Field Application of Shotcrete

An overview of field shotcrete operations

Excavate
Muck

Material removed in the process of excavating or mining

Support

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The shotcrete process has grown into an important and widely used construction technique. In 1910, a double chambered cement gun was introduced to the construction industry. The sand-cement product of this device was given the proprietary name Gunite. In the ensuing years, trade marks such as Guncrete, pneucrete, Blastcrete, Blocrete, Jetcrete, and the terms pneumatically applied mortar and concrete, were introduced to describe similar processes.
Introduction and History

- The early 1930s saw the generic term "shotcrete" introduced by the American Railway Engineering Association to describe the Gunite process.
- In 1951, the American Concrete Institute (ACI) adopted the term shotcrete to describe the dry-mix process.
- Shotcrete is now applied to the wet-mix process and has gained universal acceptance in the United States.

Definition Of Terms / References

- Gunite / Mortar: Maximum aggregate size = sand
- Shotcrete: Maximum aggregate size = 3/8” typical (1/2” max)
- AKA: Sprayed Concrete (Europe)
- Relevant ACI Publications
  - 506R-90 Guide to Shotcrete
  - 506.3R-91 Guide to Certification of Shotcrete Nozzlemen
  - 506.4R-94 Guide for the Evaluation of Shotcrete
  - 506.2-95 Specification for Materials, Proportioning and Application of Shotcrete
  - 506.1R-98 State of the Art Report on Fiber Reinforced Shotcrete
Component Materials

- Aggregate
  - Fine = 60 - 70% of combined weight of aggregates
  - Coarse = 30-40% of combined weight of aggregate
- Portland Cement
  - Types I, II = 6.5 - 9.0 sack (611 - 846 lb/yd³)
- Water (potable)
  - Target W/C = 0.33 - 0.45
- WRA
  - Objective = workability with reduction of W/C ratio
- Microsilica
  - Typical range = 5% - 15% by weight of cement
- Latex Modifier
  - More commonly used in thin layer repair work than in ground support
- Accelerator
  - Silicates
  - Aluminates
  - Dosage = 2 - 5% by weight of cementitious material
### Strength Development

**Strength Development of Sprayed Concretes**

- Compressive strengths in N/mm² (MPa)
  - 2900 psi
  - 1450 psi
  - 725 psi
  - 290 psi
  - 145 psi

### Shotcrete Applications

- **Sealing of Ground Mass Interface**
  - Prevent erosion and/or air slaking (crumbling)
  - Deter exfiltration/infiltration

- **Component of Excavation Support System**
  - Sole Support
  - Rockbolt / shotcrete system
  - Rockbolt / shotcrete / lattice girder system

- **Final Lining**
  - Practical, functional or esthetic considerations do not require formed concrete

- **Repair Work**
What is Shotcrete Good For?

- Very wet conditions
- Frozen ground conditions
- Ground conditions wherein bond is unreliable
- Intermittent application - small quantities - remote areas

**Dry Process Technique + Flow Chart**

**Dry process** - Dry materials are combined in a "pot", transported pneumatically to a nozzle where water, any liquid admixtures and accelerator are introduced into the streamfeed and then immediately sprayed onto the target surface with a velocity developed by compressed air under a pressure of 90 - 100 psi.
Wet Process - All materials with exception of accelerator are combined within a batch/mix plant, transported via positive displacement pump to a nozzle where accelerator is introduced into the streamfeed and then immediately sprayed onto the target surface with a velocity developed by compressed air under a pressure of 90 - 100 psi.

Comparison of the Dry- and Wet-Mix Processes

<table>
<thead>
<tr>
<th>Dry-mix process</th>
<th>Wet-mix process</th>
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<tbody>
<tr>
<td>1. Instantaneous control over mixing water and consistency of mix at the nozzle to meet variable field conditions.</td>
<td>1. Mixing water is controlled at the delivery equipment and can be accurately measured.</td>
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<tr>
<td>2. Better suited for placing mixes containing lightweight aggregates, refractory materials and shotcrete requiring early strength properties</td>
<td>2. Better assurance that the mixing water is thoroughly mixed with other ingredients</td>
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<td>3. Capable of being transported longer distances</td>
<td>3. Less dusting and cement loss accompanies the gunning operation</td>
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<td>4. Start and stop placement characteristics are better with minimal waste and greater placement flexibility</td>
<td>4. Normally has less rebound resulting in less material waste</td>
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<td>5. Capable of higher strengths</td>
<td>5. Capable of greater production</td>
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**Weigh Batch / mix Equipment Selection**

- **Batch/Mix Equipment**
  - **Weigh batcher**
    - Drum (turbine-screw) mixer
    - Admixture feeder(s) - furnished by supplier
    - Fiber feeder - furnished by supplier
    - ASTM Spec ref = C94-90
      Standard Specification for Ready-Mixed Concrete

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**Volumetric Batch/ mix Equipment Selection**

- **Volumetric batcher**
  - Screw (drum, turbine) mixer
  - Admixture feeder(s) - furnished by suppliers
  - Fiber feeder - furnished by suppliers
  - ASTM Specification reference =C685-90
    Standard Specification for Concrete Made By Volumetric Batching and Continuous Mixing

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Transport Equipment Selection

- Transit (drum) mixer
- Agitating vessel
- Non-agitating vessel
- Pneumatic transport (dry process material)
- Pump Transport (wet process material)

Placement Equipment Selection

- Wet Process Equipment
  - Compressed Air
  - Water (construction water for cleanup)
  - Positive displacement pump (or shotcrete pot)
  - Accelerator dosing pump
  - Robotized placer
Typical Wet Process Spread

- Compressed Air
- Water (potable)
- Shotcrete Pot
- Accelerator dosing device
- Robotized placer
Selected Dry Process Equipment

Selected Dry Process Equipment
Other Selection Considerations

- Required operating parameters
  - Role of shotcrete in the intended operation
  - Strength gain constraints
  - Accessibility to appropriate equipment
- Process type selection as a function of labor supply
  - Recent volume of similar work in the area
  - Labor agreements, local economic situations which would deter importing skilled labor.
  - Quality and work ethic of labor force.
  - Wet process favored when any of preceding are negative.
- Opinion: wet process offers better control of more of the critical variables:
  - W/C ratio is determined by the batch/mix process
  - Moisture content of the raw materials is less critical
  - Calibrated accelerator dosage
  - Wet mix affords a more uniform mix in place (more coarse aggregate, less rebound)

Preparation

- Although the dry process is similar, let’s assume the wet process for procedural discussion. Preparation requires:
  - Procure materials (compatibility testing)
  - Develop trial mixes (compatibility testing!!!)
  - Mobilize equipment and labor force
  - Shoot test panels
Operation

- Surface preparation is essential - will probably require pressure washing
- Make up a cement/water mix about the consistency of mayonnaise (a volume of ±1 ft³)
- Pour this lubricating mix into pump hose before starting to pump the production mixture
- When the pumped production mixture reaches the nozzle, turn on compressed air, accelerator and robotic placer motions
- Using good nozzle technique, apply shotcrete evenly to target surfaces
- Clean pump lines by blowing a rabbit and finishing with a thorough water flush of the entire system
- Cure of in place material = important consideration (+85% humidity = best solution)

Nozzle Technique
Nozzle Technique

Measurement For Payment

- Shotcrete by the unit price
  - Measurement for payment = calculated area (volume)
    - All plant and process waste
    - All rebound
    - All variations in thickness
    - All variations in plant yield
    - All materials expended in test phase
  - Measurement for payment = plant cubic yard
    - It poses minimal risk
  - Shotcrete paid as a lump sum