CONCRETE
SikaFiber® TECHNOLOGY

BUILDING TRUST

FIBER REINFORCEMENT

Fibers are an ideal ingredient for concrete and mortar. Fibers improve these materials where they can otherwise have weaknesses. Primarily they increase performance in energy absorption and fire resistance, whilst also reducing shrinkage crack formation and crack widths. This produces a concrete which needs significantly less reinforcing steel than a conventional reinforced concrete, but which is still very durable, or even more durable. The idea of using fiber reinforcement in building materials goes back hundreds if not thousands of years and yet is also more useful than ever with modern technologies. Concrete has developed considerably over recent decades and fiber technology has evolved rapidly with it. Concrete applications with fibers have expanded and new fiber materials are also increasingly capable of replacing traditional fibers such as steel and glass. SikaFiber® Technology is in the vanguard of these developments.

FIBERS IMPROVE YOUR CONCRETE AND YOUR STRUCTURE

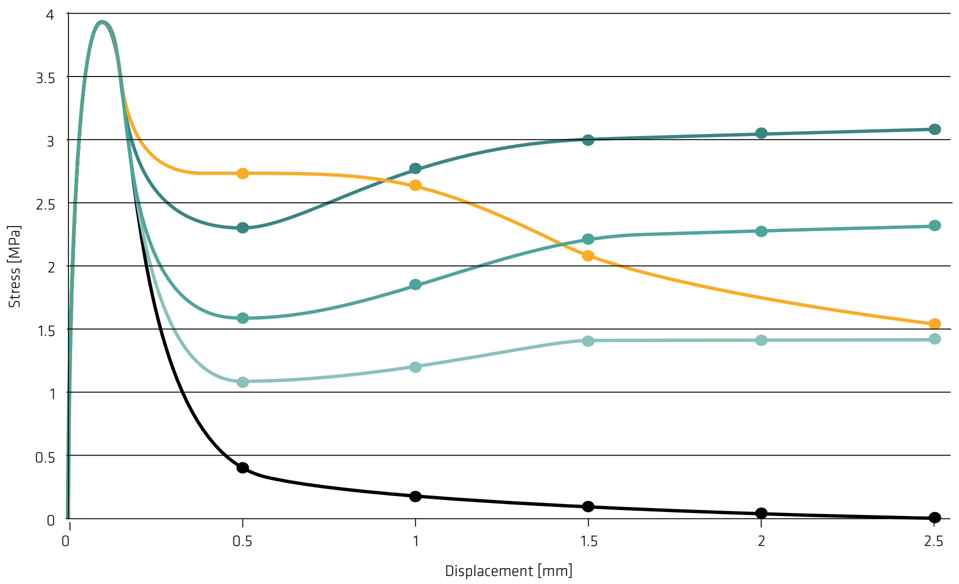
FIBER REINFORCED CONCRETE IS concrete to which fibers have been added during production to improve its cracking and fracturing behavior. After many years of research and development, fiber reinforced concrete is now fully established in the market for its important advantages.

The fibers are embedded in the cement matrix and have no significant effect until during the hardening process they inhibit the emergence of cracks through their tensile strength and extensibility. Where there is greater strain they prevent larger cracks by causing them to dissipate into more numerous, but very fine and generally harmless ones. Cracks can occur at different times in the concrete: in the beginning during the hardening process, where it is mainly early-age shrinkage cracking; then with increasing age and hardness, stress cracks can occur from loading. If cracking occurs in the concrete then the E-modulus of the fibers is crucial, as this defines the resistance of the fibers to counteract their elastic deformation. Because fibers are also easy to handle and dose for mixing and they have a good bond in the matrix, they are ideal for improving the performance of concrete and mortar for many applications.

The addition of suitable fibers 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
- Increased abrasion resistance
- Protection against freeze-thaw attack
- Increased fire resistance

EN 14651 Residual Strength Test



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

TYPICAL APPLICATIONS FOR FIBER REINFORCED CONCRETE

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

SPRAYED CONCRETE

The addition of fibers 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 fibers can accommodate the tensile forces and act as an excellent yielding support. This interaction between sprayed concrete and fibers, 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 microfibers make concrete very much more fire resistant. The fibers are added to the concrete mix during its production. If a fire breaks out, e.g. in a tunnel, the synthetic fibers melt within the concrete and this creates a capillary system through which the water vapor pressure can be relieved. Concrete spalling is prevented or very significantly reduced, as are any necessary repairs, whilst increasing the durability, stability and safety of the structure.

SLABS / RUNWAYS / ROADS

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

FLOOR SCREEDS

Fibers 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 there are split into many smaller fine cracks with greatly reduced potential for damage. This fiber reinforcing also greatly improves the impact resistance and fracture toughness of the mortar.

PRECAST CONCRETE

The use of fibers in precast concrete results in lighter and more economic units because the possible reduction in steel reinforcement saves weight and reduces production time. The homogeneous distribution of the fibers 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 fibers there is no hidden risk of injury to workers during production or installation.

REFURBISHMENT

Repair mortars formulated and produced with fibers have greater durability with 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)

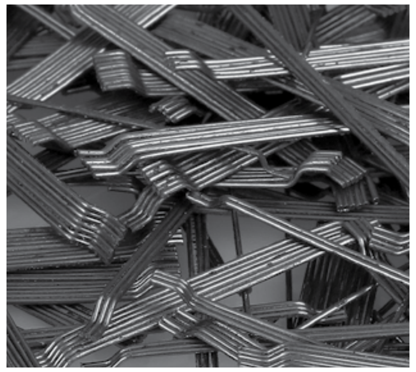
High structural stability (load bearing capacity and serviceability) under extreme conditions (e.g. earthquakes) and very slender components require the use of HSC or UHPC. With the use of thin, short fibers with a high E-modulus, untensioned reinforcement can be reduced; alternatively, very high energy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

FIBER TYPES

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

SYNTHETIC MACRO-FIBERS

Synthetic macro-fibers have a lower E-modulus than steel fibers (5 – 15 GPa). Unlike steel fibers, synthetic macro-fibers 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 FIBERS

Steel fibers 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 fibers can pose a risk of injury or damage to waterproofing membranes.

SYNTHETIC MICRO-FIBERS

Synthetic micro-fibers have an even lower E-modulus (3 – 5 GPa) than synthetic macro-fibers. 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-fibers are non-corrosive.

BEST USE OF THE DIFFERENT TYPES OF FIBERS

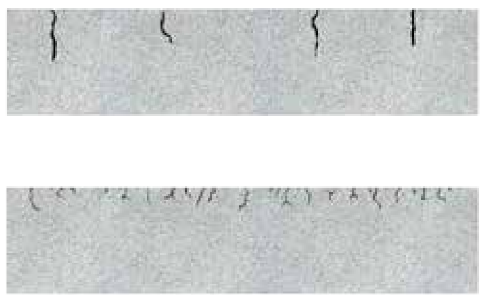
State of concrete or mortar	Effect / property improvement	Recommended fiber type
Fresh	Homogeneity improvement	Micro-PP fibers
Until about 12 hours	Early-age cracking reduction	Micro-PP fibers
1–2 days	Reduction of cracks induced by restraint or temperature	Micro & Macro-PP fibers
28 days hardening or more	Transmission of external forces	Macro-PP & Steel fibers
28 days hardening or more	Improvement of fire-resistance	Micro-PP fibers

INCREASED CONCRETE PERFORMANCE WITH FIBERS

SPECIFIC CONCRETE CHARACTERISTICS are obtained by using different fiber types, or mixtures of different fibers, according to the characteristics and performance required. For example longer fibers with a high E-modulus and good anchorage properties are used for high energy absorption and smaller low modulus fibers are added for crack reduction. Additionally longer low modulus fibers are used for increased ductility and crack reduction, plus small fibers with a low melting point provide increased fire resistance. Therefore there are also many different applications where different combinations and quantities of different fibers can be used to meet combinations of these different requirements simultaneously.

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 collapses without warning. As with conventional steel reinforcement, high forces can also be transferred and distributed within the concrete using suitable fibers. Crack-bridging fibers not only improve post-cracking behavior but also reduce further propagation of macro-cracks. The fibers that cross the crack and are anchored in the matrix on both sides, effectively “sew” its two sides together and prevent it widening. Fiber reinforced concrete, therefore, has increased ductility and is capable of absorbing higher energy in the area under load vs deflection.

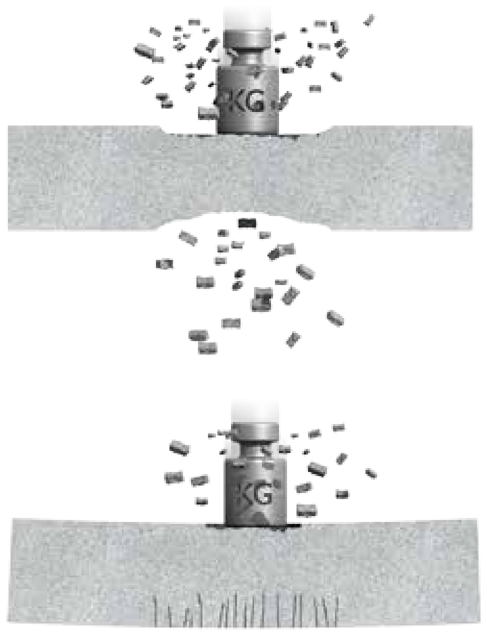


CRACK DISTRIBUTION

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 fibers, the stresses are split and distributed so that macro-cracks are prevented from forming, as the shrinkage volume is compensated by micro-crack formation. Micro-cracks do not significantly reduce strengths, improve the surface aspect and can also allow autogenous healing. Thus, the addition of fibers 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 vapor pressure will become. If the vapor pressure cannot be reduced (or 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. However, the addition of polypropylene fibers gives a considerable or even total reduction in such explosive concrete spalling, due to their relatively low melting point of 160°C. This means the fibers will start to progressively melt almost immediately after a fire starts to create a capillary system through which the evaporating water can escape, without 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 fibers. Synthetic fibers and most steel fibers are suitable. A combination of fibers 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 fibers and also polypropylene fibers in quantities of only 0.1% by volume. The impact strength also improves considerably as this quantity of fibers is increased.

HANDLING – HOW TO USE FIBERS

TO ACHIEVE THE OPTIMUM EFFECT and the desired characteristics or performance of the concrete, then in addition to good concrete practice, all of the potentially influencing factors for the use of fibers have to be considered. The most critical factors are usually selection of the right fiber type or combination (material and size); how the concrete mix design is adapted, including the fiber dosing system and timing; 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.

FIBER DOSING QUANTITIES

Reason for use – Objective	Fiber type	Quantity
High loading capacity	Synthetic macro fiber Steel macro fiber	4 – 8 kg 20 – 40 kg
Extremely high loading capacity	Steel micro fiber	50 – 100 kg
Reduced early-age shrinkage cracks (plastic shrinkage)	Synthetic micro fiber	0.5 – 1 kg
Increased fire resistance	Synthetic micro fiber	2 – 3 kg
Increased impact strength	Synthetic micro fiber	0.5 – 1 kg

MIX DESIGN

A well-balanced mix design is the key factor for the optimum fiber performance. Fibers 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 fiber quantity, and any other additives and admixtures. A well-developed mix design positively influences all steps of fiber reinforced concrete production, placing and performance:

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

Placing-Pouring
- Easy hopper grill passing
- Good pumpability
- High cylinder fill grade
- Low pump pressure
- Good sprayability
- Less rebound

Performance
- Good fiber-cement bonding
- Low W/C

DOSING METHOD

The fiber dosing and mixing method has a great influence on their optimum distribution in the concrete. Macro-fibers 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 fibers to prevent balling.

DELIVERY & PLACING

The concrete placing system can influence the fiber distribution and content, plus their alignment in the matrix. Some fiber 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 fiber type evaluation and selection process.

FIBER TYPE

The requirement usually effectively defines the fiber type and therefore macro- or micro- fibers 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 fibers in the concrete, or damage to the fibers. The quantity to be added and the mixing time must therefore also be specified and followed.

CONCRETE PRODUCTION SIMPLIFIED WITH FIBERS

FIBERS 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 delays can also save costs. With regards to increasing the fire resistance, fibers 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 fibers are used.

TUNNELING AND MINING

By using fiber reinforced sprayed concrete, conventional reinforcement can be dispensed with, given moderate rock pressures. 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 fibers can significantly increase the joint spacing's. Also, as a blinding layer can be partially omitted, the layer thicknesses of the slabs can also be reduced. Optimum distribution of the fibers 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 micro-fibers 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 fiber fire protection within the concrete generates significant time savings and maximizes the available space.

STANDARDS & TESTING

THE MANY DIFFERENT APPLICATIONS AND USES of fiber reinforced concrete require test methods tailored to these applications, so that the specific performance and functionality required 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.

FIBER 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	EN 14651	Beam test
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 C 1581-04	Test method for determining restrained shrinkage
Impact resistance	Various local standards	Impact energy tests

Round panel test: ASTM C1550

Square panel test: EN 14488-5


Beam test: EN 14651

CASE STUDIES

FIBER 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 fiber 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-fibers 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-fibers were added to the sprayed concrete to increase the ductility of the concrete lining. Fiber reinforced sprayed concrete of this kind produce a more efficient and cost effective excavation support.

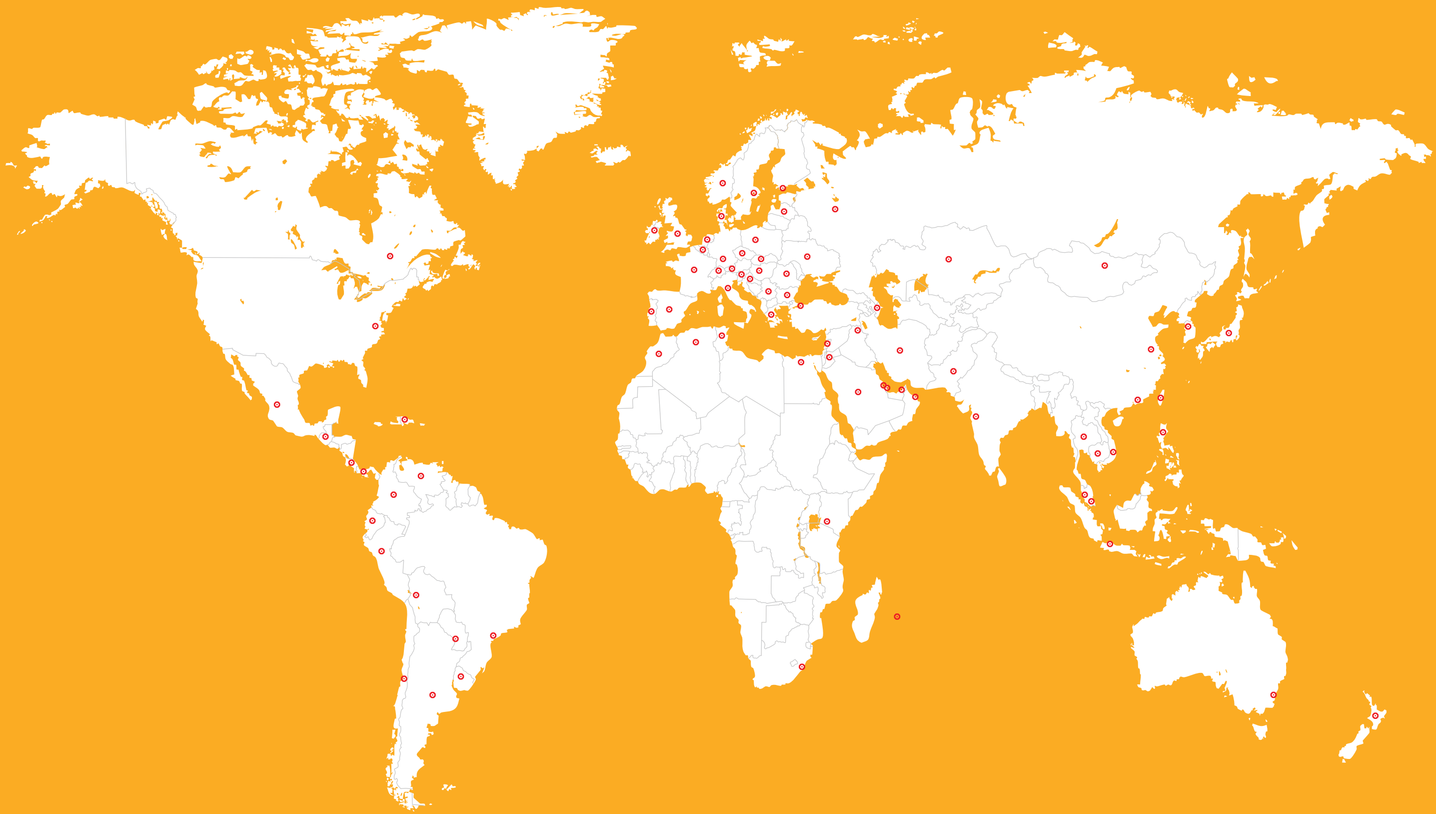
OIL TERMINAL, GERMANY

SikaFiber® Force synthetic macro-fibers were used in combination with the German 'White-topping' method for repairing the slabs in an oil harbor in Stuttgart. The fibers 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-fibers were used at a dosage of 1.2 kg/m³ of concrete to prevent explosive spalling of concrete in the event of fire in the tunnel.

GLOBAL BUT LOCAL PARTNERSHIP



FOR MORE CONCRETE INFORMATION:

WHO WE ARE
Sika AG, Switzerland, is a globally active specialty chemicals company. Sika supplies the building and construction industry as well as manufacturing industries (automotive, bus, truck, rail, solar and wind power plants, facades). Sika is a leader in processing materials used in sealing, bonding, damping, reinforcing and protecting loadbearing structures. Sika's product lines feature highquality concrete admixtures, specialty mortars, sealants and adhesives, damping and reinforcing materials, structural strengthening systems, industrial flooring as well as roofing and waterproofing systems.

since 1986

since 1997

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