Tunneling & Mining

Sika® Shotcrete Systems

Technology and Concepts for Shotcrete

Sika Shotcrete Technology

Sika – The Leader by permanent Innovation

The high reputation enjoyed by Sika in tunnelling is so widely known because the Company's activities 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 was always clearly marked by 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.

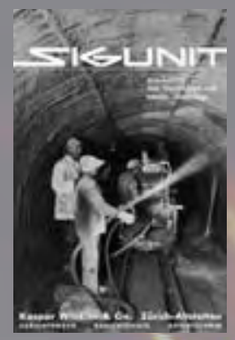
Introduction

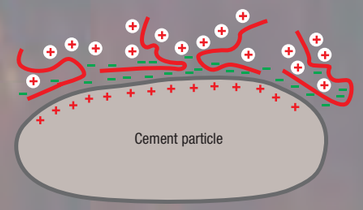
For reasons of flexibility, speed and economy, shotcrete has grown continuously in importance over recent decades, especially for heading support in tunnelling. The main basis for this was new developments or improvements in shotcrete and process technology.

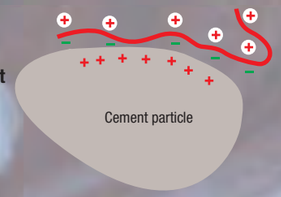
New developments in concrete additives and fillers, cements and methods of application are leading to innovative new applications and enabling shotcrete to be produced by the wet spraying process which can meet the highest strength and durability requirements. This potential has yet to be utilized to 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.

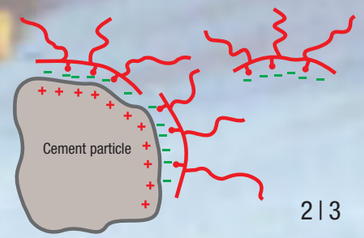
Clients and project designers can rely on the experience gained and can go ahead confidently with creative, innovative ideas and solutions.

	Machines	Accelerators	Flow Control Agents
1920		**In 1933 the Sigunite® Brand was born** In powder form, added by hand Quantity added 3 – 7 %	
1940	**Spribag BS-12/MS-12** First dry-mix machines (compressed air process) with a spraying capacity of up to 3 m³/hr.		**Naphthalene Sulphonate Melamine Sulphonate** **Sikament®, still a reliable flow control agent in tunnelling** Working time up to 2 hours
1960		**Alkaline Aluminates** The first liquid setting accelerators for shotcrete, **Sigunite®-L Liquid** Quantity added 3 – 6 %	
1980	**Sika® Aliva®-200/285** Rotor spraying machines and systems for dry and wet mixes	**Aluminium Sulphate** **Sigunite®-49 AF Powder,** the first alkali-free 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
2000	**Sika®-PM500** Highly-mechanized shotcretingsystems for dry or wet mix shotcrete	**Aluminium Hydroxide Aluminium Sulphate** **Sigunite® AF Liquid** setting accelerator Quantity added 4 – 7 %	**Modified Polycarboxylates** **Sika® ViscoCrete®, the latest innovation for shotcreting** Working time over 6 hours









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 **Sigunite® AF** is a milestone in tunnelling.

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.

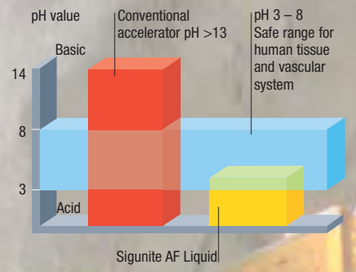
The spraying capacity is the main factor influencing the economics of the wet spraying process. Depending on the application, up to 30 m³/hour can be achieved. To obtain a high output, it is important to find the best shotcrete formulation, layer thickness and type and quantity of accelerator. A high 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 involve the extra shotcrete that has to be produced and applied.

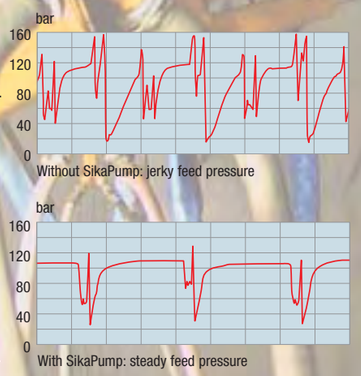
Parameters influencing the rebound quantity

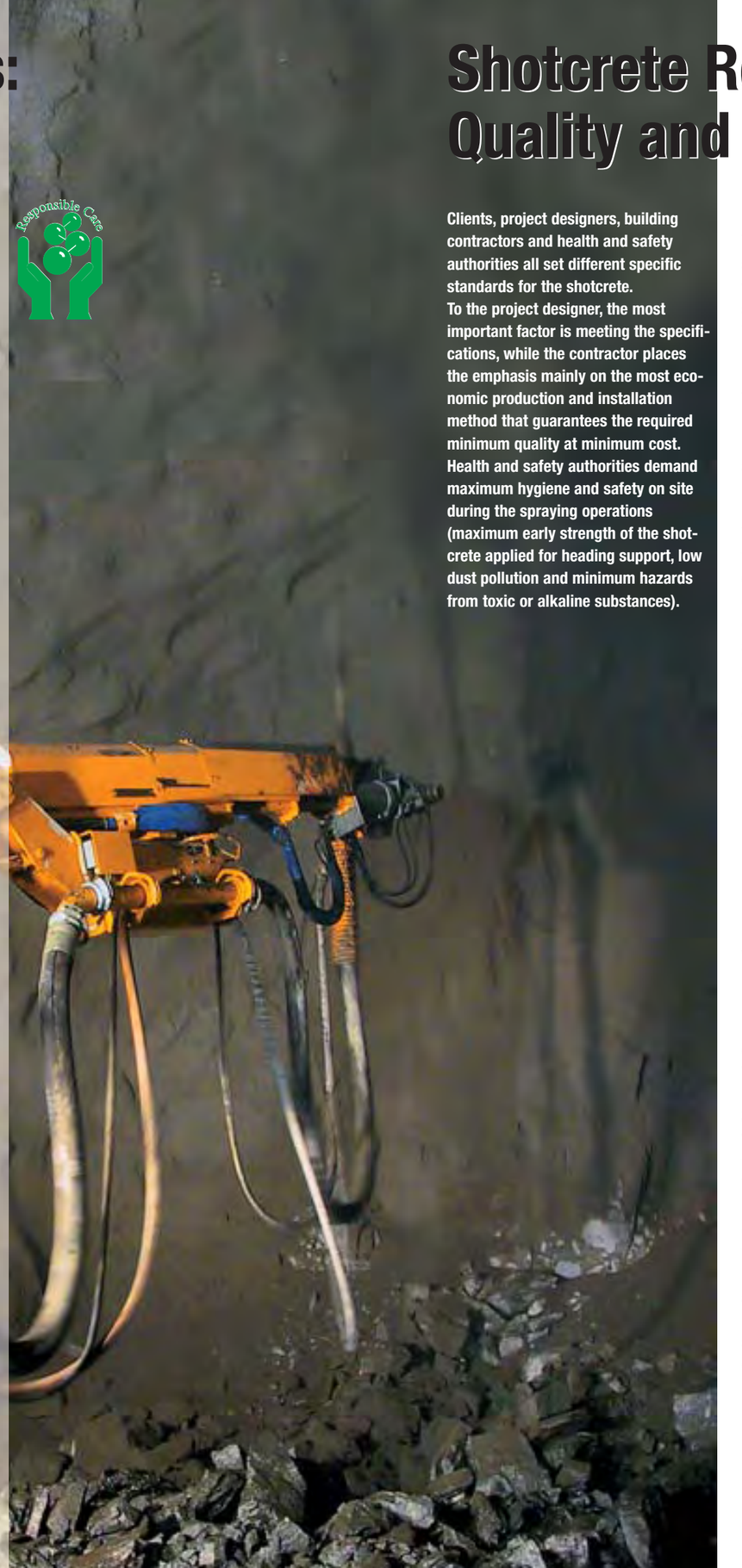
- Layer thickness
- Grading curve
- Substrate condition
- Jet trajectory
- Air volume and pressure
- Adhesion properties
- Early strength
- Fiber type
- Fiber content
- Spraying process

Our commitment to safety, health and environment



Pump pressure during concrete delivery





Shotcrete Requirements: Quality and Performance

**Clients, project designers, building contractors and health and safety authorities all set different specific standards for the shotcrete.
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 minimum quality at minimum cost. Health and safety authorities demand maximum hygiene and safety on site during the spraying operations (maximum early strength of the shotcrete applied for heading support, low dust pollution and minimum hazards from toxic or alkaline substances).**

Early Strength ❶

This is the prerequisite for overhead spraying, particularly for high outputs, when applying thick layers or when spraying onto water penetration points. The curve of strength development in the first few minutes has a strong influence on dust generation and rebound. The strength development is normally plotted for the period between 6 and 60 minutes. The strength is also measured at hourly intervals.

Final Strength ❷

The less water in the concrete mix, the lower the porosity of the hardened cement. This has an advantageous effect on most of the concrete properties, especially compressive strength. The amount of water necessary for cement hydration equates to 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 for low specifications: < 0.55
- W/C ratio for wet shotcrete for average specifications: < 0.50
- W/C ratio for wet shotcrete for high specifications: < 0.46

Durability, Watertightness ❸

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

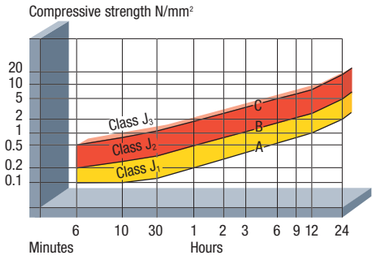
Sulphates ❹

Water-soluble sulphates react with the C_3A in the cement to form ettringite. The ettringite crystals first propagate into the pores. When the pores are filled, ettringite develops explosive pressure that can destroy the concrete structure. If sulphate-resistant shotcrete is required, sulphate-resistant cement grades must be used, e.g. composite cements with slag, pozzolana or cement with a low C_3A content and added silicafume.

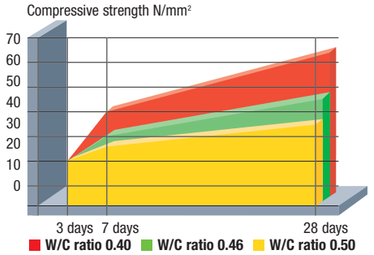
Frost

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

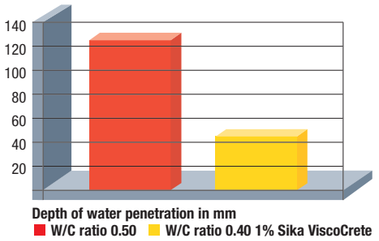
Shotcrete strength development specifications ❶



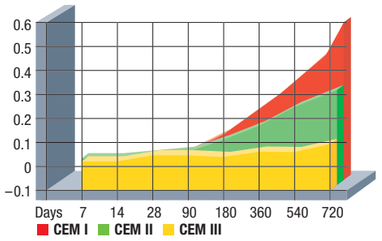
Effect of W/C ratio on compressive strength ❷



Effect of W/C ratio on depth of water penetration ❸



Sulphate resistance of concrete cores ❹
Difference in mean linear deformation between samples stored in sulphate and in water



Shotcrete Formulations

Formulations 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. **SikaFume®** is used for much higher watertightness (durability) and reduced rebound. **SikaTard® (retarder)** is used for long-time retarded shotcrete and **SikaTard®** or **ViscoCrete® (flow control agents)** for better workability at a reduced water content. Steel fiber increase 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 spraying result.

The maximum aggregate particle size depends on the layer thickness and the surface finish required for the shotcrete layer. 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 broken 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 Concrete Formulations

Dry-mix shotcrete 0 – 8 mm			
Cement		280 kg	
SikaFume®-HR/-TU		20 kg	
Retarder SikaTard®-930	0.3 %		
0 – 4 mm with 4% inherent moisture	55 %	ca. 680 kg	
4 – 8 mm with 2% inherent moisture	45 %	ca. 560 kg	
Dry mix moist m³		***ca. 1540 kg**	
*Must be checked by a yield test			
Cement content			
For 1000 litres dry mix, 280 kg cement is added to 800 litres aggregate			
For 1250 litres dry mix, 350 kg cement is added to 1000 litres aggregate			
Shotcrete from 1 m³ dry mix gives on the wall			
Accelerated with **Sigunite® AF Powder** (rebound 16 – 20 %) 0.58 – 0.61 m³			
Accelerated with **Sigunite® AF Liquid** (rebound 20 – 25 %) 0.55 – 0.58 m³			
Cement content in the shotcrete ca. 450 – 460 kg/m³			

Wet-mix shotcrete 0 – 8 mm			
Cement		425 kg	135 l
SikaFume®-HR/TU		20 kg	9 l
Flow control SikaTard®/ Sika® ViscoCrete®	1.2 %		
Retarder SikaTard®-930	0.3 %		
Aggregate:			
0 – 4 mm with 4% inherent moisture	60 %	967 kg	358 l
4 – 8 mm with 2% inherent moisture	40 %	791 kg	293 l
Added water (W/C = 0.47)		155 kg	155 l
Air voids (4.5 %)			45 l
Steel fiber		40 kg	5 l
Shotcrete			**1000 l**
Density per m³		**2398 kg**	
1 m³ of applied shotcrete gives set on the wall			
Accelerated with **Sigunite® AF Liquid** (rebound 6 – 10 %) 0.90 – 0.94 m³			
Cement content in shotcrete 450 – 470 kg/m³			
Steel fiber content in shotcrete 30 – 36 kg/m³			

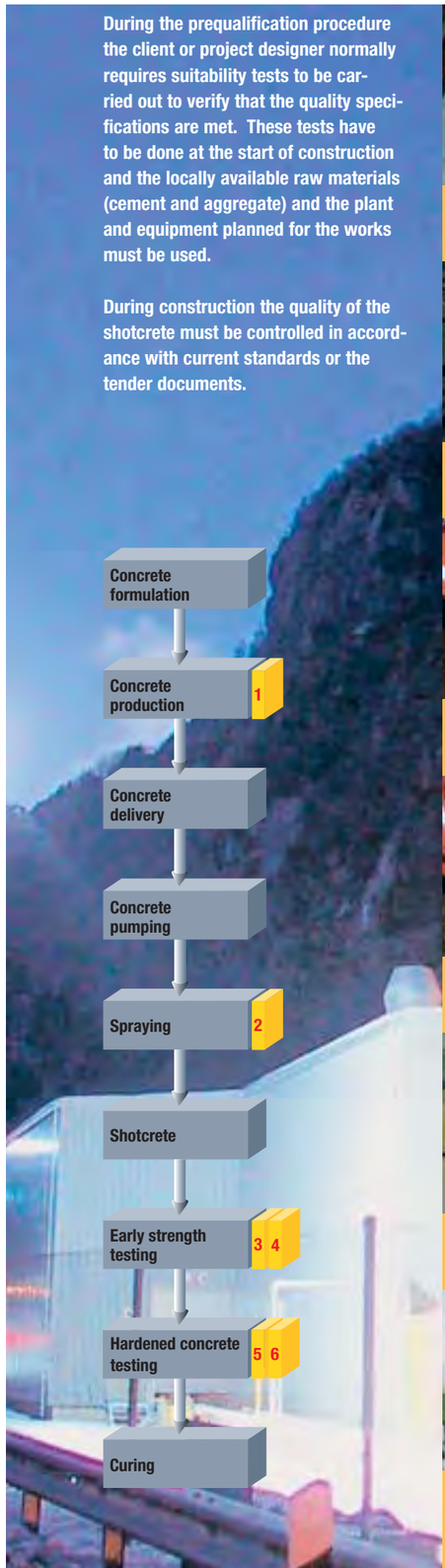
Sufficient fines ≤ 0.125 mm are important for pumpability. Recommended fines content (total aggregate + cement + additional fine aggregates):

Aggregate	0 – 8 mm	0 – 16 mm
Round	500 kg/m³	450 kg/m³
Broken	525 kg/m³	475 kg/m³

Quality Control

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

During construction the quality of the shotcrete must be controlled in accordance with current standards or the tender documents.




Flow-table spread testing of fresh concrete **1**


Concrete spraying, spraying shadow/rebound **2**

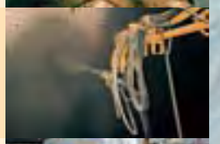
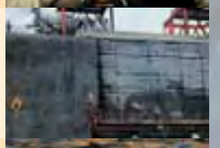

Early strength of 0 – 1 N/mm²
Penetrometer method **3**


Early strength of 1 – 15 N/mm²
Stud-shooting method **4**


Compressive strength of core sample
Compression press **5**


Water impermeability
Testing with water under pressure **6**

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 function) High adhesion Resistant to temperatures of over 1200 °C	
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 harbour walls	High mechanical resistance High resistance to chemical effects Low elastic modulus	
Bridge reconstruction	New concrete not susceptible to vibration from traffic Frost and freeze/thaw resistance	

Wet Spraying Process

Dense flow process
Sika®Aliva®-278/Sigunite® AF Liquid

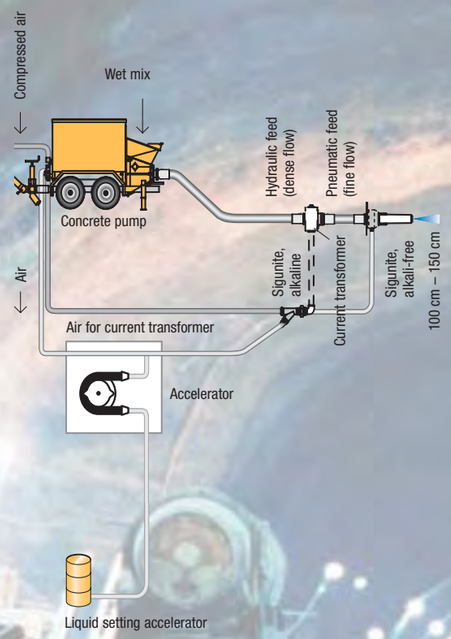
- **The shotcrete (wet mix) is loaded into the piston pump funnel tube**
- **Delivery to the nozzle is by the dense flow process**
- **Just before the nozzle (distance depending on whether the accelerator is alkali-free or alkaline) the dense flow is broken up in the current transformer by high air pressure**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

Advantages

- **Low wear costs**
- **The machine can also be used for pumping/backfilling**
- **Shotcrete with steel fiber**
- **High output up to 30 m^3/h**
- **Low compressed air consumption**

Disadvantages

- **Complex start-up and cleaning process**



Fine flow process
Sika®Aliva®-263/Sigunite® AF Liquid

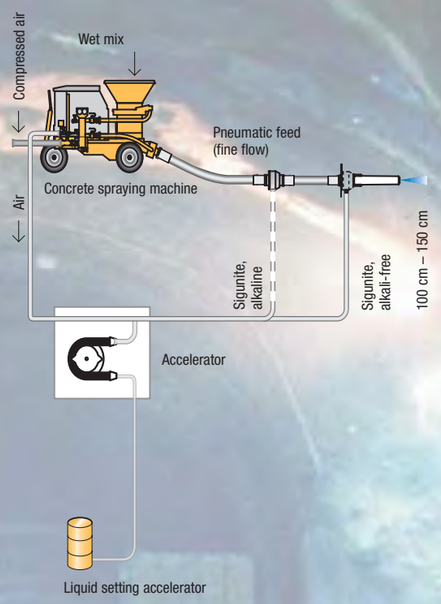
- **The shotcrete (wet mix) is loaded into the rotor machine funnel tube**
- **Delivery to the nozzle is by the fine flow process**
- **Just before the nozzle (distance depending on whether the accelerator is alkali-free or alkaline) the Sigunite® accelerator is added to the shotcrete with air**

Advantages

- **Easy to handle**
- **The concrete does not have to be pumpable**
- **Start-up and pause without prelubrication or cleaning**
- **Dry-mix spraying without change of machine**
- **Spraying with steel fiber**

Disadvantages

- **Problems with fine aggregate (caking)**



Dry Spraying Process

Fine flow process
Sika®Aliva®-263/Sigunite® AF Powder

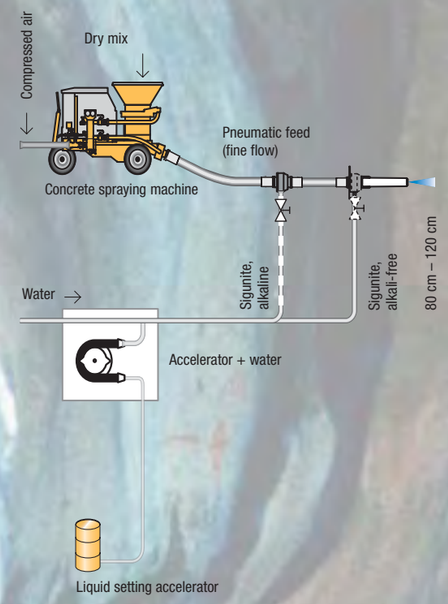
- **The shotcrete (dry mix) is loaded into the rotor machine funnel tube**
- **Delivery to the nozzle is by the fine flow process**
- **Just before the nozzle (distance depending on whether the accelerator is alkali-free or alkaline) the Sigunite® accelerator is added to the shotcrete with water**

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

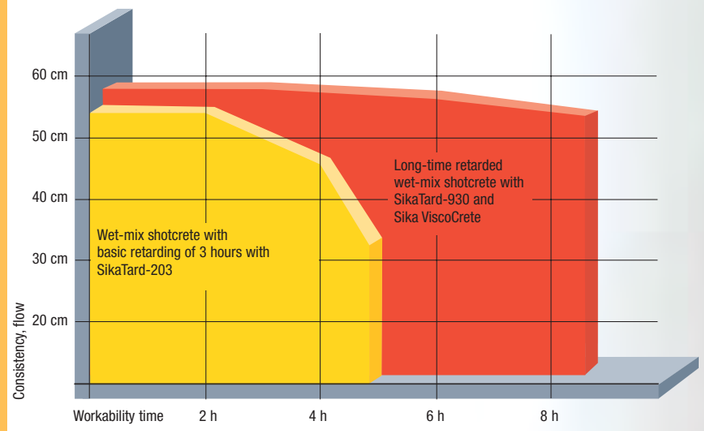


Table of Additives and Fillers for Shotcrete

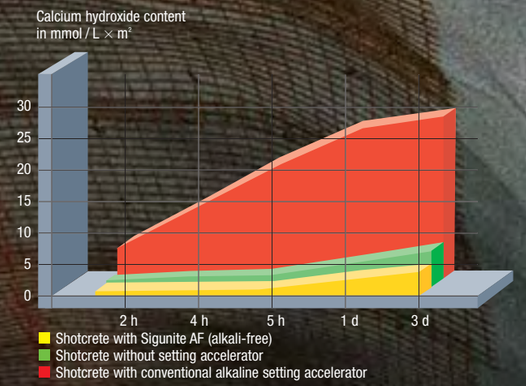
Type	Product	Use/effect	Remarks
Flow control agent (FM) High-performance flow agent	**SikaTard®** **Sika® ViscoCrete®**	■ High water reduction ■ Better workability ■ Time controlled workability ■ Rapid increase in strength ■ Better shrinkage and creep properties ■ Higher watertightness	■ Optimum effect when added after the mix water ■ Optimum dosage depends on cement type ■ For specific properties, preliminary tests with the cement and aggregates to be used are essential
Retarder (VZ)	**SikaTard®-930**	■ Adjustable workability ■ No cleaning of pumps and hoses necessary during the retarding phase	
Silicafume slurries Silicafume powder	**Sikacrete®-L** **SikaFume®**	■ Improved fresh concrete homogeneity ■ Much higher watertightness ■ Improved adhesion between aggregate and hardened cement ■ High frost and freeze/thaw resistance ■ Lower rebound	■ Added at the batching plant ■ Optimum curing is necessary because silicafume concrete dries out very quickly on the surface
Polymer-modified silicafume powder	**Sikacrete®-PP1**	■ As for **SikaFume,®** plus: ■ Significant water reduction ■ For very high quality specifications	■ As for **SikaFume®**
Pumping agents and stabilizers	**SikaPump®** **Sika® Stabilizer**	■ Improvement in homogeneity and internal cohesion for unsuitable concrete mixes ■ Increase in spraying output with lower energy consumption, even for mixes with broken aggregate	Addition increases the power input of the mixer and the concrete consistency – do not adjust by adding water

Shotcrete Accelerators

Table of the various Accelerator Types and their main Properties

Property	Accelerator type		
	Alkaline Aluminate-based	Alkaline Silicate-based	Alkali-free
Dosing range	3 – 6 %	12 – 15 %	4 – 7 %
pH value	13 – 14	11 – 13	3
Na_2O equivalent	20 %	12 %	<1 %
Very early strength at same dosage	++++	++++	+++
Final strength	+	--	+++
Watertightness	++	--	+++
Leaching behaviour	---	--	-
Occupational health	-	+	+++
Occupational and transport safety	---	+	+++

Elutability of the Calcium Hydroxide $Ca(OH)_2$



Liquid, alkali-free setting accelerator	**Sigunite® AF Liquid**	■ Heading stabilization in tunnelling ■ Rock and slope stabilization ■ High-quality lining shotcrete ■ Very high early strength ■ Increased watertightness ■ Reduced eluate quantity ■ Better health and safety	■ 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
Powder, alkali-free setting accelerator	**Sigunite® AF Powder**		
Liquid, alkaline setting accelerator	**Sigunite® Liquid**	■ Heading stabilization in tunnelling ■ Rock and slope stabilization ■ Very high early strength ■ Lower rebound ■ Can be sprayed on a wet substrate	■ For the dry or wet spraying process ■ Corrosive ■ Final strength reduction compared with the non-accelerated original concrete
Powder, alkaline setting accelerator	**Sigunite® Powder**		

Dry and Wet Mix Spray Mortars

SikaShot®

Stabilization and sealing gunite

- For significant water presence
- Maximum early strength
- High watertightness
- Good adhesion to substrate
- Dry spraying process
- Usable with rotor machines
- 1-component ready-mix gunite, highly accelerated

SikaCrete®-Gunite®

Sealing gunite Silicafume-modified

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

SikaCem®-Gunite®

Sealing gunite Polymer-modified

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

Sika® MonoTop®

Repair mortar Silicafume and polymer-modified

- Repair of concrete structures
- High frost and freeze/thaw resistance
- Good adhesion to substrate
- Ideal surface workability
- Wet spraying process
- 1-component ready-mix mortar

Machines for Shotcreting

Concrete Spraying Systems

Sika®-PM500

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

Experts on Sprayed Concrete

Concrete Spraying Machines

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

Spraying Robots for TBM Heading

Aliva®-TBM Spraying Robots

- Shotcreting robot for immediate stabilization and lining by shotcreting
- Medium to high outputs

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

Concrete Spraying Pump

Sika®-PM702

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

Uses of Shotcrete

Shotcrete Stabilization in conventional Heading

Sika Solution

Flow control agent **SikaTard®/Sika® ViscoCrete®**
Retarder **SikaTard®-930**
Setting accelerator **Sigunite® AF Liquid,** second generation
Shotcreting systems **Sika®-PM500/Aliva®-503**

Sika-PM500 shotcreting system for large sections

Aliva-503 shotcreting system for small sections

Shotcrete Stabilization in TBM Heading

Sika Solution

Flow control agent **SikaTard®/Sika® ViscoCrete®**
Retarder **SikaTard®-930**
Setting accelerator **Sigunite® AF Liquid,** second generation
Robot sprayer **Aliva®-303 L1/Aliva®-303 L2**

Shotcrete stabilization in TBM heading

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**

Slope stabilization

Excavation stabilization

Concrete Repair with Dry Mix Spray Mortars

Sika Solution

Bonding coat **Sika® MonoTop®**
Patching mortar **Sika® MonoTop®**
Concrete spraying machine **Aliva®-246**

Bridge repair

Sika Solution

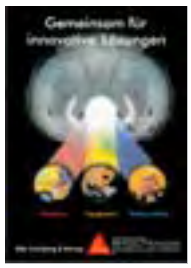
Seal **SikaShot®**
Patching mortar **SikaCem®-Gunite®**
Concrete spraying machine **Aliva®-252**

Tunnel repair

Sika® Shotcrete Systems

Technology and Concepts for Shotcrete

Concrete System Documentation









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