Officer. A heated eye wash capable of sustaining a 15-minute stream of clean, room temperature water shall be provided at the mixer and at the application site. Materials coming into direct contact with the skin shall be immediately removed using soap and water.

(4) Prevent the contamination of soil or water at the job site by liquid components.

(5) Dispose of liquid components and excess materials at the job site by combining the materials in the same manner and procedure used for mixing polymer concrete, placing the mixed materials in an open container, and allowing the material to harden. Hardened polymer concrete is nonpolluting and may be disposed of as a solid nonhazardous waste.

f. Concrete preparation. - In addition to the requirements of section 2, the concrete surface shall be dry and primed with an approved primer. The primer and the polymer concrete shall not be applied until the surface preparation meets the approval of the Contracting Officer. The dryness of the surface shall be determined by taping a sheet of transparent polyethylene sheeting to the surface and exposing it to the full rays of the sun for at least 4 hours and observing the interior surface of the polyethylene sheeting for the occurrence of condensed moisture. As an alternative method, a calibrated moisture meter which meets the approval of the Contracting Officer may be used to determine the dryness of the surface.

g. Preparation and application requirements. -

(1) Initiator and promoter. - The initiator and promoter shall be prebatched and packaged separately from each other in a manner so that the two components cannot be combined until the time of the concrete mixing operation. The promoter shall be combined with the monomer or resin system prior to the addition of the initiator. UNDER NO CIRCUMSTANCES SHALL THE INITIATOR BE ADDED TO OR DIRECTLY CONTACT THE PROMOTER. THE DIRECT COMBINATION OF PROMOTER AND INITIATOR WILL RESULT IN AN EXTREMELY VIOLENT AND EXPLOSIVE REACTION.

(2) Sequence of addition and combination of materials at the mixer. - The polymer concrete materials shall be combined in the sequence and manner specified by the manufacturer.

(3) Mixing of polymer concrete. - The polymer concrete shall be mixed in a paddle-type power mixer, a rotating drum-type power mixer, or other type of power equipment approved by the Contracting Officer. Polymer concrete materials shall be mixed according to the recommendations of the manufacturer of the polymer concrete materials for at least 3 minutes.

(4) Removal of polymer concrete from the mixer. - The polymer concrete shall be removed from the mixer immediately after mixing.

(5) Appropriate forms shall be used for polymer concrete whenever necessary to confine the polymer concrete and shape it to required lines. The surfaces of the forms shall be coated with a release agent that will effectively prevent sticking without damage to the polymer concrete surfaces.

## 3.10 THIN POLYMER CONCRETE OVERLAY

a. General. - Thin polymer concrete overlay shall consist of one coat of primer and one or more coats of sealant as directed by the Contracting Officer.

The coat of primer shall consist of vinyl ester resin, initiator, and promoter. Each coat of sealant shall consist of the same materials as in the primer, but with the addition of silica filler, titanium dioxide pigment, and carbon black pigment.

b. Submittals. - The Contractor shall, before starting work, provide a manufacturer's affidavit which indicates the chemical constituents of the

material by proportion. The chemical constituents shall correspond to the requirement of subparagraph 3.10.d.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications.

The vinyl ester resin shall be stored in the shipping containers and kept in the shade, well ventilated, and out of direct sunlight. The recommended storage temperature is 50 to 75 EF. Resin shall not reach 80 EF or higher, as it will start to gel. The resin has a storage life of about 3 months. During storage, the resin shall not come in contact with copper, brass, zinc, or rust, as discoloration, polymerization, or interference with normal cure conditions can occur. Resin shall also not contact rubber, as resin is a solvent for rubber.

Styrene monomer, which is a component of vinyl ester resin, is flammable and forms explosive mixtures in the air; however, it is not sufficiently flammable to be listed as a "flammable liquid" under Interstate Commerce Commission definitions (flash point at or below 80 EF). The explosive limits are 1.1 to 6.1 percent volume in air.

The Contracting Officer will not allow the use of vinyl ester resin if it has already polymerized, gelled, discolored, or will not cure under normal conditions. Substandard materials shall be replaced at the expense of the Contractor.

d. Materials. -

(1) Vinyl ester. - The vinyl ester resin material shall be Dow Derakane 8084 elastomer-modified vinyl ester resin, manufactured by Dow Chemical Co., 2800 Mitchell Drive, Walnut Creek CA 94596; or equal. It shall meet the requirements of 3.9.d.(1)(b).

(2) Initiator. - The initiator shall be cuemene hydroperoxide - 78 percent as manufactured by: Lucidol Division, Penwalt Corp., 1740 Military Road, Buffalo NY 14240; Reichold Chemicals, Inc., 107 South Motor Avenue, Azusa CA 91706; Witco Chemicals, U.S. Peroxygen Division, 850 Morton Avenue, Richmond CA 94804; or equal.

(3) Promoter. - The promoter shall be cobalt napthenate; 6 percent.

(4) Filler. - The filler shall be ground silica, minus 45 µm (No. 355) sieve size as manufactured by: Ottawa Silica Co., Ottawa, Illinois; VWR Scientific (Silco Seal 395 Ground Silica), PO Box 3200, San Francisco CA 94119; or equal.

(5) Pigment for opaqueness. - Two pigments shall be used and they shall be:

(a) Titanium dioxide powder as manufactured by: VWR Scientific, PO Box 3200, San Francisco CA 94119; MCB Manufacturing Chemist, Inc., 470 Valley Drive, Brisband CA 94005; or equal.

(b) Carbon lamp black or bone black powder. - (Do <u>not</u> use activated carbon)

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications. No smoking, flame, or other ignition source shall be present during mixing and the application procedures. Fire extinguishers (types B or ABC) shall be provided. Equipment contacting resins shall be grounded for safe discharge of static electricity. Tools used shall be the non-sparking, special alloy type.

Workers shall be provided with rubber boots, rubber gloves, protective clothing, safety goggles or face shields, and organic vapor respirators. It is important to avoid inhalation of vapors and direct eye or skin contact. Eyewash facility shall be available which will provide a clean, room temperature flushing stream for a minimum of 15 minutes. Contaminated clothing shall be discarded immediately. Proper tools and facilities to quickly remove spills shall be at the worksite.

Personnel shall follow manufacturer's recommendations for safe handling of vinyl ester resin and all additives.

<u>CUEMENE HYDROPEROXIDE INITIATOR SHALL NEVER BE ADDED DIRECTLY TO COBALT NAPTHENATE PROMOTER OR AN EXTREMELY VIOLENT AND EXPLOSIVE REACTION WILL OCCUR.</u>

f. Concrete preparation. - Concrete surfaces designated to receive the thin polymer concrete overlay shall be prepared in accordance with section 2. The minimum preparation shall consist of wet sandblasting or water blasting the concrete to a clean, sound surface condition followed by drying.

g. Application of the thin polymer concrete overlay. -

(1) Coverage. - An average coverage rate of 50 to 75 square feet per gallon of applied material per coat over the entire surface is anticipated for this work. The surface texture of the concrete may affect this coverage rate.

(2) Mixing proportion. -

(a) Primer: 5.0 gallons vinyl ester resin
0.60 pound initiator
0.25 pound promoter

(b) Sealant: 5.0 gallons vinyl ester resin
1.35 pounds initiator
0.27 pounds promoter
40.0 pounds filler
4.0 pounds titanium dioxide pigment
0.02 pound carbon lamp black pigment

(3) Variations. - The proportions of cobalt napthenate promoter and cuemene hydroperoxide initiator were selected to give a 2- to 4-hour pot life at a temperature of about 70 EF. The rate of the polymerization reaction also depends on temperature - in colder weather the reaction will be slower, and in hot weather or in sunshine, the reaction will proceed faster. The temperature effects can be compensated for, to a certain extent, by increasing the total amount of initiator <u>plus</u> promoter in cold weather and decreasing the amount in hot weather.

Great care shall be exercised in proportioning the titanium dioxide and the carbon black to ensure exact color between batches of sealant layer.

The Contracting Officer may require variations from the proportions and quantities specified above and trial mixtures.

At no additional cost to the Government the Contracting Officer may require two trial mixtures utilizing a total of 5 gallons of vinyl ester resin with a proportional amount of other materials as indicated in subparagraph 3.10.g.(2). The Contractor shall supply, mix, and apply the trial polymer overlay where directed and in a manner as indicated by these specifications. The Contracting Officer shall be given 12 hours' notice before a trial mix is applied.

(4) Mixing. - The filler, pigments, and cobalt napthenate promoter shall be mixed with vinyl ester resin in a paddle-type or rotating drum power mixer in advance of the application. Mixtures shall be prepared in maximum volumes of 5 gallons of resin per mixed batch.

The Contractor shall mix the required constituents, with the exception of the cuemene hydroperoxide, to the satisfaction of the Contracting Officer. The sealant material will then be required to set for 45 to 90 minutes for the filler and pigment to become thoroughly wetted by the vinyl ester resin. Just prior to use, the cuemene hydroperoxide initiator shall then be added and the sealant mixture mixed again to the Contracting Officer's satisfaction. CUEMENE HYDROPEROXIDE INITIATOR AND COBALT NAPTHENATE PROMOTOR SHALL NEVER BE ADDED TOGETHER DIRECTLY, OR AN INSTANTANEOUS AND VIOLENTLY EXPLOSIVE REACTION COULD OCCUR. For the primer, the setting period may be omitted, but the initiator must still be added after the first mixing of the promoter, then mixed again.

(5) Application. - The primer shall uniformly and completely cover the surface by being spread and scrubbed into the concrete surface with a paint roller, brush, or push broom. Discontinuities and puddles shall be eliminated by vigorous scrubbing action. The application rate of primer is expected to be 1 gallon per 50 to 75 square feet of surface area, but may vary due to texture of the prepared surface.

The pigmented sealant layers of the overlay material shall be applied not less than 4 and no greater than 24 hours after the application of the primer or succeeding sealant layer. The primer layer may not have completely cured during this time period. The sealant shall be applied to dry, primed surfaces, and provisions shall be taken to prevent wetting of the surfaces from rain or leakage and seepage of water. The sealant layers shall also be applied with a paint roller, brush, or push broom. The application rate of the sealant is expected to be 1 gallon per 50 to 75 square feet of surface area.

The primer and sealant layers shall be spread evenly and uniformly over the surface.

3.11 RESIN INJECTION

a. General. - When hardened concrete is cracked in depth or when hollow plane delaminations or open joints exist in hardened concrete and when

structural integrity or watertightness must be restored for the structure to be serviceable, resin injection shall be used for repair, as directed.

However, since not all cracked, delaminated, or jointed concrete can be restored to serviceable condition by resin injection, resin injection repairs shall be made only as directed by the Contracting Officer.

Two basic types of injection resin are used to repair concrete:

(1) Epoxy resins are used to rebond cracked concrete and to restore structural soundness. Epoxy resins may also be used to eliminate water leakage from concrete cracks or joints, provided that cracks to be injected with epoxy resin are stationary. Cracks that are actively leaking water and that cannot be protected from uncontrolled water inflow shall not be injected with epoxy resin. Cracks to be injected with epoxy resin shall be between 0.005 inch and 0.25 inch in width.

(2) Hydrophilic polyurethane resin is used to eliminate or reduce water leakage from concrete cracks and joints and can be used to inject cracks subject to some degree of movement. Hydrophilic polyurethane resin shall not be used to inject concrete cracks or joints when restoration of structural bond is desired. Cracks to be injected with polyurethane resin shall be 0.005 inch in width or greater.

Other types of injection resin are available for nonstandard or specialized repair applications. Use of these materials shall require specific approval of the Contracting Officer.

b. Submittals. - The Contractor shall provide the Contracting Officer with evidence that the Contractor is qualified to perform resin injection repairs. The data shall show that the Contractor has a minimum of 3 years of experience in performing resin injection work similar to that detailed in the drawings and specifications.

The Contractor shall submit a list of 5 projects in which resin injection was successfully completed. The list shall contain the following information for each project:

(1) Project name and location.

(2) Owner of project.

(3) Brief description of work.

(4) Date of completion of resin injection work.

If the repair work is performed by the Contractor's personnel under the supervision of the manufacturer's representative, the data shall show that the resin manufacturer has a minimum of 5 years' experience providing resin materials similar to those specified.

Manufacturer's brochures, technical data sheets, Material Safety Data Sheets, and any other information describing the polyurethane resin, the proper formulation to achieve the required tensile strength, bond strength, and elongation of the cured resin mixture, and recommended injection

procedures shall be submitted to the Contracting Officer for approval at least 30 days prior to commencement of crack repairing operations.

The Contractor shall furnish the Contracting Officer a manufacturer's certification of conformance of the epoxy or polyurethane resin system with these specifications. The certification shall identify the Reclamation solicitation/specifications number(s) under which the resin is to be used and shall include the quantity represented, the batch numbers of the resin, and the manufacturer's results of tests performed on the resin system.

The Contractor shall submit a detailed proposal for epoxy injection repair to the Contracting Officer for approval. The approval will be based on the degree of conformance of the proposal with procedures contained in Reclamation's Concrete Manual, chapter 7, Eighth Edition, revised reprint, and the report of ACI Committee 503, section 7.2.5, "Use of Epoxy Compounds with Concrete."

The Contractor shall submit a detailed proposal for polyurethane resin injection repair to the Contracting Officer for approval. The approval will be based on the degree of conformance to the basic steps of polyurethane resin injection and on the Contracting Officer's judgment of the technical feasibility of the Contractor's proposal.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. The repair work may be performed by the Contractor or by the Contractor's personnel under the supervision of the resin manufacturer's representative. If the Contractor performs the repair work, the Contractor shall provide a full-time, onsite supervisor throughout the duration of the resin injection work.

If the repair work is performed by the Contractor's personnel under the supervision of the resin manufacturer's representative the Contractor shall have the resin manufacturer provide a representative who will train the Contractor's personnel on the proper techniques of injecting resin with an injection system approved by the manufacturer. Also, the Contractor shall provide a full-time, onsite, manufacturer-certified injection supervisor throughout the duration of the resin injection work.

d. Materials. -

(1) Epoxy resin. - Epoxy resin for injection shall meet the requirements of specification ASTM C-881 for a type I, grade 1 epoxy system. The class of the system shall be appropriate for the temperature of the application.

(2) Polyurethane resin. - The polyurethane resin system for injection into cracked concrete shall be a two-part system composed of 100 percent hydrophilic polyurethane resin and water. The polyurethane resin, when mixed with water, shall be capable of forming either a flexible closed-cell foam or a cured gel dependent upon the water-to-resin mixing ratio. The amount of water mixed with the polyurethane resin shall be such that the cured material meets the following physical properties:

(a) Minimum tensile strength -- 20 pounds per square inch.

(b) Bond to concrete (wet) -- greater than 20 pounds per square inch.

(c) Minimum elongation -- 400 percent.

The injection of pure polyurethane resin, not mixed with water, shall not be allowed.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications.

(1) Epoxy resins. - Certain additional safety precautions shall be employed when using uncured epoxy materials. Skin contact with uncured epoxy shall be avoided. Protective clothing, including rubber or plastic gloves, shall be worn by all persons handling epoxy materials. All exposed skin areas that may come in contact with the material shall be protected with a protective barrier cream formulated for that purpose. Adequate ventilation shall be provided and maintained at all times during use of epoxy and epoxy solvents. Fans used for ventilating shall be explosion proof. If necessary, respirators that filter organic fumes and mists shall be worn. All epoxy-contaminated materials such as wipes, empty containers, and waste material shall be continually disposed of in containers which are protected from spillage. Epoxy spillage shall be immediately and thoroughly cleaned up. Appropriate solvents may be used to clean tools and spray guns, but in no case shall the solvents be incorporated in any epoxy resin or in the placing operation. Solvents shall not be used to remove epoxy materials from skin. Only soap, water, and rags shall be used for this purpose.

All tools shall be completely dried after cleaning and before reuse.

(2) Polyurethane resins. - Polyurethane injection resin systems contain either toluene diisocyanate or methylene dephenyl diisocyanate. Both isocyanates can create risks if safe handling procedures are not followed. The principal hazards arise from isocyanate vapor, which will irritate the membranes of the nose, throat, lungs, and eyes. Adequate ventilation is required to prevent vapor concentrations from approaching the Threshold Limit Value (TLV). Protective clothing, including rubber or plastic gloves and protective glasses, shall be worn by all persons handling polyurethane resins. If necessary, respirators that filter isocyanate vapors and mists shall also be worn. Monomeric urethane resins react with water to produce polyurethane and carbon dioxide gas. If this reaction occurs inside a closed container, excessive pressures can develop that may rupture the container. Care must be taken to prevent contamination of monomeric urethane resin with water.

Polyurethane resin spillage shall be immediately and thoroughly cleaned up. Spilled polyurethane resin can be absorbed in sand and removed for burial.

(3) Cleanup and disposal of injection resin. - All materials, tools, and containers contaminated with injection resin, surface sealers, or other contaminants shall be removed from the site for disposal in accordance with appropriate local or Federal regulations.

f. Concrete preparation. - The concrete surface to be repaired by resin injection shall be thoroughly cleaned of all deteriorated concrete, efflorescence, and all other loose material. The area to be injected shall then be thoroughly inspected and an injection port drilling and pumping pattern established.

Upon completion of resin injection, all excess material shall be removed from the exterior surfaces of the concrete. The final finished surfaces shall match the texture of the surfaces adjoining the repair areas.

g. Application of resin injection repairs to concrete. -

(1) Epoxy resin injection repair. - The process used for epoxy injection shall fill the entire crack or hollow plane delamination with liquid epoxy resin system and shall contain the resin system in the crack until it has hardened. The Contractor shall be responsible for drilling and removing three, a minimum of 2-inch-diameter cores from the injected concrete at locations determined by the Contracting Officer to determine the completeness of the injection repair. Injection shall be considered complete if more than 90 percent of the void is filled with hardened epoxy. If injection is not complete, reinjection and additional cores may be required at the direction of the Contracting Officer at no additional cost to the Government.

Epoxy injection repair methods shall be in accordance with the approved detailed proposal for epoxy injection repair and shall be adjusted to fit the repair situations encountered.

(2) Hydrophilic polyurethane resin injection repairs. - The process used for polyurethane injection of cracks or joints to reduce water leakage shall consist of the following basic steps:

(a) Intercept the water flow paths with valved drains installed into the concrete to control the leakage.

(b) Install injection ports by drilling holes designed to intersect the cracks at depth below the concrete surface. The maximum spacing of injection ports shall not exceed 60 inches, and closer spacing of ports may be required.

(c) All injection holes shall be flushed with clean water to remove drilling dust and loose debris and to clean the intersected crack line. Each drill hole shall be water tested at the resin injection pressure to determine if the crack intersection is open. Polyurethane resin shall not be pumped into a drill hole that refuses to take water at the resin injection pressure.

(d) Inject polyurethane resin system into cracks or joints at the minimum pressure required to obtain the desired travel, filling, and sealing. The mix water to resin ratio shall be 1:1 unless otherwise approved by the Contracting Officer. The Contractor should anticipate the necessity to provide a surface seal for the crack or joint to contain the injection resin. It may also be necessary to inject the crack or joint in an intermittent manner to achieve filling and sealing. Injection shall be by the method of split

spacing unless otherwise approved by the Contracting Officer. Primary holes shall be drilled and injected on centers not exceeding 10 feet. Secondary holes, half way between the primary holes, will then be drilled and injected. If resin take occurs in the secondary holes, a series of tertiary holes, half way between the secondary and primary holes, shall then be drilled and injected. All holes shall be injected to absolute refusal.

(e) Remove drains, injection ports, and excess polyurethane upon completion of resin cure.

This process shall entirely stop the water leakage to a dust dry condition or as directed by the Contracting Officer.

The pump used to inject the polyurethane resin system shall be a two-component positive-displacement-type pump with static mixing head and pressure regulation necessary to control injection pressures while pumping low volumes. The equipment will be subject to approval by the Contracting Officer. The use of single component pumps and/or the injection of pure water followed by injection of pure resin will not be approved.

Polyurethane resin injection methods shall be in accordance with the approved, detailed proposal for injection repair and shall be adjusted to fit the repair situations encountered.

## 3.12 HIGH MOLUCULAR WEIGHT METHACRYLIC SEALING COMPOUND

a. General. - A concrete sealing compound is defined as a liquid that is applied to the surface of hardened concrete to prevent or decrease the penetration of liquid or gaseous media, such as water, aggressive solutions, and carbon dioxide, during the service exposure, preferably after initial drying to facilitate its absorption into voids and cracks.

The sealing of concrete surfaces with a high molecular weight methacrylic monomer-catalyst system and sand shall be in accordance with these specifications. Other types of concrete sealing compounds may be used by the Contractor only when approved by the Contracting Officer.

The high molecular weight methacrylic sealing compound shall not be used to seal concrete subject to frequent or permanent immersion in water; nor shall it be used on concrete surfaces exposed to high abrasion forces.

b. Submittals. - The Contractor shall provide the Contracting Officer a table showing preparation of initiator and promoter to be added to the monomer to achieve the cure time requirements based on concrete surface temperature. The temperature of the surface to be treated shall range from 45 to 100 EF. If it is desired to work outside these temperature ranges, approval of the Contracting Officer is required, and the monomer manufacturer should be consulted for technical advice.

A MSDS shall be furnished to the Contracting Officer prior to shipment of material with information pertaining to the safe practices for storage, handling and disposal of the materials and their explosive and flammable characteristics, health hazards, and the manufacturer's recommended fire

fighting techniques. The MSDS shall be posted at all storage areas and at the job site.

The Contractor shall furnish, for approval, a detailed written description of the methods the Contractor plans to use for clean up of all spills and residue in open containers. See subparagraph 3.12.g.(4).

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. -

(1) High molecular weight methacrylic monomer. - The monomer shall be a high molecular weight or substituted methacrylate that conforms to the following properties:

| | | |
|---|---|---|
| (a) | Vapor pressure | Less than 1.0 mm HG @ 77 EF (ASTM D 323) |
| (b) | Flash point | Greater than 200 EF (Pensky-Martens CC) |
| (c) | Density | Greater than 8.4 lb/gal at 77 EF (ASTM D 2849) |
| (d) | Viscosity | 12 ± 4 cps (Brookfield No. 1 Spindle 60 rpm, at 73 EF) |
| (e) | Index of refraction | 1.470 ± 0.002 |
| (f) | Boiling point @ 1 mm Hg, degrees F | 158 |
| (g) | Shrinkage on cure -less than- | 11% |
| (h) | Glass transition temperature (DSC), degrees F. | 135 EF (ASTM D 3418) |
| (i) | Curing time (100 g mass) | Greater than 40 minutes at 77 EF, with 4% cuemene hydroperoxide (ASTM D 2471) |
| (j) | Bond strength | greater than 1,500 $lb/in^2$ (ASTM C 882) |

(k) No unreactive solvents or diluents shall be permitted in the monomer system.

(2) Initiator-promoter system. -

(a) Initiator Cuemene hydro peroxide - 78 percent

(b) Promoter Cobalt Napthenate - 6 percent

The initiator/promoter system shall be capable of providing a surface cure time of not less than 40 minutes nor more than 3 hours at the surface temperature of the concrete during application. The initiator/promoter system shall be such that the gel time may be adjusted to compensate for changes in temperature that may occur throughout the treatment application.

(3) Sand. - The sand shall be clean, dry, and free of organic materials, silt, and clay. Except as otherwise approved by the Contracting Officer, the sand shall conform to the following grading:

| U.S. standard sieve size | Percent passing |
|---|---|
| 4.75 mm (No. 4) | 100 |
| 2.36 mm (No. 8) | 90-10 |
| 850 µm (No. 20) | 5-10 |
| 300 µm (No. 50) | 0-10 |

This grading is intended to allow the use of commercially available silica sands of No. 8/20 or No. 10/20.

e. Safety. - All work shall be performed in accordance with the requirements of paragraph 1.6 and these specifications. The materials shall be stored, handled, and applied in accordance with the manufacturer's recommendations. Storage of all materials shall be in the original shipping containers and as specified in this paragraph.

INITIATORS AND PROMOTERS SHALL BE STORED SEPARATELY SINCE COMBINATION CAN RESULT IN A VIOLENT REACTION OR EXPLOSION.

Personnel exposed to monomer, initiator, or promoter, or their vapors shall use minimum protective equipment as follows: safety eye glasses, impervious gloves and aprons, and rubber boots as required. As determined by the Contracting Officer, personnel may be required to use full-face protective shields, self-contained respiratory equipment, or both. All personnel handling the monomer or catalysts shall be thoroughly trained in their safe use in accordance with the manufacturer's recommendations.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of the monomer and catalysts shall in all cases comply with the requirements of applicable Federal, State, and local safety requirements and ordinances.

The Contractor shall provide an eye wash and water washing facility for use in the event of accidental splashing of the monomer or catalysts on the workers. Eyewash facility shall be capable of providing a clean, room temperature flushing stream for a minimum of 15 minutes. All sources of sparks or flame must be removed from areas used for storage and handling. In these areas storage and mixing vessels shall be provided with electrical grounds to prevent static sparks.

Mixing and transfer equipment shall be explosion proof, and sufficient ventilation shall be provided to prevent the formation of explosive sealant/air mixtures. In accordance with applicable safety regulations, warning signs, such as "No Smoking" signs, shall be posted. In public areas, care shall be taken to eliminate sources of sparks or flame when the monomer system is present. Particular attention should be given to removal of welding operations, posting of "No Smoking" signs, and to traffic control to eliminate accidental fires from these sources. Visitors at the job site should be warned of the potential hazards and provided with applicable safety equipment. The Contractor shall also place an adequate number of 4-A:60B:C fire extinguishers on the job, so that no portion of

the monomer system application is conducted farther than 100 feet from the nearest fire extinguisher.

f. Concrete preparation. - The concrete surfaces to be treated shall be clean, dry, and physically sound. All deteriorated concrete shall be removed in accordance with paragraph 2.1 to obtain a physically sound surface for treatment. The Contractor shall perform all work required to bring the surfaces to this condition.

Concrete surfaces shall then be prepared by power sweeping and by blowing with high-pressure air to remove all dirt and foreign material from the surface and from all cracks. Contaminants, such as asphalt and heavy oil and rubber stains, shall be removed, at the discretion of the Contracting Officer, by scraping and cleaning with solvents. Well-bonded surface contaminants and existing painted surfaces shall be removed by wet sandblasting. High-pressure water blasting will be permitted only if it can be demonstrated to the satisfaction of the Contracting Officer that the concrete surface and cracks can be completely dried prior to the application of the polymer treatment.

g. Application. - The methacrylic concrete sealing compound shall be mixed, applied to the prepared concrete surface, and cured in accordance with these specifications.

(1) Mixing of materials. - The monomer shall be mixed with initiator and promoter in the following proportions (proportions may be adjusted by the Contracting Officer to give a satisfactory pot life based on concrete surface temperatures and recommendations of the monomer system manufacturer):

| | | Parts by weight |
|---|---|---|
| (a) | Substituted Methacrylate Monomer | 100 |
| (b) | Cuemene Hydroperoxide (78%) | 4.0 |
| (c) | Cobalt Napthenate (6%) | 2.0 |

<u>DO NOT MIX COBALT NAPTHENATE DIRECTLY WITH CUEMENE HYDROPEROXIDE AS THIS WILL PRODUCE AN EXTREMELY VIOLENT AND EXPLOSIVE CHEMICAL REACTION.</u>

The cobalt napthenate and cuemene hydroperoxide shall be mixed with the substituted methacrylate monomer in separate steps; i.e., first add and mix cobalt napthenate with the substituted methacrylate monomer, and then add and mix the cuemene hydroperoxide with the cobalt napthenate/ methacrylate monomer mixture.

The materials shall not be premixed. The monomer system shall be applied to the concrete surface within 5 minutes after mixing the cuemene hydroperoxide with the cobalt napthenate/substituted methacrylate monomer mixture.

For manual application, the quantity of monomer system mixed shall be limited to 5 gallons at a time. A significant increase in viscosity or change in gel time prior to application shall be cause for rejection.

Machine mixing and application of the methacrylic sealing compound may also be performed by using a two-part monomer system utilizing a promoted monomer for one part and an initiated monomer for the other part. Adequate mixing shall be done to achieve a uniform blend of the two parts.

The use of machine mixing and application requires approval by the Contracting Officer and treatment of a 10- by 50-foot test site to demonstrate that the equipment is working properly and capable of providing a uniform monomer mixture.

(2) Application of sealing compound. - Prepared surfaces shall be protected from rain and moisture. Surfaces shall be treated with sealing compound within 24 hours after surface preparation is completed. The surface shall be allowed to dry thoroughly for a minimum of 48 hours before treatment. At the discretion of the Contracting Officer, the following test shall be made to determine if the concrete surface is sufficiently dry to proceed with the polymer treatment. A 2-foot-square piece of clear polyethylene sheeting shall be taped to the surface of the concrete and allowed to remain there for a minimum of 2 hours exposed to sunlight. Moisture condensation on the inside surface of the polyethylene sheeting shall be considered as evidence that the concrete surface is not sufficiently dry, and an additional period for drying will be required before proceeding with the polymer treatment. Additional tests may be required, at the discretion of the Contracting Officer.

The monomer system shall be applied to the concrete surfaces during nighttime and early morning hours as directed by the Contracting Officer and with concrete temperatures between 45 and 85 EF. Monomer application will not be permitted in the direct rays of the sun as this may cause a premature curing of the system.

The concrete surfaces shall be treated with monomer at an application rate of 75 to 100 square feet per gallon. The concrete surfaces shall be flooded with the monomer mixture, allowing full penetration of the concrete and filling all cracks, and brushed with a stiff bristle broom. Puddles of excess monomer shall be removed by the Contractor.

The sealing compound may also be spray-applied by machine using a two-part mixing procedure described in subparagraph 3.12.g.(1). The pressure at the spray nozzle shall not be great enough to cause monomer mist to drift more than 2 feet beyond the nozzle. Compressed air shall not be used to produce the spray.

(3) Application of sand and curing. - Within 15 to 20 minutes after application of the methacrylic sealing compound, and before significant gelling has occurred, the entire treated area of concrete shall be covered by sand broadcast to achieve a uniform coverage of 0.25 to 0.50 pound per square yard. This sand shall be left on the concrete surface until the sealing compound has cured to a tack-free condition. Any excess sand, not bonded to the concrete, shall then be removed by the Contractor. Sand shall not be applied to vertical surfaces that have been treated with methacrylic sealing compound.

Treated areas shall be protected and not put back into service for 24 hours after treatment to allow the sealing compound to fully cure.

(4) Cleanup. - The Contractor shall keep the mixing equipment and tools clean during the course of the treatment, using a suitable solvent such as acetone or methyl ketone (both flammable), or 1,1,1,-trichloroethane (nonflammable). Soap and water are also satisfactory for cleanup of fresh monomer from the tools. The Contractor shall quickly clean up all spills by a method previously approved by the Contracting Officer.

After the repair work is completed, the residue in the open containers of cuemene hydroperoxide and cobalt napthenate shall be safely destroyed by using some of the excess monomer resin to wash out the catalyst containers and then allow it to cure before disposal or by other methods recommended by the manufacturers and approved by the Contracting Officer.

3.13 SURFACE IMPREGNATION

a. General. - These specifications present the requirements for impregnating concrete with a methyl methacrylate based monomer-catalyst system followed by in situ polymerization of the monomer by heat.

b. Submittals. -

(1) The Contractor shall provide the Contracting Officer with the manufacturer's certifications that the monomers and catalyst meet these specifications. Representative samples of the monomer system components, or of the combined monomer system if purchased premixed, shall be delivered to the Contracting Officer at least 30 days prior to use. At the Contracting Officer's option, these samples will be tested to determine specifications compliance.

(2) At least 30 days prior to beginning the concrete impregnation process, the Contractor shall deliver to the Contracting Officer a written report describing the Contractor's planned treatment procedures. Included in this report shall be a detailed description of the drying, impregnation, monomer mixing and storage, polymerization and quality control procedures, facilities, and equipment the Contractor intends to use to treat the concrete. The Contracting Officer will review this report and approve or disapprove the plan within 30 days of the date of receipt. In no event shall the Contractor proceed with the surface impregnation treatment until approval of the Contractor's procedures, materials, and equipment has been received.

(3) During the drying, cooling, impregnation, and polymerization cycles, the Contractor shall obtain and supply to the Contracting Officer concrete temperature data accurate to ±5 EF from at least nine points uniformly spaced on the surface of each treatment area and from at least one point 1 inch below the concrete surface at the approximate center of each treated area.

These data shall be in the form of a continuous record or periodic readings recorded at 1-hour intervals. The technique and equipment used to obtain the temperature data required in subparagraph 3.13.g.(1) shall

be described in the written procedures report required above and subject to the Contracting Officer's approval.

(4) The Contractor shall maintain and supply to the Contracting Officer monomer and catalyst records listing the dates of manufacture, storage temperatures, date of use and application rates, and quantities as applied to the concrete.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4 and these specifications. Representative material samples submitted by the Contractor, as specified in subparagraph 3.13.b.(1) will be tested, at the Contracting Officer's option.

d. Materials. -

(1) Monomer system. - The monomer system shall be composed of 95 percent by weight methyl methacrylate (MMA) and 5 percent by weight trimethlolpropane trimethacrylate (TMPTMA). A polymerization catalyst, 2,2-azobis-(2,4-dimethylvaleronitrile), shall be added to this monomer system at the rate of 1 part catalyst to 200 parts monomer by weight, or as directed by the Contracting Officer.

(a) MMA. - MMA shall meet the following requirements:

| | |
|---|---|
| Formula | $CH_2=C(CH_3)C00CH_3$ |
| Inhibitor | 25 parts per million hydroquinone (HQ) |
| Molecular weight | 100 |
| Assay (Gas Chromatography) % | 99.8 min |
| Density | 7.83 lb/gal (0.938 kg/L) |
| Boiling | 212 EF (100 EC) |
| Flash point (Tag, ASTM D 1310) | 55 EF (13 EC) |

(b) TMPTMA. - TMPTMA shall meet the following requirements:

| | |
|---|---|
| Formula | $(CH_2=CH_3\ COOCH_2)_3CCH_2CH_3$ |
| Inhibitor | 100 parts per million hydroquinone (HQ) |
| Assay, % | 95.0 min |
| Density | 8.82 lb/gal (1.058 kg/L) |
| Flash point | Greater than 300 EF (149 EC) |

(c) The polymerization catalyst shall be 2,2-azobis-(2,4-dimethyl-valeronitrile). Empirical formula: $C_{14}H_{24}N_4$.

Monomer system components shall be used within 6 months after manufacture.

(2) Sand. - The impregnation sand shall be composed of clean, hard, dense, low-absorptive particles that will pass a 1.18-mm (No. 16) sieve, but with not more than 5 percent passing a 150 µm (No. 100) sieve.

e. Safety. - All work shall be performed in accordance with paragraph 1.6 and these specifications. Because of the hazards associated with improper use and handling of the monomer and catalyst, the following additional safety requirements shall be adhered to during the surface impregnation process.

Personnel working with the monomers or catalyst shall be provided with and use safety eyeglasses or goggles, impervious gloves, aprons, and boots. Normally, in an outdoor monomer application, respiratory equipment will not be necessary. In storage and mixing operations, however, accidental spills or equipment failures may result in hazardous vapor concentrations requiring self-contained respiratory equipment for personnel protection. The Contractor shall provide a field eye wash and water washing facility for use in the event of an accidental splash of monomer on the workers. Eye wash facility shall be capable of providing a clean, room temperature flushing stream for a minimum of 15 minutes.

All sources of sparks or flame shall be removed from areas for monomer storage and handling. In these areas monomer storage and mixing vessels shall be provided with electrical grounds to prevent static sparks. Mixing and transfer equipment and motors shall be explosion proof, and sufficient ventilation shall be provided to prevent the formation of explosive monomer vapor-air mixtures. In accordance with applicable safety regulations, warning signs such as "No Smoking" regulations shall be posted. At the construction site, care shall be taken to eliminate sources of sparks or flame when monomer is present. Particular attention shall be given to removal of welding operations, posting of "No Smoking" signs, and to traffic control to eliminate accidental fires from these sources. Visitors at the job site shall be warned of the potential hazards and provided with applicable safety equipment.

Catalyzed monomer not used within 4 hours of catalyst addition shall be stored in an explosion proof storage facility at a maximum storage temperature of 0 EF until it can be used or destroyed as approved by the Contracting Officer. Storage of catalyzed monomer for periods longer than 2 days will not be permitted.

Monomer and catalyst storage and handling. - The monomers, MMA and TMPTMA, or the premixed monomer system shall be stored in their original shipping containers or in other clean containers as approved by the Contracting Officer. Maximum monomer storage temperature shall not exceed 90 EF. The storage area shall be selected to provide protection from direct sunlight, fire hazard, and oxidizing chemicals. Sufficient ventilation shall be maintained in the storage area to prevent the hazardous buildup of monomer vapor concentrations in the storage air space. The polymerization catalyst shall be stored in accordance with the manufacturer's recommendations, but in no event shall the catalyst storage temperature be allowed to exceed 35 EF. Personnel exposed to monomer or monomer vapor shall use minimum protective equipment as follows: safety eyeglasses, impervious gloves and

aprons, and rubber boots as required. As determined by the Contracting Officer, personnel may be required to use full face protective shields, self-contained respiratory equipment, or both. All personnel handling the monomers or catalyst shall be thoroughly trained in their safe use in accordance with manufacturer's recommendations.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of monomer shall in all cases comply with the requirements of applicable Federal, State, and local safety requirements and ordinances.

During the polymerization cycle, the heating enclosure shall be provided with a means of positive ventilation to prevent hazardous concentrations of monomer vapor within the enclosure. Open flame heat sources will not be approved for use during polymerization.

The monomer mixing area shall be free of sources of ignition and shall be well ventilated. Spilled monomer shall be contained with absorptive materials such as vermiculite or dry sawdust and removed with non-sparking equipment.

f. Concrete preparation. - Deteriorated concrete shall be removed from the surface by wet sandblasting or other suitable means. Concrete containing surface contaminants such as oil, paint, or protective coatings shall be cleaned by wet sandblasting or by other approved means to remove these materials. After the removal of these materials, the concrete surface shall be swept and air-blown to remove sand, leaves, trash, gravel, or other miscellaneous loose materials to the satisfaction of the Contracting Officer.

The Contractor shall install a temporary dike along the high side of the area to be impregnated to divert possible rainwater around the area to be impregnated. The Contractor shall also install a temporary dike along the low side of the area to be impregnated to act as a barrier to prevent monomer from accidentally escaping due to an accidental spill or excess application.

g. Application of the surface impregnation process. -

(1) Drying. - After the concrete surface area to be treated has been cleaned in accordance with subparagraph 3.13.f., it shall be uniformly covered with a 1/4- to 1/2-inch thick layer of sand meeting the requirements of subparagraph 3.13.d.(2) and dried to permit polymer penetration. The equipment used to accomplish drying shall consist of a weatherproof enclosure with either an electric infrared, or hot-air heat system, or other technique as approved by the Contracting Officer. Exposed flame infrared heat systems, if selected for drying, shall not be used for polymerization.

Drying shall be accomplished by raising the concrete surface temperature at a rate not exceeding 100 EF per hour to between 250 and 275 EF, and maintaining that surface temperature range for 8 hours. If a higher maximum temperature is desired, approval by the Contracting Officer shall be obtained. During the drying period, sufficient airflow shall be maintained over the concrete surface to ventilate the water vapor removed from the concrete and to provide uniform concrete surface

temperature. During the drying cycle, the Contractor shall obtain continuous or periodic surface temperature measurements, as specified in subparagraph 3.13.b.(3), at a sufficient number of locations over the heated concrete surface [normally one location per 100 square feet] to ensure temperature uniformity. The maximum temperature variation over the heated concrete surface shall not exceed ±20 EF of mean concrete surface temperature at the time measurements are taken.

(2) Cooling. - After the concrete has been dried, it shall be cooled prior to monomer application. The cooling rate for concrete surface temperature shall not exceed 100 EF per hour. Cooling shall continue until the maximum temperature at a depth of 1 inch below the surface of the concrete is 100 EF or less.

During the cooling and impregnation cycles, the dried concrete shall be protected to prevent moisture from reentering the concrete. It may be necessary, if determined by the Contracting Officer, to repeat the drying and cooling cycles prior to monomer application should moisture reenter the concrete.

(3) Monomer mixing. - The monomer MMA and TMPTMA may be premixed in the specified ratio and stored prior to use. Storage of premixed monomer shall be as required in subparagraph 3.13.e. All monomer mixing and transfer equipment shall be as required in subparagraph 3.13.e. All monomer mixing and transfer equipment shall be of explosion proof design and shall be provided with electrical ground cables. Monomer transfer shall be from bottom to bottom of the vessels or through dip pipes in the vessels to prevent the buildup of static charge during transfer. Pipe fittings, valves, pump impellers, or other equipment which will come into contact with monomer shall not be made of copper or brass or certain plastics attacked by the monomer.

(4) Catalyst-monomer mixing. - The polymerization catalyst shall be mixed with the monomer system immediately prior to use. Monomer system temperature at the time of catalyst addition shall not exceed 90 EF. Mixing shall be accomplished with explosion proof equipment in electrically grounded containers in a well-ventilated area.

(5) Impregnation. - Following the drying and cooling cycles, the sand on the concrete surface to be impregnated shall be uniformly leveled if necessary.

The temperature on the surface of the concrete shall not exceed 100 EF at the time of monomer application nor at any time during the impregnation cycle.

Monomer application shall be made at a rate sufficient to uniformly saturate the sand layer to a slight excess without applying so much monomer that it would drain away from the impregnated area. The monomer application rate should be 0.8 pound of monomer per square foot of concrete surface. This is approximately 0.9 gallon per square yard of surface area. However, sand layer thickness, sand particle size, and slope may necessitate application rate adjustment to achieve the described saturation. Following application, the monomer shall be allowed to soak into the concrete for approximately 6 hours. If at any

time during the soak cycle the sand should become dry, additional monomer shall be applied as directed by the Contracting Officer.

In order to protect the monomer-saturated sand from the polymerizing effects of direct and indirect solar radiation, monomer application and subsequent soaking shall occur during the time period sunset to sunrise unless the Contractor provides shielding, as approved by the Contracting Officer, to prevent solar radiation from reaching the area being impregnated. Immediately following monomer application, a continuous mylar membrane a minimum of 6 mils thick shall be placed over the monomer-saturated surface to reduce monomer evaporation. This membrane shall remain in place, except for the short periods of monomer application or surface inspection, throughout the impregnation cycle and until the polymerization cycle is complete.

(6) Polymerization. - Polymerization of the monomer impregnated into the concrete shall be accomplished by uniformly heating the treated concrete to a surface temperature of at least 165 EF and not exceeding 185 EF and maintaining it for a minimum of 5 hours. The rate of temperature increase and allowable surface temperature variation shall be as required in subparagraph 3.13.g.(1).

The equipment and procedures used to accomplish heating of the concrete for polymerization shall be of the type described in subparagraph 3.13.g.(1) as approved by the Contracting Officer. See subparagraph 3.13.b.

(7) Cleanup. - Following completion of the surface impregnation treatment process, the Contractor shall remove the sand from the concrete surface and dispose of the sand at the site as directed by the Contracting Officer.

3.14 SILICA FUME CONCRETE

a. General. - Silica fume concrete shall be used to repair concrete damaged by abrasion-erosion action. Silica fume concrete may also be used in the infrequent occasions where a high strength (compressive strength in excess of 10,000 lbs per square inch) repair concrete is required. Silica fume concrete shall be used on areas of damaged concrete greater than 1 square foot having a depth greater than 6 inches or a depth extending 1 inch below or behind the backside of reinforcement. If the depth of repair is at least 2 inches but less than 6 inches, epoxy bonding agent shall be used in accordance with the provisions of paragraph 3.8, to bond fresh silica fume concrete to concrete being repaired. Silica fume concrete shall not be used for repairs that are less than 2 inches in depth.

b. Submittals. - The Contractor shall submit certification of compliance for materials in accordance with subparagraph d. below.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - All concrete materials shall be obtained from previously tested and approved sources. Materials will be accepted on certificate of compliance with the following ASTM Standards:

(1) Portland cement. - Portland cement shall meet the requirements of ASTM C 150 for type I, II, or V cement. The specific cement type shall be as directed by the Contracting Officer and determined by the environment in which the repair is conducted.

(2) Silica fume. - The silica fume mineral admixture shall be obtained as a byproduct from the manufacture of solely silicon metal in electric blast furnaces. The condensed silica fume shall be processed and sized to a fineness of approximately 200,000 $cm^2$ per gm (20,000 $m^2/kg$) at a porosity (t) of 0.500 when tested in accordance with ASTM C 204 and have an amorphous silica ($Si0_2$) content of not less than 85 percent of the total fume. When tested in accordance with ASTM C 311, the silica fume shall have a moisture content of less than 3 percent and a loss on ignition of not greater than 6 percent. A manufacturer's certificate of compliance with these requirements and applicable provisions of ASTM C 618 is required. The silica fume shall be supplied, proportioned and combined with other admixtures, as necessary, from a supplier regularly engaged in the sale of this combination product as a concrete admixture. This combination admixture shall be batched with the concrete in either of two forms or types.

(a) The wet type shall consist of water slurry containing approximately 45 percent silica fume solids with a water-reducing admixture meeting all requirements specified.

(b) The dry form shall be a densified powder blended with a dry water reducing admixture. Both types shall be compatible with a water reducing admixture that could be added at the concrete plant or at the placement site.

(3) Admixtures. - The Contractor shall furnish air-entraining and chemical admixtures for use in concrete.

(a) Air-entraining admixture shall be used in all silica fume concrete and shall conform to ASTM C 260.

(b) Chemical admixtures. - The Contractor may use type A, D, F, or G chemical admixtures. If used, they shall conform to ASTM C 494.

(c) Use of other admixtures must be approved by the Contracting Officer.

(4) Water. - The water used in making and curing silica fume concrete shall be free from objectionable quantities of silt, organic matter, salts, and other impurities.

(5) Aggregate. - The term "sand" is used to designate aggregate in which the maximum size particle will pass a 4.75-mm (No. 4) sieve. The term "coarse aggregate" is used to designate all aggregate which can be retained on a 4.75-mm (No. 4) sieve. Sand and coarse aggregate meeting the requirements of ASTM C 33 shall be used in all concrete.

(6) Curing compound. - Wax-base (type I) and water-emulsified resin-base (type II) curing compounds shall conform to the requirements of Reclamation's "Specifications for Concrete Curing Compound" (M-30) dated October 1, 1980.

(7) Evaporation retarder. - Monomolecular membrane evaporation retardant formulated for use with silica fume concrete requirements shall be equal to "Confilm", manufactured by Master Builders, Lee at Mayfield, Cleveland, OH 44118.

e. Safety. - All work shall be performed in accordance with paragraph 1.6.

f. Concrete preparation. - After damaged or unacceptable concrete has been removed as specified in section 2. the surface on which the silica fume concrete will be placed shall be prepared. An acceptable surface shall have the appearance of freshly broken, properly cured concrete. The surface shall be free of any deleterious materials such as free moisture, ice, petroleum products, mud, dust, carbonation, and rust. The perimeters of the repair shall be saw cut to a minimum depth of 1 inch.

The clean surface is not ready to receive repair silica fume concrete until it has been brought to a saturated, surface-dry condition. This condition is attained by saturating the surface to a depth that no concrete mixture water may be absorbed from the fresh concrete. Then, just prior to placing concrete against the surface, all free moisture (moisture capable of reflecting light) shall be removed from the prepared surface.

g. Application. - Silica fume concrete shall be composed of cement, silica fume, coarse aggregate, sand, water, and approved admixtures, all well mixed and brought to the proper consistency. Silica fume concrete mixtures shall be proportioned in accordance with Reclamation's "Concrete Manual", Eighth Edition, revised, chapter III, except that silica fume shall be added to the mixture at a ratio of 7 to 12 percent by mass of the portland cement as directed by the Contracting Officer. The water-cementitious ratio of the concrete (exclusive of water absorbed by the aggregates) shall not exceed 0.35 by weight. Slump of the silica fume concrete, when placed, shall not exceed 3 inches for concrete in slabs that are horizontal or nearly horizontal and 4 inches for all other concrete. Silica fume concrete with less slump should be used when it is practicable to do so. The concrete ingredients shall be thoroughly mixed in a batch mixer. The concrete, as discharged from the mixer, shall be uniform in composition and consistency from batch to batch.

(1) Forms. - Forms shall be used for silica fume concrete whenever necessary to confine the concrete and shape it to the required lines. The forms shall be clean and free from encrustations of mortar, grout, or other foreign material. Before silica fume concrete is placed, the surfaces of the forms shall be coated with a form oil that will effectively prevent sticking and will not soften or stain the concrete surfaces or cause the surfaces to become chalky or dust producing.

(2) Placing. - Placing of silica fume concrete shall be performed only in the presence of an authorized representative of the Contracting Officer. Placement shall not begin until all preparations are complete and the authorized representative of the Contracting Officer has approved the preparations. Silica fume concrete shall not be placed in standing or running water unless, as determined by the Contracting Officer, the structure under repair cannot be economically dewatered. If underwater silica fume concrete placement is required, special placing procedures shall be required. A suggested guide is ACI 394R.

When appropriate, silica fume concrete shall be placed in layers not greater than 20 inches thick. Each layer, regardless of the thickness, shall be adequately consolidated using immersion-type vibrators or form vibrators when approved. Adequate consolidation of silica fume concrete is obtained when all undesirable air voids, including the air voids trapped against forms and construction joints, have been removed from the concrete.

(3) Finishing. - The class of finish required shall be a finish closely resembling the finish of the surrounding concrete. Silica fume concrete does not normally develop bleed water and special finishing procedures may thus be required. The ambient temperature of surfaces being finished shall be not less than 50E F. Immediately following placement of silica fume concrete to finished grade, the surface shall be screeded to bring the surface to finished level with no coarse aggregate visible. No cement or mortar shall be added to the finishing operation.

A monomolecular membrane evaporation retarder shall be applied to the surfaces of the silica fume concrete, in accordance with manufacturer's recommendations, immediately after the screening operation.

Floating, if necessary to achieve the specified finish, shall be performed immediately following the application of evaporation retarder.

h. Curing and protection. - Proper curing of silica fume concrete is essential if bond failure and shrinkage cracking are to be eliminated. Silica fume concrete repairs shall be cured, preferably by water curing, or alternately, by application of a uniform and continuous membrane of wax-base (type I) or water-emulsified resin-base (type II) curing compound meeting the requirements of subparagraph 3.6.d.(6). and as approved by the Contracting Officer. If the use of curing compound is approved, daily inspection by the Contractor shall be performed to ensure the maintenance of a continuous, water-retaining film over the repaired area. The water-retaining film shall be maintained for 28 days after the concrete has been placed.

Silica fume concrete surfaces to which curing compound has been applied shall be adequately protected during the entire curing period from pedestrian and vehicular traffic and from any other possible damage to the continuity of the curing compound membrane. Areas where curing compound is damaged by subsequent construction operation within the curing period shall be resprayed.

Water curing shall commence immediately after the concrete has attained sufficient set to prevent detrimental effects to the concrete surface. The concrete surface shall be kept continuously wet for a minimum of 14 days. Whenever possible, silica fume concrete shall be water cured by complete and continuous inundation for a minimum period of 14 days.

The Contractor shall protect all silica fume concrete against damage until acceptance by the Government. Whenever freezing temperatures are imminent, the Contractor shall maintain the newly placed repair concrete at a temperature of not less than 50 EF for 72 hours. Water-cured silica fume

concrete shall be protected from freezing for the duration of the curing cycle and an additional 72 hours after the water is removed.

## 3.15 ALKYL-ALKOXY SILOXANE SEALING COMPOUND

a. General. - A concrete sealing compound is defined as a liquid that is applied to the surface of hardened concrete to prevent or decrease the penetration of liquid or gaseous media, such as water, aggressive solutions, and carbon dioxide, during the service exposure, preferably after initial drying to facilitate its absorption into voids and cracks. An alkyl-alkoxy siloxane sealing compound, herein after referred to as siloxane, shall be applied to concrete surfaces when it is desired that application of a sealing compound cause no change in the appearance of the sealed surfaces.

The sealing of concrete surfaces with siloxane shall be in accordance with these specifications.

Siloxane sealing compound shall not be used to seal concrete subject to frequent or permanent immersion in water; nor shall it be used on concrete surfaces exposed to high abrasion forces.

b. Submittals. - The Contractor shall, before starting work, shall submit to the Contracting Officer manufactures data and certification that the concrete cleaner and siloxane sealing compound furnished by the Contractor meets the requirements of this specifications. The chemical constituents shall correspond to the requirement of subparagraph 3.15.d.

A MSDS shall be furnished to the Contracting Officer prior to shipment of material with information pertaining to the safe practices for storage, handling and disposal of the materials and their explosive and flammable characteristics, health hazards, and the manufacturer's recommended fire fighting techniques. The MSDS shall be posted at all storage areas and at the job site.

The Contractor shall furnish, for approval, a detailed written description of the methods the Contractor plans to use to apply the siloxane and for clean up of all spills and residue in open containers.

c. Quality assurance. - Quality assurance shall be in accordance with paragraph 1.4.

d. Materials. - The siloxane sealing compound shall be a clear, ready to use sealer based on oligomeric alkyl-alkoxy siloxane containing not less than 20 percent active siloxane solids by mass.) The compound when properly applied to concrete shall conform to the following performance standard:

| | | |
|---|---|---|
| Chloride screening | 91% (minimum) | (NCHRP 224, Series I) |
| Reduction of Chlorine Penetration vs untreated concrete | 92.4(minimum) | (NCHRP 224, Series IV) |
| Moisture Vapor Transmission | 97.5%(minimum) | (ASTM E-96) |
| Water Repellency Rating | 92%(minimum) | (ASTM C-140, ASTM C-67) |
| Water Absorption | 1.40%(maximum) | (ASTM C-67, ASTM C-140) |
| Scaling Resistance to Deicers | Excellent | (ASTM C-672) |

| | | |
|---|---|---|
| Resistance to Chlorine Penetration | 0.07 lbs/cu.yd. (maximum) | (AASHTO T-259/260) |
| Surface Friction Reduction | 0 | (ASTM E-303) |
| Penetration (1 application) | 1/8" - 1/4" | |

The compound shall have a high flash solvent carrier with a strong chloride screen and shall exhibit alkaline stability and form a chemical bond with the treated concrete.

The concrete sealing compound shall be Consolideck SX as manufactured by ProSoCo Inc., P.O. Box 1578, Kansas City, KS 66117, (913) 281-2700, or approved equal.

e. Safety. - The Contractor shall take the necessary precautions to avoid wind drift onto auto and pedestrian traffic. The materials shall be stored, handled, and applied in accordance with the manufacturer's or supplier's recommendations. Storage of all materials may be in the original shipping containers. The material should be stored in sealed containers and kept away from extreme heat. The sealant contains blended solvents and should be handled accordingly. Do not use near fire or extreme heat and provide good ventilation to avoid buildup of solvent fumes. Personnel applying the concrete sealant shall wear NIOSH/MSHA approved respirators, goggles, rubber gloves, and plastic or rubber suits to avoid splash to skin and eyes. Clothing that becomes contaminated with the concrete sealant shall be changed as quickly as possible.

Unsafe handling practices will be sufficient cause to discontinue work until the hazardous procedures are corrected. The handling and use of the concrete sealant shall in all cases comply with the requirements of applicable federal, state, and local safety requirements and ordinances.

f. Concrete preparation. - The concrete surfaces to be treated shall be clean and physically sound. Unsound or deteriorated surfaces shall be removed in accordance with the requirements of section 2. All needed repair work shall be adequately cured prior to application of the siloxane.

Concrete surfaces shall be prepared by power sweeping and blowing with high pressure air to remove all dirt and foreign material from the surface and from all cracks. Contaminants, such as asphalt and heavy oil and rubber stains, shall be removed at the discretion of the Contracting Officer by scraping and cleaning with solvents. Well bonded surface contaminants and existing painted surfaces shall be removed by high pressure water blasting or wet sand blasting. The concrete surface and all cracks shall be completely dried prior to the application of the siloxane.

g. Application. - If the concrete sealant is a product other than Consolodeck SX, a test application of the concrete sealant shall be made to an area selected by the Contracting Officer using the same equipment and procedures proposed for the project. The test procedure is to insure compatibility of the product, to determine the waterproofing results and to check for surface discoloration from the procedure. The Contractor shall not proceed with the remainder of the work until the Contracting Officer approves the results of the test application. If the results of the test application are deemed unsatisfactory by the

Contracting Officer, the Contractor shall modify his sealant materials, procedure, and/or equipment as directed by the Contracting Officer and the test application shall be repeated.

The siloxane sealant shall not be applied at surface and air temperatures below 40 degrees F, or above 100 degrees F. Surfaces shall be treated within 24 hours after the surface preparation is completed. The prepared surfaces shall be maintained in a dry condition and protected to prevent contamination prior to the siloxane application. If the prepared surface becomes contaminated, it shall be recleaned in accordance with paragraph 3.15.f. The Contracting Officer shall determine if the surface is dry enough to receive sealant. If the Contracting Officer determines that the surface is too damp for application of the sealant, application of the sealant shall not commence without approval of the Contracting Officer.

The sealant shall be applied with low pressure (20) psi airless spray equipment fitted with solvent resistant hoses and gaskets. Heavily saturated brush or roller may be used in isolated incidents if the Contracting Officer determines that brush or roller application is the most effective means.

Adjoining glass, metal and painted surfaces shall be protected from overspray and splash of the siloxane sealant. Any accidental or unintentional overspray or splash on adjoining glass, metal or painted surfaces shall be removed using mineral spirits before the solution has dried on the surface.

When applying to exteriors of occupied areas, all exterior air conditioning and ventilation vents shall be covered during application and air handling equipment shall be turned off during application to avoid solvent odors within the occupied areas.

The concrete surfaces shall be given a full and complete application of the siloxane sealant at the following application rate of 80-120 sq.ft./gal.

(1) Horizontal surfaces. - When applying the siloxane to flat horizontal concrete surfaces, the siloxane shall be applied in two "wet-on-wet" coats. Flood the surface and broom or squeegee the material around for even distribution. Allow the surface to absorb the siloxane and follow immediately with a second application before the surface dries. Puddles of excess siloxane sealant shall be broomed out thoroughly until they completely penetrate into the surface.

(2) Vertical surfaces. - When applying the siloxane to vertical surfaces, the siloxane shall be applied in two "wet-on-wet" applications. Apply the siloxane in a flooding application, from the bottom up with sufficient material applied to produce a 6" to 8" rundown below the contact point of the spray pattern with the concrete surface. Allow the first application to penetrate the surface (approximately three to five minutes) and reapply in the same saturating manner. If the siloxane sealant is applied to surfaces of extremely dense, mirror finish concrete the Contracting Officer may direct that the siloxane be applied in one saturating application to prevent surface darkening.

h. Curing. - The treated areas shall be protected from rain and foot traffic for six hours after application. Vehicular traffic will not be allowed on the treated area until after 24 hours after the application of the siloxane.

i. Measurement for Payment. -

(1) Measurement for payment of surface preparation of the concrete surfaces will be made of the actual surface area prepared. Payment for surface preparation will be made at the unit price per square foot bid therefor in the schedule, which unit price shall include all costs of preparing the concrete surfaces for the siloxane as specified in paragraph 3.15.f.

(2) Payment for seal coating of the concrete surfaces will utilize the same area as measured for the surface preparation. Payment for seal coating of concrete surfaces will be made at the unit price per square foot bid therefor in the schedule, which unit price shall include all costs for storing and handling materials, of applying the siloxane system, of cleanup, and of providing all the necessary safety equipment, and any other work required under these specifications to properly complete the job.

Notes