CONCRETE
SikaFiber® Technology

BUILDING TRUST

FIBER REINFORCEMENT

Fibers are an ideal ingredient for improving the performance of concrete and mortar. They increase energy absorption and fire resistance, whilst reducing shrinkage crack, fracture formation and crack widths. By adding fibers to the mix during production, concrete becomes more durable and resistant. When used in construction projects, it ultimately requires a lot less reinforcing steel than conventionally-reinforced concrete. For centuries, fiber reinforcement has been a major part of construction, and as materials and processes have evolved, so too has fiber technology. Concrete applications with fibers have expanded considerably in recent times, and are now fully-established in the market – with new materials now capable of replacing traditional fibers, like steel and glass. SikaFiber® Technology is well and truly at the forefront of these developments.

FIBERS IMPROVE YOUR CONCRETE AND YOUR STRUCTURE

CRACKING AND FRACTURING BEHAVIOUR IS GREATLY IMPROVED thanks to fiber-reinforced concrete. During the concrete's hardening process, embedded fibers in the cement matrix inhibit the emergence of cracks through their tensile strength and extensibility. Where the strain is greater, they prevent larger cracks by causing them to dissipate into a number of smaller, finer and generally harmless ones.

THE STRENGTH OF FIBERS

Cracks can occur at different times during the life of concrete. In the beginning during the hardening process, the main concern is early-age shrinkage cracking. With older, hardened concrete, stress cracks can occur from loading.

If cracking in the concrete does occur, then the elastic (E) modulus of the fibers is crucial, because it defines the resistance of the fibers against deformation.

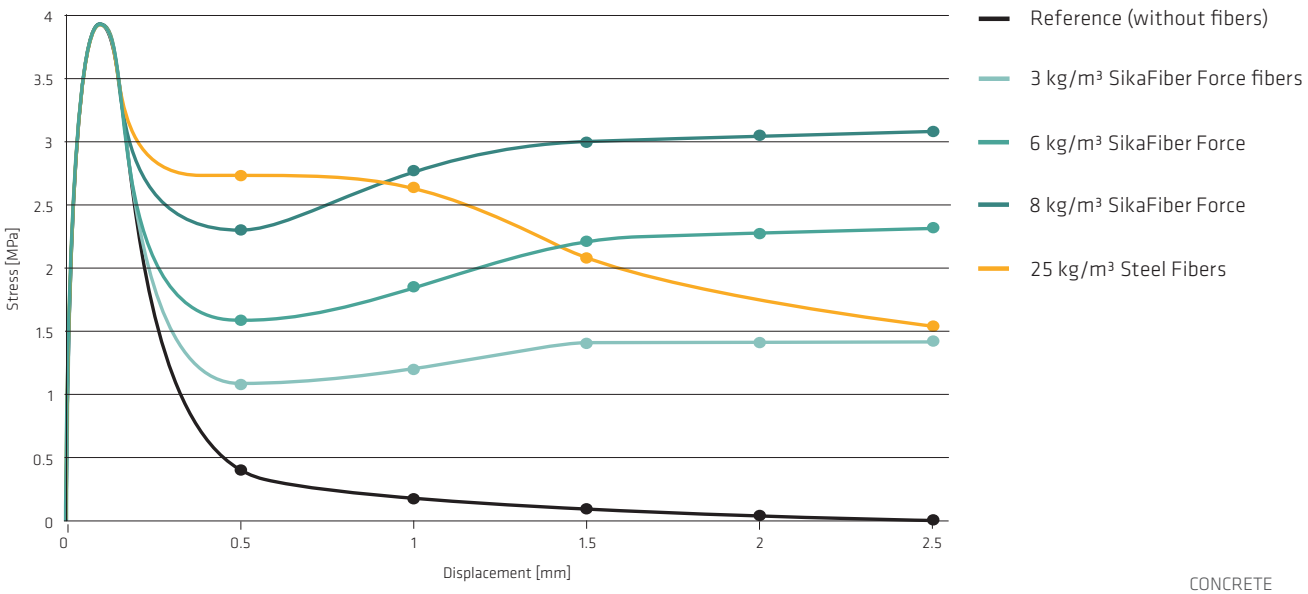
The graph below illustrates how different fibers work under stress:

- **Steel fibers** exhibit a higher E-modulus and stress capacity after the concrete's first crack. Due to the shorter steel fiber length (35 mm), this stress level decreases with increasing displacement.
- **Polypropylene fibers** exhibit 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.

THE BENEFITS OF Fiber REINFORCEMENT

- 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
- Increased fire resistance
- Potential to reduce CO^2

EN 14651 Residual Strength Test



TYPICAL APPLICATIONS FOR FIBER REINFORCED CONCRETE

FIBERS ARE THE IDEAL COMPONENT for enhancing and improving concrete and mortar, because they are easy to work with and bond well with the mix, whatever the application. They can increase impact resistance and reduce cracking damage in roads, bridge decks, floor screeds and precast concrete units. Plus, fibers can improve the ductility of sprayed concrete linings and increase the fire resistance of tunnel linings. Here are some examples of typical applications:

SPRAYED CONCRETE

The addition of fibers increases the ductility of sprayed concrete. If the sprayed concrete lining of an excavated tunnel support is cracked due to high flexural stresses, the fibers can accommodate tensile forces and act as an excellent yielding support. Fibers also increase the mechanical capacity of the lining, meaning extra reinforcement can then be reduced, or even omitted completely. This would ultimately result in tunnel excavation supports that are both quicker to install and more cost-effective.

FIRE PROTECTION

Synthetic micro-fibers make concrete a lot more fire-resistant, which is particularly important in structures like traffic tunnels. If a fire were to break out, the synthetic fibers melt within the concrete and create a capillary system through which water vapour pressure can be relieved. Concrete spalling is either reduced significantly or prevented completely, so the amount of repair work required is reduced too. All this results in a structure that is safer, more stable and more durable.

SLABS / RUNWAYS / ROADS

Using fibers in concrete floor slabs and runways helps to stabilise the concrete mix and greatly reduces early-age shrinkage cracks. Fibers also result in better flexural behaviour, greater impact resistance and greater durability. This means the amount of extra reinforcement needed can be reduced and the joint spacing increased. Fibers also help to prevent the joints and other perimeter edges from shearing.

FLOOR SCREEDS

Fibers are used in many types of floor screeds to improve the workability, impact resistance and fracture toughness of the fresh mortar. They also improve the quality and durability of the hardened screed by controlled crack distribution and shrinkage reduction. If any cracks form during the initial hardening phase, they are split into a number of small, fine cracks instead of single larger cracks, which means the potential for damage is reduced considerably.

PRECAST CONCRETE

Using fibers in precast concrete units reduces the amount of extra steel reinforcement needed, which makes for lighter units that are quicker to produce and install. The consistent, even distribution of the fibers throughout the concrete cross-section also gives high-impact resistance throughout the unit. As a result, units can be installed securely and without any damage. With 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 thicknesses to be applied, increasing the application rate and reducing the overall cost as a result.

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

Particularly slender components usually require HSC or UHPC, as do projects where high structural and load-bearing stability is needed during extreme conditions like earthquakes. Thin, short fibers that have a high E-modulus can be used in these cases. This means extra untensioned reinforcement can either be reduced, or be combined with the fiber reinforcement to greatly increase energy absorption capabilities.

FIBER TYPES

DIFFERENT Fiber TYPES ARE USED TO DELIVER DIFFERENT PERFORMANCE REQUIREMENTS.
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. One size doesn't always fit all, and special requirements demand special fiber materials and shapes – Ultra High Performance Concrete (UHPC) requires short fibers with a high E-modulus, for example. Sika provides solutions for all these eventualities, as well as other special types and lends 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 fibres are characterised by high E-modulus (200 GPa) and high tensile strength (2500 MPa). They prevent creep of the concrete but don't counteract early-age shrinkage. If any corrosion occurs, it won't cause spalling of the concrete – just a change of colour on the concrete surface. Protruding steel fibres 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're mainly used to reduce early-age shrinkage cracking and to improve fire resistance, thanks to their low melting point (160°C). Like macro-fibers, they're also corrosion-resistant.

BEST USE OF THE DIFFERENT TYPES OF FIBERS

State	Effect / property improvement	Recommended fiber type
Fresh	Improved rheology	Micro-PP fibers
Up to about 12 hours old	Reduction of early-age shrinkage cracking	Micro-PP fibers
1-2 days	Reduction of cracks induced by restraint or temperature	Micro-PP and Steel fibers
28 days' hardening or more	Transmission of external forces	Micro-PP and Steel fibers
28 days' hardening or more	Improvement of fire resisance	Micro-PP fibers

SIKAFIBER® FORCE MACRO FIBER AND SIKAFIBER® PPM MICRO FIBER

SIKA PROVIDE A RANGE OF HIGH PERFORMANCE MACRO AND MICRO FIBERS FOR USE IN CONCRETE

SikaFiber® Force fibers are macro synthetic fibers which are specially extruded, embossed and cut to specific lengths to suit a wide range of concreting applications. They can be used in ready-mixed concrete, precast and sprayed concrete applications both above and below the ground, such as:

- Internal floor slabs
- External hardstandings and pavements
- Precast concrete elements
- Agricultural areas
- Marine/coastal defence concrete
- Shotcreting applications

The extruded, embossed profile of the fibers improves the bond within the concrete, reducing pull-out and enhancing the concrete's performance. The fibers have been designed to replace traditional steel reinforcement and provide a number of benefits including:

- Easier and safer to handle compared to steel
- Reduce construction time
- Ready-mixed concrete trucks can discharge at the 'live' edge of the concrete
- Cannot be misplaced
- No need to cut, fix or place steel mesh
- Reduce wear on concrete pumps
- Reduce carbon footprint
- Fibers do not rust or corrode
- Provide a 3-dimensional reinforcement system

SikaFiber® PPM is a polypropylene monofilament micro-fiber. The fibers are coated with surfactant to improve dispersion. They are extremely fine and therefore hardly visible within the hardened surface of the end cementitious product. Typically these micro-fibers are used for:

- Internal floor slabs
- Concrete buildings
- Repair materials
- External hardstandings
- Pattern imprinted concrete
- Bridges
- Precast concrete
- Extruded concrete
- Agricultural areas
- Piling concrete
- Shotcrete/Gunite
- Water retaining structures

Micro-fibers are specially designed to provide the following benefits:

- Reduce plastic shrinkage cracks, plastic settlement and bleeding
- Offer an alternative to crack control mesh with the appropriate design
- Reduce water and chemical permeability
- Increase abrasion resistance and impact resistance

IMPROVED CONCRETE PERFORMANCE WITH FIBERS

SPECIFIC CONCRETE CHARACTERISTICS ARE OBTAINED BY USING DIFFERENT FIBER TYPES, or mixtures of different fibers, depending on what the performance requirements are. Longer high E-modulus fibers are used to achieve high energy absorption, whilst longer low E-modulus fibers are used for increased ductility and crack reduction. With smaller fibers, those with a low E-modulus also improve the reduction of cracking, whilst those with a low melting point provide increased fire resistance. As such, different combinations and quantities of these fibers can be used across a wide range of applications and project requirements. Here are some of the most commonly sought-after requirements in more detail:

STRUCTURAL BEHAVIOUR

Concrete is generally strong in compression but weak in tension.If concrete fractures because of high bending stress and no extra reinforcement has been used, the system collapses without warning. As with conventional steel reinforcement, high forces can be transferred and distributed within the concrete using suitable fibers.

Crack-bridging fibers not only improve post-cracking behaviour but also help to keep bigger cracks from spreading. The fibers that cross the crack and are anchored in the matrix on both sides, effectively “sew” its two sides together and prevent it from widening. As a result, fiber-reinforced concrete has increased ductility and is capable of absorbing higher energy in the area, under load versus deflection.

CRACK DISTRIBUTION

When cement-based binders start to harden, shrinking stresses can often lead to the concrete cracking, which can be seen visually as damage. By adding fibers to the mix, these stresses are split and distributed. Bigger cracks are not able to form because the shrinkage volume is compensated for by the formation of smaller cracks instead, which will not significantly reduce the concrete’s strength.

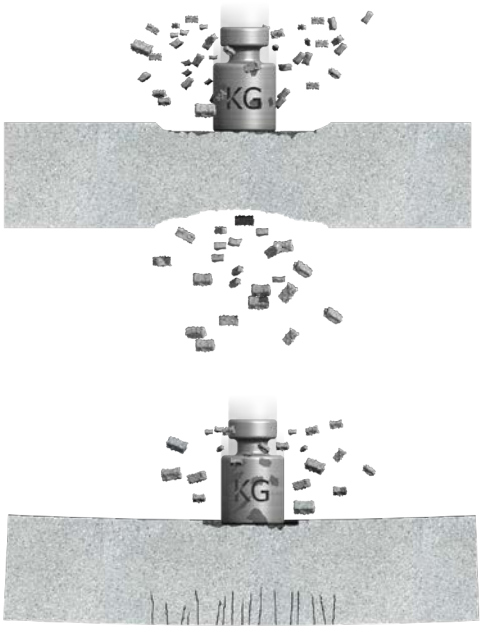
The surface aspect is improved and the concrete is able to essentially heal itself. As such, the concrete is a lot more durable with the addition of fibers.

FIRE PROTECTION

Traditional concrete can be problematic when exposed to fire, because the sharp rise in temperature makes the concrete's physically and chemically-bound water evaporate very quickly.

When the water turns to vapour, its volume increases a thousand-fold. The denser the matrix and higher the moisture content of the concrete, the higher the developing vapour pressure will become. If this pressure is not relieved quickly enough, explosive concrete spalling can happen after only a few minutes. Any extra reinforcement is then exposed to damage from the fire, leading to extensive and deep-reaching damage to the overall structure.

By adding polypropylene fibers to the concrete, the risk of explosive spalling in a fire is reduced considerably, if not completely. These fibers have a relatively low melting point of 160°C, which means they will progressively melt and 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 with synthetic fibers and most steel fibers.

Impact strength can be improved by adding steel or polypropylene fibers in quantities of only 0.1% by volume. This strength improves considerably when a higher quantity of fibers is used, and adding a combination of fibers with a high and low E-modulus and high elongation at break has proved beneficial too.

HOW TO USE AND HANDLE FIBERS

FOR THE CONCRETE TO PERFROM AT ITS VERY BEST,
and to achieve the characteristics that are needed from it, a number of key factors have to be considered when using fibres in the initial concrete design. These include:

- Selecting the right fibre type or combination in terms of
- size and material (this is particularly critical)
- Determining how the concrete mix design is adapted
- The fibre dosing system and timing
- How the overall mixing procedure will work

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 correct choice of binder and water content
- The correct aggregate grading curve
- Optimum fiber quantity
- Considering 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
- Low pump pressure
- Good sprayability
- Less rebound

Performance
- Good fiber-cement bonding
- Low water-cement ratio

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

USING FIBERS IN CONCRETE CAN SIMPLIFY THE PRODUCTION PROCESS, in both precasting and on-site workflows. That is because the need for extra steel reinforcement can be reduced at many points, or even eliminated completely, which helps to speed up a project and make it more cost-effective. Because synthetic fibers increase fire resistance, there is no need to over-design concrete cross-sections, or post-apply fire protection systems – making the construction process even simpler.

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 PERFORMANCE AND CHARACTERISTICS OF FIBER-REINFORCED CONCRETE NEED TO BE TESTED with methods tailored to suit the specific end application, to make sure it can be used safely in future specifications. These test methods are now fully-standardised internationally through the European Standards (EN), as well as the American Society for Testing and Materials (ASTM).

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

SUCCESSFUL CONSTRUCTION PROJECTS ALL AROUND THE WORLD HAVE BENEFITTED from fiber-reinforced concretes and mortars, as well as from Sika's technical expertise and extensive practical experience. The advantages of fibers can be seen most clearly in tunnelling and mining projects, as well as in precast construction, flooring and any project that requires excellent fire resistance. Here are just a few examples:

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

OAKFIELD RECYCLING CENTRE, UK

Oakfield recycling centre in Hucknall needed a concrete slab that could withstand the impact of heavy machinery to replace their existing steel mesh system. The use of SikaFiber® Force synthetic macro-fibers delivered the strength required while also eliminating the risk of corrosion and other issues associated with traditional steel reinforcement.

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.

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