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New applications for steel fiber reinforced concrete and combined reinforcement

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New applications for steel fiber reinforced concrete and combined reinforcement

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ABSTRACT

After years of research and development, recommendations as well as codes are now available for the design and construction of steel fiber reinforced concrete (SFRC). Model Code 2010, which is regarded as state of the science and serves as a template for an upcoming Eurocode version, has dedicated a whole chapter to the design and construction of SFRC with or without traditional reinforcement (combined reinforcement). Further standards and recommendations have been worked out in different countries.

The aforementioned standards cover a new range of applications. These include foundation slabs of multi-story buildings, clad rack buildings, structural floors, fluid-tight floors and many more slab types subject to high structural and serviceability requirements.

The application area has been expanded thanks to extensive committee work, while trendsetting progress has also been achieved for such steel fiber products. After years of research, new types of steel fibers are now being introduced in the market, raising performance to another level.

INTRODUCTION

The question about the ‘need’ for new fiber types for SFRC finds its answer in a consideration of all recent possibilities of applications that have evolved over years of experience with this construction material and which – after years of committee work – are now supported by guidelines, standards and codes.

Model Code 2010 is widely regarded as state of the science and might be one of the documents that will serve as a template for a future Eurocode version in which SFRC will likely be covered. Within the scope of Model Code 2010, SFRC is described as suitable for the design and construction of structural applications.

The anchorage of steel fibers is designed to allow a controlled pull-out behavior under advanced deformation.

A BRIEF REVIEW OF STEEL FIBER PROPERTIES

The following review outlines three of the essential parameters of steel fiber properties. The performance of SFRC is mainly based on these steel fiber material properties. The following specifications apply to typical concrete strength classes between C20/25 and C35/45.

Anchorage

The anchorage of steel fibers is designed to allow a controlled pull-out behavior under advanced deformation. Here, the resistance against pulling out of the concrete matrix plays a crucial role. The proven system is the typical end hooked anchorage. It offers sufficient resistance against pulling out and yet assures the mechanism of controlled fiber pull-out

Tensile strength

The tensile strength of a steel fiber needs to be aligned to the anchorage. This is how the tensile strength capacity can be utilized best while maintaining ductility.

The tensile capacity of a wire with higher tensile strength can only be utilized if the anchorage/anchorage resistance is adapted accordingly.
If the anchorage is too strong in relation to the tensile strength, brittle material behavior can be observed, causing the fiber to snap.
Normal strength fibers with a typical single end hook have proven to be best for steel fibers usually found in the market.

Ductility

Ductility might be the term and the material property most commonly linked to SFRC. Concrete reacts in a brittle manner, and typically so do fibers.

For all typical steel fibers known in the market, ductility is established by the aforementioned pull-out procedure. It does not refer to ductility typically associated with wire.

THE NEW STEEL FIBER GENERATION

Bekaert has created fiber families to clearly distinguish between fibers of different levels of performance. All well-known fibers with hooked end anchorage and a normal tensile strength of around 1100 N/mm² are clustered into the Dramix® 3D fiber family. All typical applications apply to these fiber types and the fiber pull-out mechanism remains.

Tensile curves 3D-4D-5D wire qualities

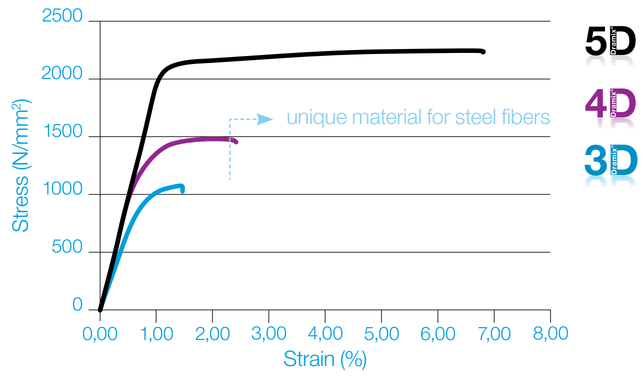

Figure 1: Strain capacity of different steel fiber types

A logical evolution was to increase the tensile strength of the wire as well as to improve the anchorage. The development of the double hook end and tensile strength of 1500 N/mm² lifts performance to a higher level and further sustains the pull-out mechanism as previously described. Bekaert has clustered these fibers into the Dramix® 4D fiber family, which is designed for optimal serviceability.

The Dramix® 5D series is a completely new steel fiber concept. The uniqueness of this fiber type lies in the mechanism of action of the SFRC. The anchorage is designed as a perfectly shaped hook that is fully restrained into the concrete and does not follow the typical pull-out procedure. Ductility is hence not ensured by fiber pull-out. On the contrary, for a steel fiber specific material, a distinctive treated wire type serves as source material. This is an ultra-high tensile strength wire that incorporates very large strain capacity (figure 1).

At full anchorage of the 5D fiber type, snapping will be avoided due to the strain capacity of its material. This is an entirely new principle for SFRC; an approach akin to structural concrete. This mode of action enables the tensile strength capacity to be maximized, and gives a logical reason for the use of ultra-high tensile strength wire. Figure 2 illustrates the utilization of tensile

Pull-Out test of Dramix® 3D, 4D and 5D

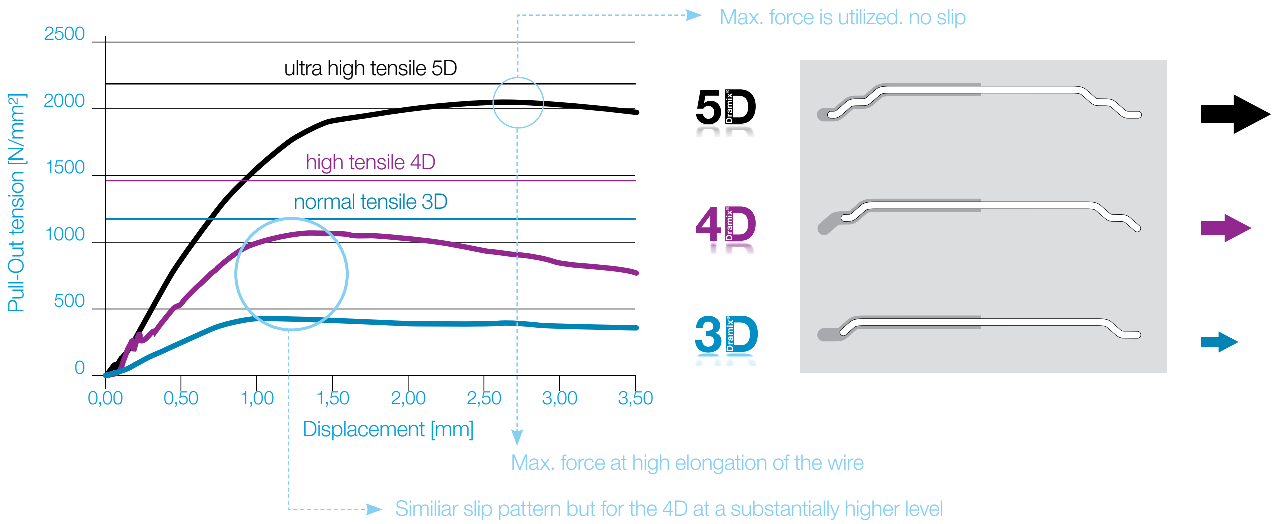

Figure 2: The pull-out test illustrates the different workings of the 3 Dramix® fiber types. The hook in the 3D and 4D series slowly deforms during the pull-out process, while the 5D hook stays firmly rooted, but the wire is elongated to create ductility in the concrete.

strength of Dramix® 3D, 4D and 5D fibers in a reference concrete. The optimized utilization of wire tensile strength for the 5D fiber type is clearly visible. This investigation is based on a pull-out test of a single fiber.

To measure the performance of SFRC, statically determined beam tests are well established. Multiple cracking can be observed for 5D fibers used in these beam tests, indicating a performance beyond the flexural strength of concrete. 5D fibers give strain hardening material behavior at a reasonable/usual dosage rate in these statically determined beam tests; behavior that to date is not associated with steel fibers. The 5D fiber type is designed for the most demanding conditions, particularly for verifications in the ultimate limit state design of concrete structures. Figure 3 illustrates typical results in a beam test according to EN 14651 for 3D, 4D and 5D fibers.

LARGE-SCALE TESTING

Ground-supported applications

To check the performance of the new Dramix® 5D fiber, large-scale testing on elastic bedded slabs was conducted at the University of Kaiserslautern. Comparison was made with typical 3D fibers tested in the same manner (see figure 4). The large-scale tests proved the high level of performance of the new 5D fibers. In comparison with conventional fibers, the 5D fibers displayed impressive performance with both higher load bearing capacity and a much more pronounced multiple cracking effect with considerably smaller crack openings.

Figure 4: Large-scale testing of elastic bedded slab specimens

To verify material properties while also serving as a basis for a back calculation, beams were cast and tested according to EN 14651 (see figure 5). The beam tests with the 5D fibers clearly outlined strain hardening in these single-spanned beams;

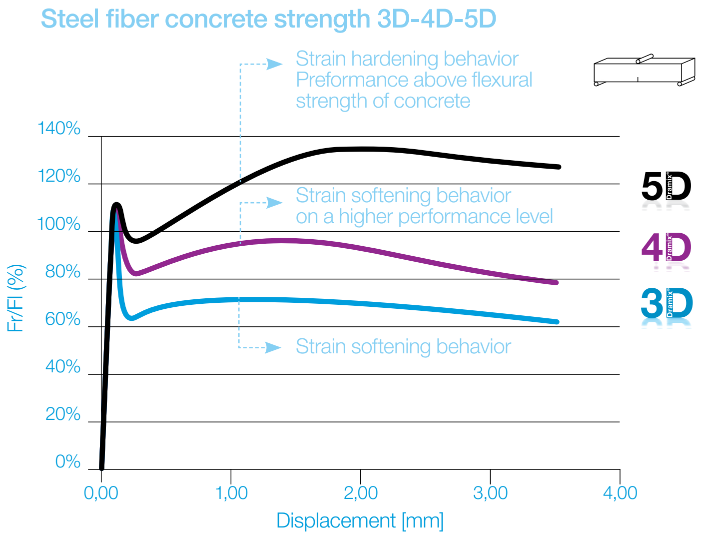

Figure 3: Typical load deflection curve in a beam test according to EN 14651

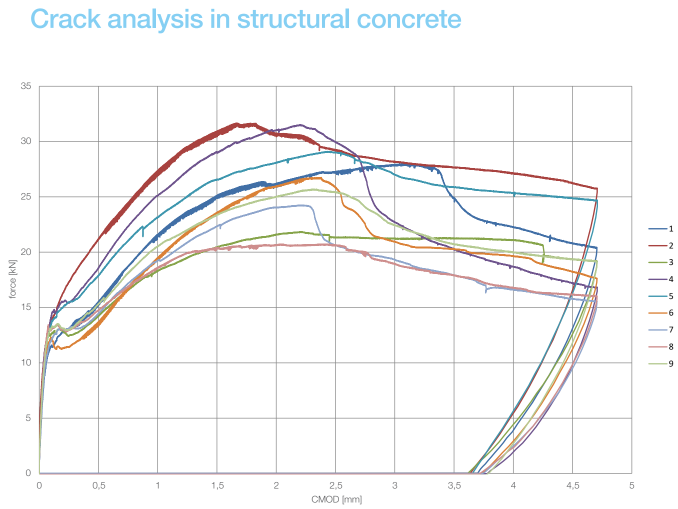

Figure 5: Load deflection curves: 40 kg/m³ Dramix® 5D 65/60BG, EN 14651 test

a material behavior that was never associated with typical steel fibers and rather reflects the behavior of structural concrete.

Floors on piles

Three large-scale tests were performed at the Ruhr-University Bochum (Germany) to measure the performance of Dramix® 5D reinforced floors on piles. The purpose of the tests was to measure the load deflection and load crack opening performance as well as crack patterns and crack propagation (figure 6).

The tests were performed on 5000 mm x 5000 mm x 150 mm concrete slabs consisting of C30/37 concrete reinforced with 40 kg/m³ Dramix® 5D 65/60BG. Each slab was supported by nine columns and loaded at four points.
The results are as follows:

- A distinct bending hardening behavior that meets the structural requirements of the floor
- Very high ductility of the structure
- Improved crack patterns
- Tight cracks and a much more distributed crack patterns
- High stiffness during yield line formation; fewer deformations in the initial phase (SLS)

THE MARKET POSSIBILITIES

Well-known application areas

The use of SFRC is mainly associated with industrial floors, underground works, precast and minor residential applications. With regard to flooring, typically non-structural floors, meaning floors that do not interfere with the integrity of the building, are a core business. Examples of such applications are saw-cut and jointless floors. The construction method of core SFRC applications of these applications is well established.
Figure 7 shows other examples of established applications. Reluctance to use steel fibers for structural applications was mainly due to lack of standards and the limited performance of typical steel fibers.

New application areas for SFRC with focus on SLS and/or ULS

Large surfaces, intensive use, no joints

Seamless industrial floors are increasingly replacing jointless floors. Whereas jointless floors still have contraction joints every 40 meters or less, seamless floors have no joints whatsoever, no matter how large the surface of the floor.
The optimized crack control and high impact resistance of the Dramix® 4D series in combination

Load deflection 5D only

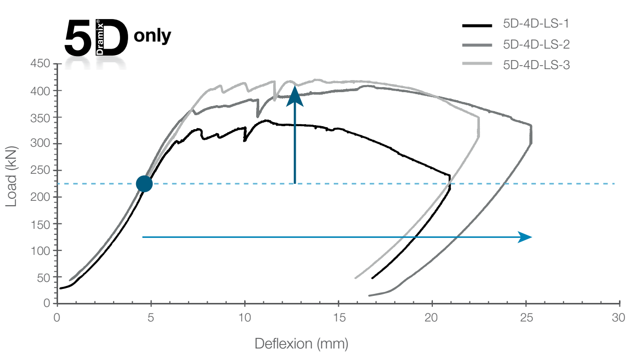

Figure 6: Tests performed according to DIN EN 14651 showing that all structural requirements are met, proving that Dramix® 5D reinforced floors are robust, reliable and safe.

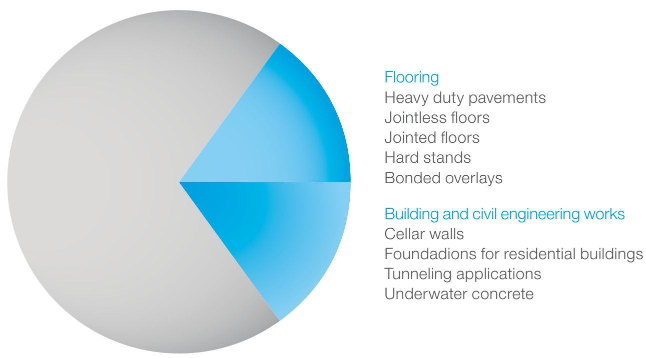

Figure 7: Well-known application areas of SFRC

with one top mesh provides a system that allows intensive use and lowers maintenance and repair costs.

Fluid-tight floors, water-tight structures and coated slabs

The Dramix® 4D series has been specifically designed to affect cracks between 0.1 and 0.3 mm, enabling durable fluid- and/or water-tight structures with the most stringent serviceability requirements. Combined reinforcement can also be used as the substrate for hard thin toppings such as epoxy layers and other coatings. Along with only one top mesh, a crack width limitation designed for the specific SLS requirement can be applied.

Figure 8 shows a typical illustration of a fluid-tight floor. A coating was applied to assure tightness. The slab is subject to a very stringent crack width limitation to allow the coating to remain undamaged. A combined solution with a single top mesh and high performing SFRC is a most practical, economical and time-saving method of construction.

Structural floors and seismic floors

Industrial floors are usually ground-supported and do not interfere with the integrity of the building. However, structural floors exist on which the entire building is erected. Those floors additionally act as a foundation slab that braces and carries the entire building load.

Figure 9 shows the raft foundation of a 30 m high production facility. The whole building is erected on the slab with cantilever columns exerting loads of more than five meganewton and two meganewton meters into the slab. An additional requirement was for a seamless construction with a crack width limitation of 0.2 mm. Design and execution of a combined reinforcement saved around 60% of the traditional reinforcement that would otherwise have been required. The major benefits of this solution are time-saving and practicability (e.g. enabling the use of Bamtech meshes).

In seismic areas, floors function as a tie beam for structural elements such as columns and pad foundations. Significant uplift forces, and in-plane forces during a seismic event, have to be considered. A combined solution offers a

Figure 8: A typical fluid-tight slab

Figure 9: Structural floor of an extremely high demanding building: combined solution

The Dramix® 4D series has been specifically designed to affect cracks between 0.1 and 0.3 mm

Figure 10: A typical clad rack system

practical, economical and time-saving solution. By using higher performing fibers like Dramix® 5D, a considerable amount of traditional reinforcement can be replaced.

Floors on piles

SFRC floors on piles are seen from time to time, although with stricter limitations in terms of pile distances, slab thickness and additional amount of reinforcement. To date, all SFRC piled floors executed are usually solutions with additional reinforcement along the pile grid or with a piece of mesh above the piles. Because of their exceptional load bearing capacities, Dramix® 5D steel fibers enable the construction of floors on piles without traditional reinforcement. This saves time during construction, and creates new possibilities for floors on piles.

Clad rack foundations

Clad rack warehouses (as shown by figure 10) refer to any type of storage system in which the shelving facility is part of the building structure, thereby avoiding the need for the civil works of a conventional building. For this type of warehouse, the shelving facility not only supports the load of the stored goods, but also the load of the building envelope, as well as external actions such as wind, snow and seismic forces. Most clad rack buildings are automatic systems (AS/RS) using robotic equipment for handling loads.

Accordingly, the foundation of this racking system is a real raft foundation that additionally has to fulfil the requirements of a floor. The raft is executed before the rack system is erected; meaning temperature needs to be considered for a monolithic slab type. A typical solution with SFRC can be in combination with or even without the use of mesh or any other traditional reinforcement method. Because of its unique capabilities, the 5D series provides utmost strength and durability to preserve the integrity of the clad rack structure from downward forces, uplift from wind loads and seismic forces. The elimination of traditional reinforcement can lead to significant savings.

Raft foundations

SFRC has been used for years in foundation slabs of residential buildings. The legal possibility to design this kind of load bearing structure is supported by local general approvals. However, foundation slabs are limited to certain loads and size measurements. Due to recent codes there is no limitation, neither of applicable load nor of size. Such raft foundations of various kinds of

Figure 11: Raft foundation of a multi-story building: combined reinforcement

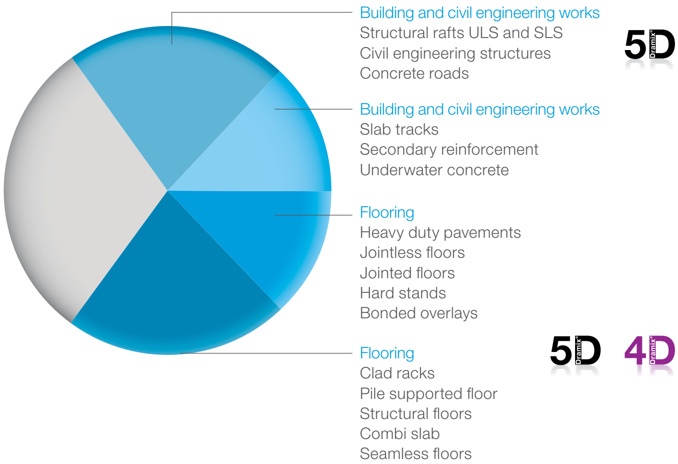

Figure 12: New application range for SFRC

multi-story buildings can be executed with SFRC, or combined reinforcement. Since these are in most cases heavily loaded rafts, large in size and subject to a stringent crack width limitation, combined reinforcement is mostly applied. As a rule of thumb, about 50% of the traditional reinforcement can be replaced. This clearly depends on the SFRC performance, where the use of Dramix® 4D or 5D fibers is particularly favorable and will generate larger savings.

The raft foundation of the building illustrated in figure 11 was carried out with combined reinforcement. A key reason for choosing SFRC was to minimize shear studs and shear reinforcement. With the solution using combined reinforcement, both have been achieved. The requirements for bending reinforcement and crack width reinforcement have largely been reduced. In addition, most foreseen shear studs and shear reinforcements have been completely skipped by using a combined solution. The resulting cost saving, time saving and ease of construction are the main benefits of using this solution. The key applications of the extended application area for SFRC are illustrated in figure 12. Different elements other than those mentioned are certainly also possible.

CONCLUSION AND PERSPECTIVE

The application area for SFRC and especially for combined reinforcement is now more diverse than ever. Thanks to wide experience, proven economic feasibility and validation in terms of codes and standards, new applications have opened up. With the development of new steel fiber products an essential element has been added. All parts of the puzzle are now available to cover the extended possibilities for steel fiber reinforced concrete for an economic, durable and time-saving construction.

Guirguis Philipp

Philipp Guirguis holds a degree in Civil Engineering from the University of Siegen in Germany. He worked for several years as a structural designer on a variety of construction projects. In January 2008 he joined Bekaert in responsibility as Technical Manager for Building Products. In this function he was responsible for projects in Central Europe, Middle East, West Asia and Russia. Since 2014, he is the responsible Sales Manager for Central Europe/UK/Israel. Philipp Guirguis is member in different working groups and committees for Steel fiber reinforced concrete.

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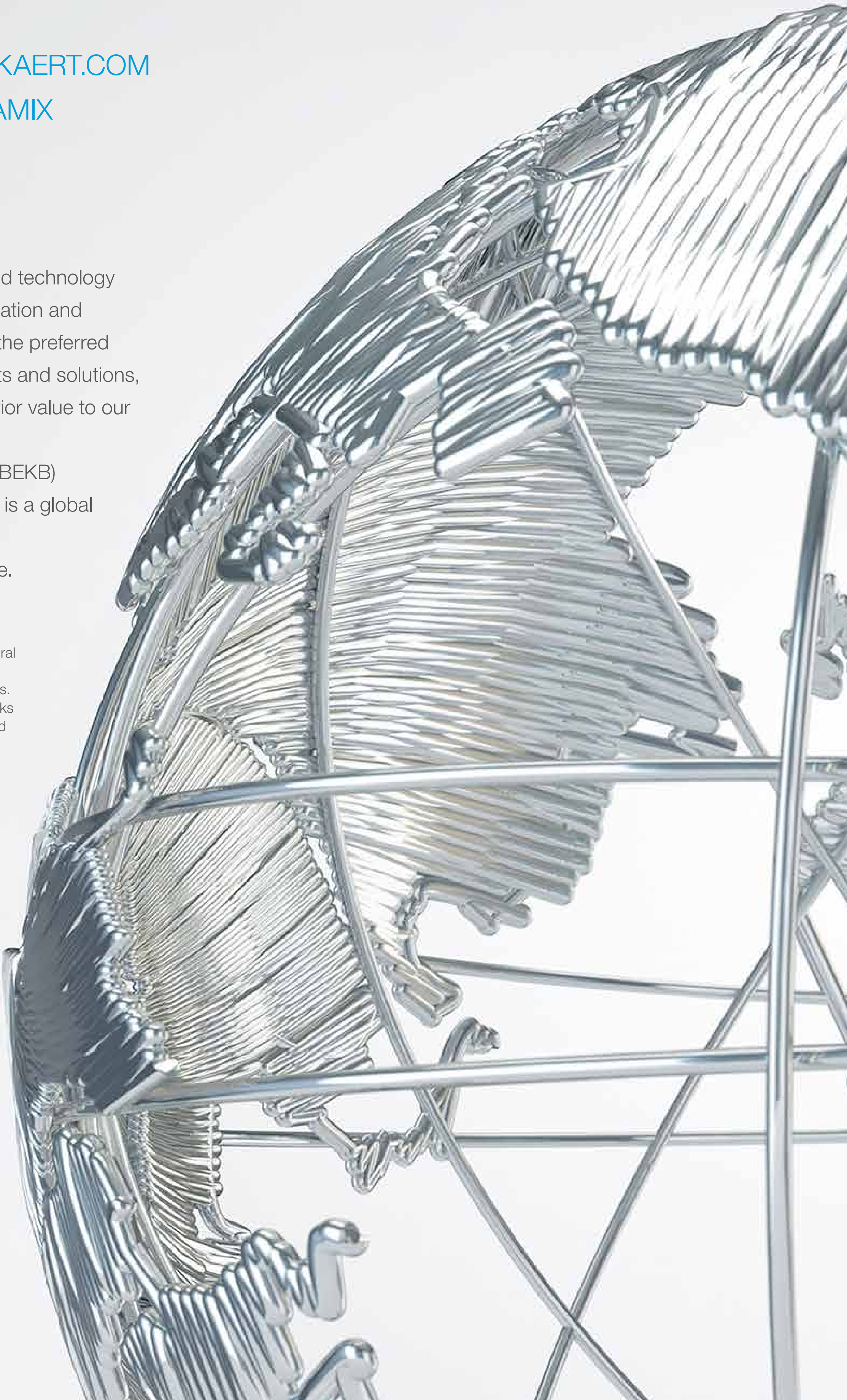

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