CONCRETE
SikaFiber® TECHNOLOGY

BUILDING TRUST
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FIBRE REINFORCEMENT

Fibres are an ideal addition to concrete and mortar and can go a long way to compensating for any weaknesses in these products. Primarily they increase energy absorption performance and fire-resistance, while also diminishing crack widths and reducing shrinkage cracking overall. Adding fibres produces a concrete which needs significantly less reinforcing steel than conventional reinforced concrete, but which is as -- or often more -- durable.

The idea of using fibre reinforcement in building materials goes back hundreds, if not thousands, of years and, yet, is more pertinent than ever thanks to modern technologies. Just as concrete has developed over recent decades, so has fibre technology. Concrete applications using fibres have increased thanks to the new fibre materials, such as steel and glass, being introduced to replace traditional fibres. SikaFiber® Technology has been at the vanguard of these developments.

FIBRES BRING IMPROVEMENTS TO CONCRETE AND STRUCTURES

FIBRE-REINFORCED CONCRETE is concrete to which fibres have been added during production to reduce cracking and improve its fracturing behavior. After many years of research and development, fibre-reinforced concrete is now fully recognized in the market for its important advantages.

The fibres are embedded in the cement matrix where they lay dormant until the concrete hardens – when they inhibit the emergence of cracks through their tensile strength and extensibility. In areas of greater stress, the fibres prevent large cracks by dissipating the energy, resulting in a greater number of fine, harmless cracks.

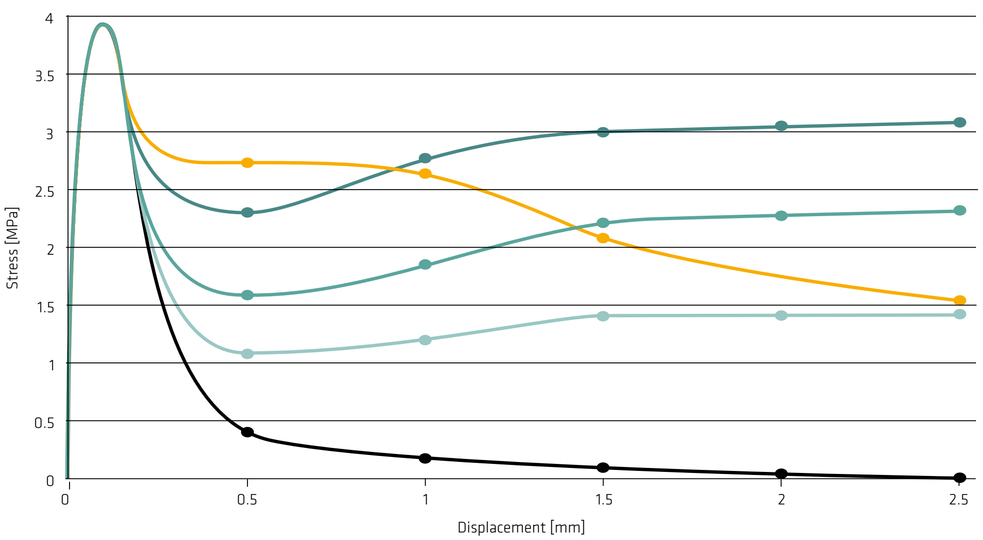
Cracks can occur at different times in the concrete: in the beginning, during the hardening process, producing early-age shrinkage cracking, and later when the concrete has cured and aged, as a result of stress-cracking from loading. In the case of cracking, the E-modulus of the fibres is crucial as it defines the resistance level of the fibres to elastic deformation.

As fibres are easy-to-handle and dose for mixing, and they bond well with the cement matrix, they are ideal for improving the performance of concrete and mortar in a wide range of applications.

The addition of suitable fibes can provide significant improvements in the properties of your concrete, including:

- Less cracking due to early-age shrinkage
- Better cohesion in the fresh concrete
- Higher flexural and shear strengths
- Improved load capacity and ductility

EN 14651 Residual Strength Test



With this graphic you can see that the steel fibre-reinforced concrete exhibits the higher elastic modulus and the largest stress capacity after the first crack. Due to the shorter steel fibre length (35 mm) this stress level decreases with increasing deflection. The polypropylene fibres, however, show a load drop after the first crack (peak load), but with increasing displacement, the fibres then take over the loads and the stress capacity of the unit actually increases significantly.

TYPICAL APPLICATIONS FOR FIBER-REINFORCED CONCRETE

FIBRES CAN ENHANCE AND IMPROVE CONCRETE AND MORTAR in many different applications. Fibres can improve the ductility of sprayed concrete linings and increase the fire-resistance of the final lining concrete in tunnel construction. They can reduce cracking in roads and bridge decks or floor screeds, plus they can increase the impact-resistance of, and reduce damage to, precast concrete units.

SPRAYED CONCRETE

The addition of fibres increases the ductility of sprayed concrete. For instance, if the sprayed concrete lining of an excavated tunnel support is cracked due to high flexural stresses, the fibres can accommodate the tensile forces and act as an excellent yielding support. This interaction between sprayed concrete and fibres, therefore, also increases the mechanical capacity of the lining. The reinforcement can then be reduced or light reinforcement can be omitted completely. The result is quicker and cheaper tunnel excavation supports.

FIRE PROTECTION

Synthetic microfibres, which greatly improve concrete's fire-resistance, are easily added to the concrete mix during its production. If a fire breaks out, e.g. in a tunnel, the synthetic fibres melt within the concrete and create a capillary system through which the water vapour pressure can be relieved. Concrete spalling is is significantly reduced or even prevented -- as are any necessary repairs -- whilst increasing the durability, stability and safety of the structure.

SLABS / RUNWAYS / ROADS

Fibres in concrete floor-slabs and runways significantly reduce early-age shrinkage cracks and help to stabilize the mix. The fibres also result in better flexural behavior and greater impact-resistance. As a consequence, the reinforcement can be reduced and the joint spacing increased. The fibres also help to prevent the joints and other perimeter edges from shearing. The durability of floor slabs and runways produced with fibres is therefore substantially increased.

FLOOR SCREEDS

Fibes are used in many types of floor screeds to improve the workability of the fresh mortar. Additionally, they improve the quality and durability of the hardened screed by controlled crack distribution and shrinkage reduction. In the hardening phase, separate large cracks are not formed, instead they are split into many smaller fine cracks with greatly reduced potential for damage. This fibre reinforcing also greatly improves the impact-resistance and fracture-toughness of the mortar.

PRECAST CONCRETE

The use of fibres in precast concrete results in lighter and more economical units because the associated reduction in steel reinforcement saves weight and reduces production time. The homogeneous distribution of the fibres throughout the concrete cross-section also gives high impact-resistance right to the edges and corners. This allows secure installation on site without damage and, with the use of synthetic fibres, there is no hidden risk of injury to workers during production or installation.

REFURBISHMENT

Repair mortars formulated and produced with fibres have greater durability and improved crack distribution, plus an increased working capacity due to their crack-bridging ability. Their improved internal cohesion also allows spray-applied layers of greater thickness to be applied, which therefore also increases the application rate and reduces the overall cost.

HIGH STRENGTH CONCRETE (HSC) AND ULTRA HIGH PERFORMANCE CONCRETE (UHPC)

High structural stability (load bearing capacity and serviceability) under extreme conditions (e.g. earthquakes) and very slender components require the use of HSC or UHPC. With the use of thin, short fibres with a high E-modulus, untensioned reinforcement can be reduced; alternatively, very high energy absorption capabilities can be achieved in structures or elements by their combination with untensioned reinforcement.

FIBRE TYPES

DEPENDING ON THE PERFORMANCE REQUIRED, different fibres are added to the concrete or mortar. Short, thin synthetic fibres are used for fire protection and crack-reduction, whilst long synthetic or steel fibres are generally used to increase energy absorption. Special requirements demand special fibre materials and shapes. For example, Ultra High Performance Concrete (UHPC) requires short fibres with a high E-modulus. Sika provides all of these and other special types and blends of fibres.

SYNTHETIC MACRO-FIBRES

Synthetic macro-fibres have a lower E-modulus than steel fibres (5 – 15 GPa). Unlike steel fibres, synthetic macro-fibres cannot take extremely high loads, but they work extremely effectively in the early phases of hardening to prevent and/or reduce the size of cracks developing in the concrete. They are corrosion resistant and give the concrete greater ductility.

STEEL FIBRES

Steel fibres are characterized by high E-modulus (200 GPa) and high tensile strength (2500 MPa). They prevent creep of the concrete but do not counter-act early shrinkage. Corrosion does not cause spalling of the concrete, just a change of color on the concrete surface. Protruding steel fibres can pose a risk of injury or damage to waterproofing membranes.

SYNTHETIC MICRO-FIBRES

Synthetic micro-fibres have an even lower E-modulus (3 – 5 GPa) than synthetic macro-fibres. They are mainly used to reduce early-age shrinkage cracking and also to improve fire-resistance due to their low melting point (160 °C). Again these synthetic micro-fibres are non-corrosive.

BEST USE OF THE DIFFERENT TYPES OF FIBRES

State of Concrete or Mortar	Effect / Property Improvement	Recommended Fibre Type
Fresh	Homogeneity improvement	Micro-PP fibres
First 12 hours	Early-age cracking reduction	Micro-PP fibres
1–2 days	Reduction of cracks induced by restraint or temperature	Micro and Macro-PP fibres
28 days' hardening or more	Transmission of external forces	Macro-PP and Steel fibres
28 days' hardening or more	Improvement of fire-resistance	Micro-PP fibres

APPLICATION GUIDELINES

MICROS	SikaFiber® HP	SikaFiber® PPM	SikaFiber® PPM (6 mm)	SikaFiber® PPF	SikaFiber® PPF-500
Bridge Deck	■	■		■	
Composite Metal Deck (CMD)	■	■		■	
Explosive Spalling			■		
Improved Plastic Shrinkage Cracking (69% reduction ratio ASTM C1579)	■	■			
Marine Applications	■	■		■	
Oil Rigs			■	■	■
Overlays / Topping Slabs	■	■		■	
Pavement	■	■		■	
Pavement - Tined / Broom Finish	■	■			
Pools	■	■		■	
Precast	■	■	■	■	■
Replacement of 6x6 WI.4/WI.4 (152x152 MW9.1/MW9.1)				■	
Residential Applications	■	■		■	
Self Compacting Concrete	■	■		■	
Shotcrete	■	■		■	■
Slab On Grade	■	■		■	
Stucco	■	■			■
Tanks	■	■		■	
Tunnel Lining			■		

MACROS	SikaFiber® Force -650	SikaFiber® Force -650 S/-665	SikaFiber® Force -600	SikaFiber® Force MS-25	SikaFiber® Force -950	SikaFiber® Force -850	SikaFiber® Force -XR	SikaFiber® Force -5535	SikaFiber® Force -1050	SikaFiber® Force -0960	SikaFiber® Force -7560
Slab Residential	■			■	■	■					
Slab CMD	■					■	■				
Slab Commercial	■			■	■	■	■		■		
Slab Light Industrial			■	■	■	■	■		■	■	
Slab Heavy Industrial			■							■	
Exposed Concrete				■	■	■					
Precast Thickness < 3"			■		■			■			
Precast Thickness >3»			■		■					■	
Tunnel Segment											■
Shotcrete		■	■					■			
Pavement			■	■	■						
Bridge Deck			■		■	■					

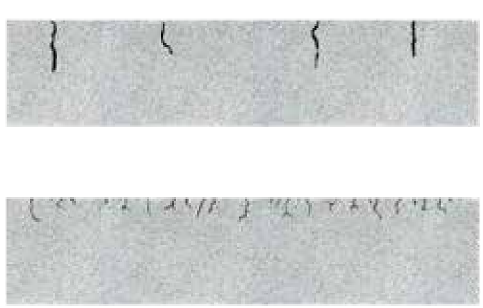
Notes
1. The slabs are shown in order from lightest reinforcing requirements to heaviest. Fibers can always be used in a lighter reinforcement requirement but the slab may be overdesigned. i.e. SikaFiber®-600 can always be used in a commercial slab but the slab will have more reinforcing than required, therefore it may not be cost effective.
2. Exposed Concete: meaning no tile or carpet.

IMPROVED CONCRETE PERFORMANCE WITH FIBRES

SPECIFIC CONCRETE CHARACTERISTICS are obtained by using different fibre types, or mixtures of different fibres, according to the characteristics and performance required. For example, longer fibres with a high E-modulus and good anchorage properties are used for high-energy absorption and smaller low-modulus fibres are added for crack-reduction. Additionally, longer low-modulus fibres are used for increased ductility and crack-reduction, plus small fibres with a low melting-point provide increased fire-resistance. By adjusting the quantities and combinations of these different fibres, any arrangement of concrete characteristic can be achieved.

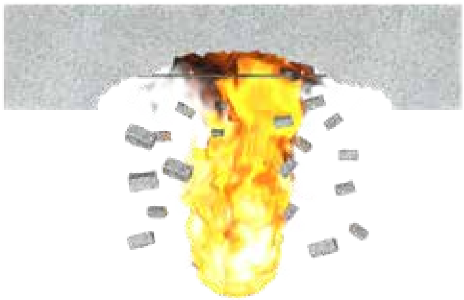
STRUCTURAL BEHAVIOUR

Concrete is generally good in compression but weak in tension. If concrete fractures due to high bending stress when no reinforcement is present, the system is likely to collapse without warning. As with conventional steel reinforcement, high forces can also be transferred and distributed within the concrete using suitable fibres. Crack-bridging fibres not only improve post-cracking behavior, but also reduce further propagation of macro-cracks. The fibres that cross the crack and are anchored in the matrix on both sides, effectively “sew” its two sides together and prevent it from widening. Fibre-reinforced concrete, therefore, has increased ductility and is capable of absorbing higher energy in the area under load vs deflection.



CRACK DISTRIBUTION

The shrinkage stresses in the hardening phase of cement-based binders frequently lead to concrete cracking that is visible to the naked eye and are perceived as damage. With the incorporation of fibres, the stresses are split and distributed so that macro-cracks are prevented from forming, as the shrinkage volume is compensated for by micro-crack formation. While micro-cracks do not significantly reduce strengths, they do improve the surface aspect and can also allow autogenous healing. Thus, the addition of fibres leads to higher durability.



FIRE PROTECTION

The problem with traditional concrete in a fire is that the physically- and chemically-bound water evaporates in a very short time due to the rapid rise in temperature. This transition to the gaseous state causes a thousand-fold increase in the volume of the water: the denser the concrete matrix and the higher the moisture content of the concrete, the higher the developing vapour pressure will become. If the vapour pressure cannot be reduced (or, at least, not quickly enough), explosive concrete spalling will result. This occurs after only a few minutes and immediately causes extensive and deep-reaching damage to the structures. If the reinforcement is then exposed, it has no protection from the fire and its structural function is soon lost.

Polypropylene fibres give a considerable or even total reduction in such explosive concrete spalling due to their relatively low melting point of 160 °C. This means the fibres will start to progressively melt almost immediately after a fire starts, creating a capillary system through which the evaporating water can escape, thus eliminating any significant destructive pressure build-up.

MECHANICAL RESISTANCE

The impact- and shock-resistance, notched-bar impact strength and edge-strength can all be increased significantly by adding specific fibres. Synthetic and most steel fibres are suitable.

A combination of fibres with a high and low E-modulus and high elongation at break has proved beneficial. An improvement in impact strength has been observed by adding steel fibres and also polypropylene fibres in quantities of only 0.1 % by volume. The impact strength also improves considerably as this quantity of fibres is increased.

HANDLING: HOW TO USE FIBRES

TO ACHIEVE THE OPTIMUM EFFECT and the desired characteristics or performance of the concrete, in addition to good concrete practices, all of the factors potentially influencing the use of fibres have to be considered. The most critical factors usually are: 1) selection of the right fibre type or combination (material and size); 2) how the concrete mix design is adapted, including the fibre dosing system and timing; 3) together with the overall mixing procedure.

An appropriate concrete placing and finishing method must also be used either in the precast factory or on site.

FIBRE DOSING QUANTITIES

Reason For Use / Objective	Fibre Type	Quantity
High loading capacity	Synthetic macrofibre	4 – 8 kg
	Steel macrofibre	20 – 40 kg
Extremely high loading capacity	Steel microfibre	50 – 100 kg
Reduced early-age shrinkage cracks (plastic shrinkage)	Synthetic microfibre	0.5 – 1 kg
Increased fire-resistance	Synthetic microfibre	2 – 3 kg
Increased impact-strength	Synthetic microfibre	0.5 – 1 kg

MIX DESIGN

A well-balanced mix design is the key factor for the optimum fibre performance. Fibres add a large surface area and so the mix design must be adjusted to ensure adequate workability and optimum bond with the cement matrix. This involves: the right choice of binder and water content, the right aggregate grading curve, optimum fibre quantity, and any other additives and admixtures. A well-developed mix design positively influences all steps of fibre-reinforced concrete production, placing and performance:

Production
- No fibre balling
- Good fibre distribution
- Low mixer resistance
- Shorter mixing time

Performance
- Good fibre:cement bonding
- Low W/C

Placing-Pouring
- Easy hopper grill passing
- Good pumpability
- Low pump pressure
- Good sprayability
- Less rebound

DOSING METHOD

The fibre dosing and mixing method has a great influence on their optimum distribution in the concrete. Macro-fibres are normally formed into bundles, which can only disperse during the wet-mixing process to ensure they are distributed homogeneously. Water-soluble bags are used for dosing smaller quantities of fibres to prevent balling.

DELIVERY AND PLACING

The concrete placing system can influence the fibre distribution and content, plus their alignment in the matrix. Some fibre types also cause far greater machine wear, whilst others generate pumping problems at high dosages. Therefore the delivery and placing process must also be taken into consideration during the fibre type evaluation and selection process.

FIBRE TYPE

The requirement usually effectively defines the fibre type and therefore macro- or microfibres are specified according to their material type, geometry and shape. The performance is also affected by the concrete production process, its surface treatment and finishing etc., which must also be specified.

MIXING PROCESS

An unsuitable or inadequate mixing process can result in non-homogeneous distribution of the fibres in the concrete, or damage to the fibres. The quantity to be added and the mixing time must therefore also be specified and followed.

CONCRETE PRODUCTION SIMPLIFIED WITH FIBRES

FIBRES IN CONCRETE CAN SIMPLIFY THE PRODUCTION PROCESS in both precasting and for work-flows on site. This is because steel reinforcement can be reduced at many points or even eliminated completely. This time saved on steel fixing can also save costs. With regards to increasing the fire-resistance, fibres have again made the construction process much simpler, as there is no need to overdesign concrete cross-sections, or post-apply fire protection systems when synthetic fibres are used.

TUNNELING AND MINING

By using fibre-reinforced sprayed concrete, conventional reinforcement can be dispensed with, given moderate rock pressure. The time-consuming steel fixing operations which interrupt the work flow are then eliminated. By eliminating the reinforcement, the sprayed concrete is also applied without 'spray shadows' and rebound is reduced. The result is optimization of the application process and improved quality of the structure.

DECK CONSTRUCTION

In addition to reducing the steel reinforcement, the use of fibres can significantly increase joint spacing. Also, as a blinding layer can be partially omitted, the layer thicknesses of the slabs can also be reduced. Optimum distribution of the fibres right into the corners also provides increased edge protection. All of these factors have a positive impact on the installation, and increase construction efficiency.

UTILITY BASEMENTS

Synthetic microfibres added to the concrete prevent or very significantly reduce concrete spalling in the event of a fire. Structural concrete elements therefore do not need to be overdesigned and additional fire protection treatment is not necessary. The use of fibre fire protection within the concrete generates significant time-savings and maximizes the available space.

STANDARDS AND TESTING

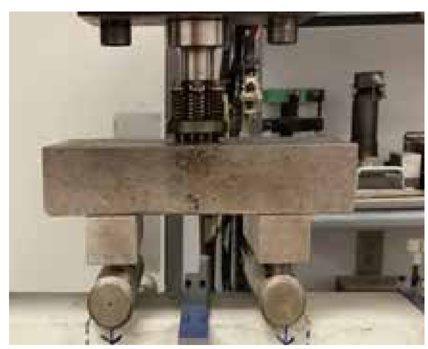
THE MANY DIFFERENT APPLICATIONS AND USES of fibre-reinforced concrete require test methods tailored to these applications. This way, specific performance and required functionality can be tested and confirmed, so that it can safely be used in future specifications. Generally, these test methods are now fully standardized internationally through the European Standards (EN) and the American Society for Testing and Materials (ASTM), for example.

FIBRE-REINFORCED CONCRETE AND MORTAR STANDARDS AND TESTING

Test Method	Standard	Description
Energy absorption	ASTM C1550	Round panel test
	EN 14488-5	Square panel test
Residual strength	ASTM C1609	Beam test yields fe3 to be used in calculations
	ASTM C1399	Beam test yields ARS to be used in fibre comparisons
Fire-resistance	RWS	Max. 1350 °C, 2 hours
	ISO 834	Starts at low temp, but continuously increasing
	HC modified	Max. 1200 °C, 4 hours
Shrinkage-cracking	ASTM C1581-04	Test method for determining restrained shrinkage
	ASTM C1579	Test method for plastic restrained shrinkage cracking
Impact-resistance	Various local standards	Impact energy tests

Round panel test: ASTM C1550


Beam test: ASTM C1399


Beam test: ASTM C1609

CASE STUDIES

FIBRE-REINFORCED CONCRETES HAVE MULTIPLE ADVANTAGES and are now widely used for many different functions and requirements all around the world. This is particularly the case in tunneling and mining, precast construction, flooring and all types of projects requiring excellent fire-resistance. Sika's technical expertise and extensive practical experience in the design, selection and installation of all of these different fibre-reinforced concretes and mortars is evident and on display in many successful projects on every continent.

ELOISE COPPER MINE, AUSTRALIA

In this mining project, SikaFiber® Force synthetic macro-fibres were used for the sprayed concrete, mainly as the excavation support. Their selection and use ensured an efficient, cost-effective and safe work flow as driving advanced.

CALDEARENAS ROAD TUNNEL, SPAIN

SikaFiber® Force synthetic macro-fibres were added to the sprayed concrete to increase the ductility of the concrete lining. Fibre-reinforced sprayed concrete of this kind produces a more efficient and cost-effective excavation support.

OIL TERMINAL, GERMANY

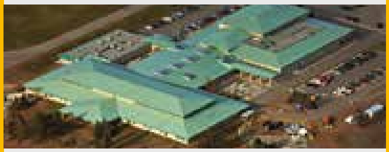
SikaFiber® Force synthetic macro-fibres were used in combination with the German 'White-topping' method for repairing the slabs in an oil harbor in Stuttgart. The fibres were used to improve the fatigue behavior of the new concrete topping.

SUBWAY TUNNEL SEGMENTS, USA

In the San Francisco Central Subway Project, SikaFiber® synthetic micro-fibres were used at a dosage of 1.2 kg/m^3 of concrete to prevent explosive spalling of concrete in the event of fire in the tunnel.

SIKA SOLUTIONS FROM ROOF TO FOUNDATION

Roofing Systems



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Concrete Production

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Sika® Plastocrete®, SikaSet®
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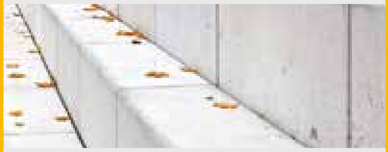
Joint Sealing



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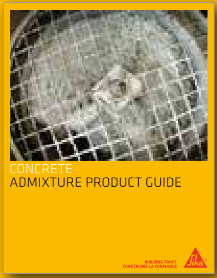
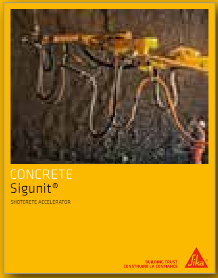
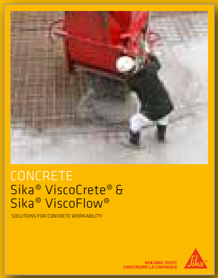
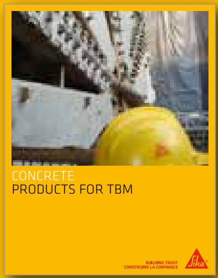
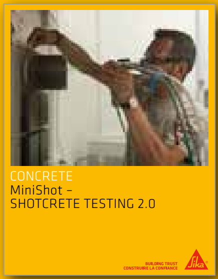
Also Available:

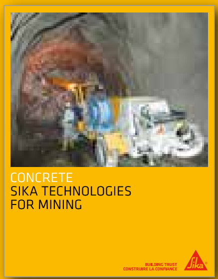












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