Sika® Shotcrete Systems
Technology and Concepts for Shotcrete

Our most current General Sales Conditions shall apply. Please consult the Product Data Sheet prior to any use and processing.
Introduction

Due to the need for flexibility, speed and economy, shotcrete has continuously grown in importance over recent decades, especially for heading support in tunnelling. The main reason for this is due to new developments and improvements in shotcrete and process technology.

New developments in concrete additives and fillers, cements, and application equipment are leading to innovative applications. For example, shotcrete is now commonly applied utilizing wet-spray techniques that result in excellent strength and durability. This potential has yet to be utilized to the full worldwide, as shotcrete is often used as temporary support concrete that only has to meet quite low quality requirements. More recently, however, the fullest possible know-how on wet-mix shotcrete has been developed in a wide variety of projects and for many different applications.

Clients and project designers can rely on the experience gained and can go ahead confidently with creative, innovative ideas and solutions.

The excellent reputation enjoyed by Sika in tunnelling is widely known because the company’s activities have always looked towards the future of tunnelling from its beginnings in 1910. The first patent for a spraying machine was registered in the year that Sika was founded, a symbolic coincidence because the history of tunnelling at Sika has always been clearly linked to the development of shotcrete technology. To cite just one example from this success story, the decision was made to use Sika products for the waterproofing to all the structures for the electrification of the railway line through the 1st Gotthard Alpine tunnel.

Sika Shotcrete Technology
Sika – The Leader by permanent Innovation

Machines

In 1933, the Sigunit® brand was born
In powder form, added by hand
Quantity added 3 – 7 %

1940
Sprbag BS-12/MS-12
First dry-mix machines (compressed air process) with a spraying capacity of up to 4 cyd/hr

1960
Sika® Aliva®-200/285
Rotor spraying machines and systems for dry and wet mixes

1980
Sika® PM500
Highly-mechanized shotcreting systems for dry or wet mix shotcrete

2000
Aluminium Sulphate
Sigunit®-49 AF Powder, the first alkali-free setting accelerator
Quantity added 4 – 7 %

1920
Naphthalene Sulphonate
Melamine Sulphonate
Sigunit®-L Liquid, still a reliable flow control agent in tunnelling
Working time up to 2 hours

Alkaline Aluminates
The first liquid setting accelerators for shotcrete, Sigunit®-L Liquid
Quantity added 3 – 6 %

Aluminium Hydroxide
Aluminium Sulphate
Sigunit®-AF Liquid setting accelerator
Quantity added 4 – 7 %

Vinyl Copolymers
SikaTard® shotcrete flow control agent
State of the art for decades
Working time up to 4 hours

Modified Polycarboxylates
Sika’ViscoCrete®, the latest innovation for shotcreting
Working time over 6 hours

Modified Polycarboxylates
Sika’ViscoCrete®, the latest innovation for shotcreting
Working time over 6 hours

State of the art for decades
Ecology and Economy

launch of alkali-free setting accelerators

Dust generation must be reduced and the sites require special attention.

Many serious accidents in the past have shown that working conditions on building sites require special attention.

The spraying capacity is the main factor influencing the economics of the wet spraying process. Depending on the application, up to 40 m³/hr can be achieved. To obtain a high output, it is important to find the best shotcrete formulation, layer thickness and type and quantity of accelerator. A high output cannot be obtained unless the concrete is easily pumpable.

If the concrete mixes are unsuitable, special additives help to prevent separation and reduce the pump pressure.

The amount of rebound loss is a crucial cost factor. In addition to loading, transporting and disposing of the rebound material, rebound costs also include the extra shotcrete that has to be produced and applied.

Fiber content

Early strength

Adhesion properties

Air volume and pressure

Substrate condition

Grading curve

Application thickness

Qualit ﬂuids for high water penetration points. The curve of strength development in the first few hours has a strongly increasing curve of strength development in the first few hours. The strength development is normally plotted for the period between 6 and 60 minutes. The strength is also measured at hourly intervals.

Final Strength

The less water in the concrete mix, the higher the porosity of the hardened cement will be, so that none of the concrete properties will be improved by an increase in the W/C ratio. The optimum amount of water necessary for cement hydration is a W/C ratio of about 0.40. Excess water evaporates after application and leaves voids in the hardened cement.

W/C ratio for wet shotcrete: lower specifications: < 0.55
W/C ratio for wet shotcrete: average specifications: < 0.50
W/C ratio for wet shotcrete: higher specifications: < 0.45

Durability

Impermeability

Durability means high impermeability. Low capillary porosity is essential for high watertightness and is obtained by correctly applied shotcrete with a low W/C ratio and correct curing.

Sulphates

Water-soluble sulphates react with the C.A in the cement to form ettringite. The ettringite crystals first propagate into the pores. When the pores are filled, ettringite develops expansive pressure that can destroy the concrete matrix. If sulphate-resistant shotcrete is required, sulphate-resistant cement grades must be used, e.g. composite cements with slag, pozzolanas or cement with a low C.A content and added silicate.

Frost

Unlike normally placed concrete, frost resistance is obtained in shotcrete by a dense microstructure rather than by introducing macropores. Fillers such as silicate cause a higher level of hydration, giving lower porosity and water absorptivity.


Shotcrete Requirements: Ecology and Economy

Sika is committed to the global chemical industry environmental management system "Responsible Care" which defines the principles for safety, health and environmental protection.

Many serious accidents in the past have shown that working conditions on building sites require special attention. Dust generation must be reduced and the hazards created by corrosive and toxic chemicals must be minimized. The market launch of alkali-free setting accelerators such as Sigunit® AF® is a milestone.

As far as dust pollution is concerned, the wet spraying process creates much less dust than dry-mix spraying. The amount of dust can also be reduced by the best possible nozzle technology. Non-toxic, alkali-free accelerators with a pH value of around 3 reduce the human and environmental hazards during handling, storage and use. The spray contains no corrosive aerosols, so that damage to the skin, mucous membranes and eyes can be avoided.

The spraying capacity is the main factor influencing the economics of the wet spraying process. Depending on the application, up to 40 m³/hr can be achieved. To obtain a high output, it is important to find the best shotcrete formulation, layer thickness and type and quantity of accelerator. A high output cannot be obtained unless the concrete is easily pumpable.

If the concrete mixes are unsuitable, special additives help to prevent separation and reduce the pump pressure.

Parameters influencing the rebound quantity

- Application thickness
- Grading curve
- Substrate condition
- Angle of application
- Air volume and pressure
- Adhesion properties
- Early strength
- Fiber type
- Fiber content
- Spraying process

Our commitment to safety, health and environment

- pH value
- Conventional accelerator pH 13
- pH 3 – 8 Safe range for human tissue and vascular
- Acid
- Basic
- Water-soluble sulphates react with the C.A in the cement to form ettringite. The ettringite crystals first propagate into the pores. When the pores are filled, ettringite develops expansive pressure that can destroy the concrete matrix. If sulphate-resistant shotcrete is required, sulphate-resistant cement grades must be used, e.g. composite cements with slag, pozzolanas or cement with a low C.A content and added silicate.

Frost

Unlike normally placed concrete, frost resistance is obtained in shotcrete by a dense microstructure rather than by introducing macropores. Fillers such as silicate cause a higher level of hydration, giving lower porosity and water absorptivity.

Shotcrete Requirements: Quality and Performance

Clients, project designers, contractors and health and safety authorities all set different specific standards for the shotcretes.

To the project designer, the most important factor is meeting the specifications, while the contractor places the emphasis mainly on the most economic production and installation method that guarantees the required quality at minimum cost. Health and safety authorities demand maximum hygiene and safety on site during the spraying operations including maximum early strength of the shotcrete applied for heading support, low dust pollution and minimum hazards from toxic or alkaline substances.
Shotcrete Mix Designs

Mix designs for shotcrete must always be adapted to the specifications of the aggregate components and cement available so that the required early strength and workability can be obtained. Preliminary tests in the concrete laboratory make the site operations easier.

The cement grade has a strong influence on both strength development in the early stages and the final strength and properties of the hardened concrete. Sikacrete® 950 DP is used for much higher watertightness (durability) and reduced rebound. SikaTard® 930 is used to retard and preserve the shotcrete mix until it is applied and ViscoCrete® high range water reducers provide better workability at a reduced water content. Steel fiber increases the load-bearing capacity and ductile bearing properties of the shotcrete. Polypropylene fiber is used for improved early shrinkage properties and higher fire resistance of the shotcrete. The air void content of the fresh shotcrete is increased, which improves the workability and finish of the shotcrete.

The maximum aggregate particle size depends on the layer thickness and the surface finish required for the shotcrete. Approximately 95% of the aggregate surface is supplied by the 0 – 4 mm sand fraction and variations in the sand component have a massive effect on the fresh concrete properties, the W/C ratio and therefore the properties of the hardened concrete. The sand fraction must be analyzed with extreme care during the quality control process. We distinguish between round and angular aggregate. The best particle form is cubic/spherical: it is very important for workability. The aggregate must be hard, clean and not weathered.

Examples of Mix Designs

**Dry-mix shotcrete**

- **Cement**: 570 lbs.
- **Sikacrete 950DP (Silica Fume)**: 40 lbs.
- **Aggregates (coarse aggregate + sand)**: 3085 lbs.
- **W/Cm**: 0.36

Shotcrete from 1 cyd dry mix produces on the wall:
- Accelerated with Sigunit AF Powder (rebound 16-20%) 0.58 - 0.61 cyd.
- Accelerated with Sigunit AF Liquid (rebound 20-25%) 0.55 - 0.58 cyd.

**Wet-mix shotcrete**

- **Cement**: 725 lbs.
- **SikaCrete 950 DP (Silica Fume)**: 50 lbs.
- **Sand**: 1690 lbs.
- **Coarse aggregates (⅜”)**: 950 lbs.
- **Water (W/Cm=0.43)**: 333 lbs.
- **Steel Fibers**: 50 lbs.
- **Sika ViscoCrete**: 3 fl. oz.
- **SikaTard 930**: 4 fl. oz.
- **Air voids (5%)**: 3798 lbs.

1 cyd of sprayed concrete produces on the wall:
- Accelerated with Sigunit AF Liquid (rebound 6-10%) 0.90 - 0.94 cyd

Sufficient amount of fines (<0.125 mm) are important for good pumpability.

Typical Grading Curve of Wet Sprayed Concrete, dense flow process

Quality Control

During the prequalification procedure the client or project designer normally requires suitability tests to be carried out to verify that the specifications are met. These tests should be done at the start of construction utilizing the locally available raw materials (cement and aggregate) and the plant and equipment planned for the project must be used.

During construction the quality of the shotcrete must be controlled in accordance with the contract documents.

**Examples of Quality Control**

- **Flow-table spread testing of fresh concrete**
- **Concrete spraying, spraying shadow/rebound**
- **Early strength of 0 – 1 N/mm²**
- **Penetrometer method**
- **Early strength of 1 – 15 N/mm²**
- **Stud-shooting method**
- **Compressive strength of core sample**
- **Compression press**
- **Water impermeability testing with water under pressure**
## Shotcrete Application

### Use | Typical requirement
--- | ---
**Heading Stabilization in tunnelling** | High early strength  Low final strength  High spraying capacity
**Tunnel lining with shotcrete** | High early strength  High final strength  High watertightness  High durability
**Mining** | High early strength  Sealing of excavation faces  Low to medium final strength
**High or increased fire resistance** | Protective layer (no load-bearing requirement)  High adhesion  Resistant to temperatures over 2200°F
**Slope stabilization**
**Excavation stabilization** | Rapid strength development  Flexible use  Flexibility of use for spraying small concrete volumes
**Tunnel repair** | Long-term resistance  Good adhesion  Chemical resistance  Suitable elastic modulus
**Repair of concrete dams** | High durability in thin layers  Low elastic modulus  Low rebound
**Repair of harbor walls** | High mechanical resistance  High resistance to chemical effects  Low elastic modulus
**Bridge repair** | New concrete not susceptible to vibration from traffic  Frost and freeze/thaw resistance

### Wet Spraying Process
- **Dense flow process**
  - The shotcrete (wet mix) is loaded into the piston pump funnel tube
  - Delivery to the nozzle is by the dense flow process
  - Just before the nozzle (distance depending on whether the accelerator is alkali-free or alkaline) the dense flow is broken up in the current nozzle by high air pressure
  - The Sigunit® accelerator is added to the shotcrete with the air at the current nozzle

#### Advantages
- Low wear costs
- The machine can also be used for pumping/backfilling
- Shotcrete with steel fiber
- High output up to 48 cyd/hr.
- Low compressed air consumption

#### Disadvantages
- Complex start-up and cleaning process

### Dry Spraying Process
- **Fine flow process**
  - The shotcrete (dry mix) is loaded into the rotor machine funnel tube
  - Delivery to the nozzle is by the fine flow process
  - Just before the nozzle (distance depending on whether the accelerator is alkali-free or alkaline) the Sigunit® accelerator is added to the shotcrete with water

#### Advantages
- Easy to handle
- Does not need pumpable concrete
- Maximum early strength
- Delivery of gravel and sand

#### Disadvantages
- Very high dust generation
- Wear costs
- Higher rebound
**Shotcrete Additives**

**Workability Time of Wet Shotcrete Mixes**

- Wet-mix shotcrete with basic retarding of 3 hours with SikaTard 203
- Long-time retarded wet-mix shotcrete with SikaTard 930 and Sika ViscoCrete

**Table of Additives and Fillers for Shotcrete**

<table>
<thead>
<tr>
<th>Type</th>
<th>Product</th>
<th>Use/Effect</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Reducers</td>
<td>SikaTard®</td>
<td>High water reduction</td>
<td>Optimum effect when added after the mix water</td>
</tr>
<tr>
<td>High Range Water Reducers</td>
<td>Sika 'ViscoCrete'®</td>
<td>Better workability</td>
<td>Optimum dosage depends on cement type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time controlled workability</td>
<td>For specific properties, preliminary tests with the cement and aggregates to be used are essential</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved workability</td>
<td></td>
</tr>
<tr>
<td>Retarder</td>
<td>SikaTard-930</td>
<td>Adjustable workability</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No cleaning of pumps and hoses necessary during the retarding phase</td>
<td></td>
</tr>
<tr>
<td>Silicafume slurry</td>
<td>Sikacrete® L</td>
<td>Improved fresh concrete homogeneity</td>
<td></td>
</tr>
<tr>
<td>Silicafume powder</td>
<td>Sikacrete® 950DP</td>
<td>Much higher workability</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improved adhesion between aggregate and hardened cement</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High frost and freeze/thaw resistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower rebound</td>
<td></td>
</tr>
<tr>
<td>Polymer-modified silicafume powder</td>
<td>Sikacrete® PP1</td>
<td>Similar to Sikacrete® 950DP plus</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Significant water reduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>For very high quality specifications</td>
<td></td>
</tr>
</tbody>
</table>

**Table of the various Accelerator Types and their main Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Accelerator type</th>
<th>Alkaline Aluminate-based</th>
<th>Alkaline Silicate-based</th>
<th>Alkali-free</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosing range</td>
<td></td>
<td>3 – 5 %</td>
<td>12 – 15 %</td>
<td>4 – 7 %</td>
</tr>
<tr>
<td>pH value</td>
<td></td>
<td>13 – 14</td>
<td>11 – 13</td>
<td>3</td>
</tr>
<tr>
<td>Na2O equivalent</td>
<td></td>
<td>16 %</td>
<td>12 %</td>
<td>≤5 %</td>
</tr>
<tr>
<td>Very early strength at same dosage</td>
<td></td>
<td>++++</td>
<td>++++</td>
<td>+++</td>
</tr>
<tr>
<td>Final strength</td>
<td></td>
<td>–</td>
<td>–</td>
<td>+++</td>
</tr>
<tr>
<td>Watertightness</td>
<td></td>
<td>++</td>
<td>–</td>
<td>++</td>
</tr>
<tr>
<td>Leaching behavior</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Occupational health</td>
<td></td>
<td>–</td>
<td>–</td>
<td>+++</td>
</tr>
<tr>
<td>Occupational and transport safety</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

**Leaching of the Calcium Hydroxide Ca(OH)$_2$**

- Shotcrete with SikaTard AF (alkali-free)
- Shotcrete without setting accelerator
- Shotcrete with conventional alkaline setting accelerator

**Commentary**

- For the dry or wet spraying process
- Non-corrosive
- Low final strength reduction compared with the non-accelerated original concrete
- Not compatible with alkaline accelerators
- Metal parts in contact with this accelerator must be of stainless steel
### Dry and Wet Mix Spray Mortars

#### Sika®-NS
- For significant water presence
- High early strength
- Water tightness
- Good adhesion to substrate
- Dry spraying process
- Usable with rotor machines
- 1-component ready-mix gunite, highly accelerated

#### Sika®-PM702
- Compact easy-to-operate concrete spraying pump
- Synchronized accelerator dosage
- Powered by electric or diesel engine

#### Sika®-PM500
- Highly mechanized concrete spraying systems for large and small tunnels
- High flexibility due to modular design
- Ideal for high slopes

#### Aliva®-246/Aliva®-252/Aliva®-263/
- Aliva®-285
- Concrete spraying machines for dry and wet spraying
- Low to medium outputs
- Mobile and multi-purpose
- For spray mortar and shotcrete

### Machines for Shotcreting

#### Concrete Spraying Systems
- Sika®/PM8500

#### Concrete Spraying Machines
- Sika®/PM8500

#### Spraying Robots for TBM
- Heading

#### Spraying Robots for TBM
- Heading

#### Concrete Spraying Pump
- Sika®/PM702
- Compact easy-to-operate concrete spraying pump
- Synchronized accelerator dosage
- Powered by electric or diesel engine

#### Spray Arms/Metering Units
- Telescopic spraying arm
- Sika®/PM Spraying Booms
- Wide radius of operation
- Maximum mobility
- Liquid metering unit
- Aliva®-403.5
- High efficiency
- Synchronized metering control

#### Sealing Gunite
- High durability
- High frost and freeze/thaw resistance
- Sulphate-resistant
- Good adhesion to substrate
- Dry spraying process

#### Sikacem® 133
- Can be applied in thin layers
- High frost and freeze/thaw resistance
- Sulphate-resistant
- Good adhesion to substrate
- Dry spraying process

#### Aliva®-TBM Spraying Robots
- Shortcrete robot for immediate stabilization and lining by shotcreting
- Medium to high outputs
Uses of Shotcrete

Shotcrete Stabilization in conventional Heading

**Sika Solution**
- High Range Water Reducers: SikaTard®/Sika® ViscoCrete®
- Retarder: SikaTard®-930
- Setting accelerator: Sigunite® AF Liquid, second generation
- Shotcreting systems: Sika® PM500/Aliva® 503

**Excavation Slope Stabilization with Wet or Dry Mix Shotcrete**

**Sika Solution**
- Flow control agent: SikaTard®
- Setting accelerator: Sigunite® AF Liquid, first generation
- Concrete spraying machines: Aliva®-263/Aliva®-285

Shotcrete Stabilization in TBM Heading

**Sika Solution**
- High Range Water Reducer: SikaTard®/Sika® ViscoCrete®
- Retarder: SikaTard®-930
- Setting accelerator: Sigunite® AF Liquid, second generation
- Robot sprayer: Aliva®303/Aliva®-303 L2

**Concrete Repair with Dry Mix Spray Mortars**

**Sika Solution**
- Patching mortar: Sikacem® 103F
- Concrete spraying machine: Aliva®-246

**Sika Solution**
- Concrete Repair with Dry Mix Spray Mortar
  - Patching mortar: Sikacem® 133
  - Concrete spraying machine: Aliva®-252

---

Shotcrete stabilization in TBM heading

Shotcrete stabilization in large sections

Aliva®-503 shotcreting system for small sections

Slopes stabilization

Excavation stabilization

Concrete repair

Tunnel repair