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NEW APPLICATIONS FOR STEEL FIBRE REINFORCED CONCRETE AND COMBINED REINFORCEMENT

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Abstract

After years of research and development not only recommendations but also codes for the design and construction of steel fibre reinforced concrete are available. The German Guideline for example is an addition to the structural concrete code of Germany and is taken up by the building authority in the list of official building materials. The Model Code 2010, which is supposed to be 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 steel fibre reinforced concrete with or without traditional reinforcement (combined reinforcement). Further guidelines are worked out in different countries.

Aforementioned standards allow covering new range of applications as for example foundation slabs of multi-storey buildings, clad rack buildings, structural floors, fluid tight floors and many more slab types subject to high structural and serviceability requirements.

Not solely the application area has been expanded thanks to the extensive committee work but also trendsetting progress has been achieved for steel fibre products as such. After years of research new types of steel fibres are introduced in the market which lift performance to another level.

Keywords: Steel fibre reinforced concrete (termed SFRC), new fibre types, strain hardening, strain capacity, combined reinforcement, structural applications

1. Introduction

The question about the “need” of new fibre types for SFRC finds its answer in considering all recent possibilities of applications which have evolved over years of experiences with this construction material and which are after years of committee work supported by guidelines, standards and codes. In particular the German Guideline SFRC, which is taken up in the list of official building materials is a guideline with code character and enables plenty of applications for SFRC and for combined reinforcement.

The Model Code 2010 is widely regarded as state of the science and might be one of the documents that will serve as template for a future Eurocode version in which SFRC will likely be engaged. Within the scope of Model Code 2010 SFRC is taken up and subject to design and construction for structural applications.

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2. A brief review of steel fibres properties

The following review outlines three of the essential parameters of steel fibre properties. The performance of SFRC is mainly based on these steel fibre material properties. The following prescription holds for typical concrete strength classes between C20/25 and C35/45.

2.1 Anchorage

The anchorage of steel fibres is designed to allow a controlled pull out behaviour under advanced deformation. Herein the resistance against pulling out of the concrete matrix plays a crucial role. Proven system is the typical end hooked type of anchorage. It offers sufficient resistance against pulling out and yet assures for the mechanism of controlled fibre pull-out.

2.2 Tensile strength

The tensile strength of a steel fibre needs to be aligned to the type of anchorage. That is the way how the tensile strength capacity can be utilised level best whilst ductility remains.

For a wire of higher tensile strength without an adoption of the anchorage strength the tensile capacity will - as a matter of fact- not be approximately utilised.

In case of too strong anchorage without adoption of tensile strength a brittle material behaviour can be observed which the result of fibre snapping is.

Normal strength fibres with a typical single end hook have proven to be best for steel fibres customary in the market.

2.3 Ductility

Ductility might be the term and the material property that is mostly linked to SFRC. Concrete reacts brittle and so do typical fibres too.

For all typical steel fibres known in the market ductility is established by the aforementioned pull out procedure. It is not a ductility of the wire type!

3. The new steel fibre generation

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

A logical evolvement was to increase the tensile strength to a high tensile strength wire of 1500 N/mm² and to improve accordingly the type of anchorage (double hook) in order to utilise the wire strength level best. This development lifts performance to a higher level but sustains further on the pull out mechanism as previous described. Bekaert has clustered these fibres into the Dramix® 4D fibre family. The Dramix® 4D series is designed with optimal serviceability in mind.

A totally novel development for steel fibres is offered by the Dramix® 5D series. The particularity using this fibre type lays 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 fibre pull out. On the contrary a for steel fibres specific material, a distinctive treated wire type, serves as source material: An ultrahigh tensile strength wire that itself disposes of huge strain capacity (figure 1).

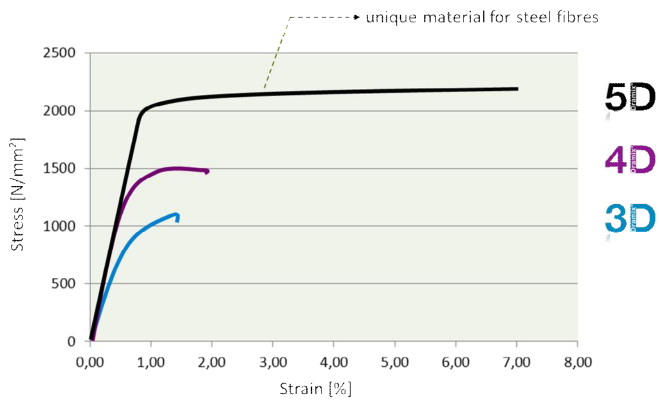

Fig. 1: Strain capacity of different steel fibre types

At fully anchorage of the 5D fibre type snapping will be avoided due to the strain capacity of its material. This is a totally new principle for SFRC, an approach that rather reminds to structural concrete. This mode of action enables to utilise the tensile strength capacity at most and gave logically reason to engage an ultrahigh tensile strength wire. Figure 2 illustrates the utilisation of tensile strength of a Dramix® 3D, 4D and 5D fibre in a reference concrete: Clearly visible the optimised utilisation of wire tensile strength for the 5D fibre type. This investigation is based on a pull out test of a single fibre.

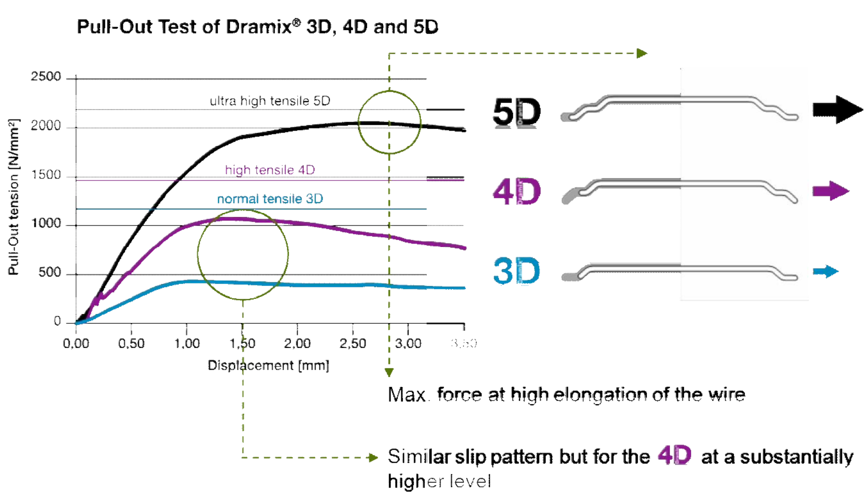

Fig. 2: Utilisation of tensile strength

As performance measure for SFRC statically determined beam tests are well established. Multiple cracking can be observed for 5D fibres being used in these beam tests which indicates a performance beyond the flexural strength of concrete. 5D fibres obtain strain hardening material behaviour at decent/usual dosage rate in these statically determined beam tests; behaviour that to date was not associated to steel fibres. The 5D fibre 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 EN 14651 for 3D, 4D and 5D fibres.

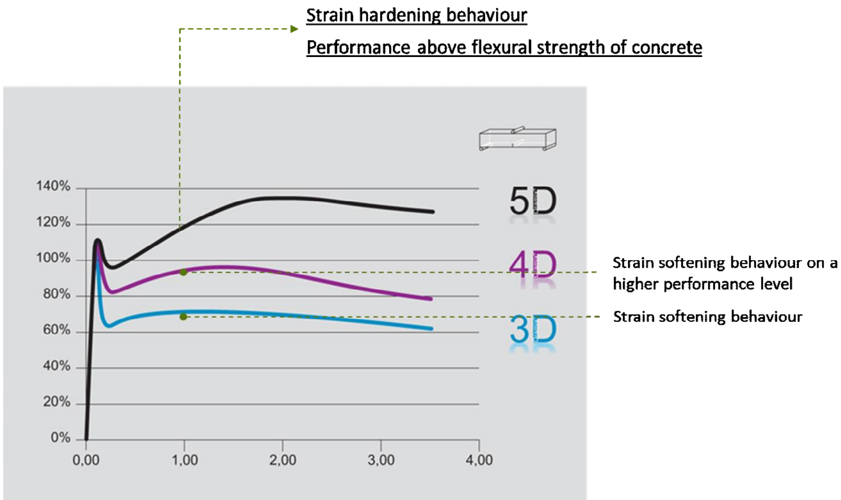

Fig. 3: Typical load deflection curve in a beam test according EN 14651

4. Large scale testing

In order to check the performance of the new Dramix® 5D fibre type large scale testing on elastic bedded slabs has been conducted at the University of Kaiserslautern. Comparison has been drawn to typical 3D fibres which have also been tested in the same manner. The large scale tests have proven the high performing level of the new 5D fibre types. In comparison with conventional fibre types the 5D fibres have shown an impressive performance with both, higher load bearing capacity and a much more pronounced multiple cracking effect with considerable smaller crack openings.

Fig. 4: Large scale testing of elastic bedded slab specimens

To verify material properties but also serving as a basis for a back calculation beams have been casted and tested according EN 14651 and according the determinations of the German Guideline. The beam tests with the 5D fibres have clearly outlined the strain hardening behaviour in these single spanned beams, a material behaviour that was never associated to typical steel fibres and rather reflects the behaviour of structural concrete.

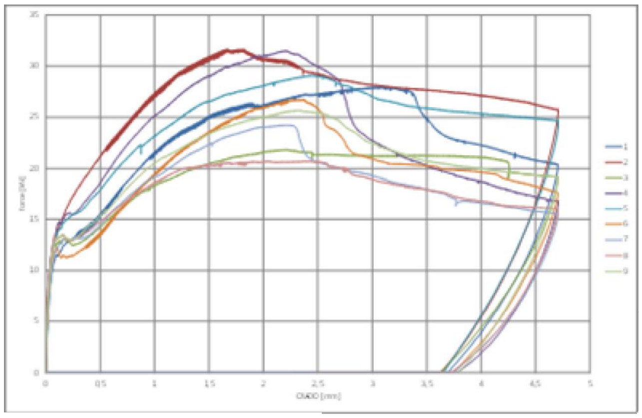

Fig. 5: Load deflection curves: 40 kg/m³ Dramix® 5D 65/60BG, EN 14651 test

5. The market possibilities

5.1 Well known application area

The use of SFRC is mainly associated to industrial floors, underground works, precast and to minor residential applications. In the scope of flooring typically non-structural floors (building is erected on foundations and the floor is laid later and does not interfere in the integrity of the building) are core business. Different construction methods like saw cut or jointless floors for internal or external areas for various kind of use are established and will remain the core application area for SFRC. Many more well-established applications are illustrated in figure 6. Towards structural applications reluctance existed which found its key reason in the lack of standards and in a limited performance of typical steel fibres.

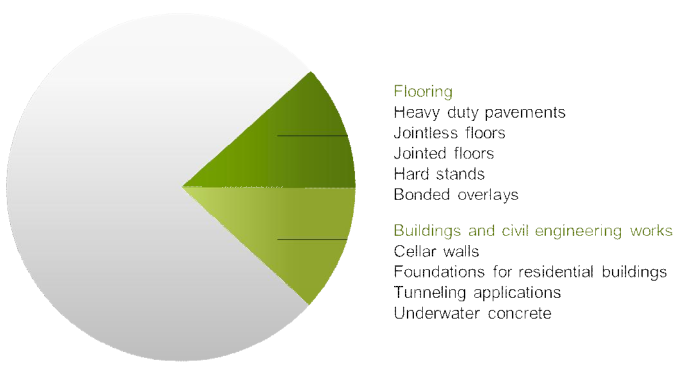

Fig. 6: Well known application area of SFRC

5.2 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 expansion joints every 40 meters or less, seamless floors have no joints whatsoever, no matter how large the surface of the floor is. The optimized crack control and high impact resistance of the Dramix®4D series in combination with only a top mesh provides a system with intensive usage, reduced 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 0.3mm, enabling you to create durable fluid and/or water tight structures with most stringent serviceability requirement. 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.

Fig. 7: Illustration of a typical fluid tight slab

Figure 7 shows a typical illustration of a fluid tight floor. A coating was applied in order to assure tightness. The slab is subject to a very stringent crack width limitation in order to allow the coating remain undamaged. A combined solution with only a top mesh + high performing SFRC is a most practical, economic and time saving way of construction.

Structural floors and seismic floors

Industrial floors are usually ground-supported and not interfering into the integrity of the actual building. However, there are structural floors on which the entire building is erected on. Those floors are additionally acting as foundation slab that is bracing and load carrying the entire building.
Figure 8 shows the raft foundation of a 30m high production facility. The whole building is erected on the slab with cantilever columns entering loads of more than 5 MN and 2 MNm into the slab. Additional requirement was for a seamless construction with crack width

limitation to 0,2mm. Design and execution was in combined reinforcement saving around 60% of the else required traditional reinforcement. Tremendous effect of this solution was the time saving outcome and the practicability (e.g. use of Bamtech meshes enabled).

Fig. 8: Structural floor of an extremely high demanding building: Combined solution

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 dealt with. A combined solution offers a practical, economic and time saving solution. By using higher performing fibres like the Dramix® 5D fibre considerable amount of traditional reinforcement can be replaced.

Floor on piles

SFRC floor on piles have already been carried out from time to time though with stricter limitations in terms of pile distances, slab thickness and additional amount of reinforcement. All as to date executed SFRC piled floors were usually solutions with additional reinforcement along the pile grid or with piece of meshes above the piles. Because of its exceptional load bearing capacities, Dramix® 5D steel fibres enable the construction of floors on piles without traditional reinforcement. This does not only save time during construction, but also creates new possibilities for floors on piles.

Clad Rack foundations

Clad Rack warehouses are 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 actions. Most clad rack buildings are automatic systems (AS/RS) using robotic equipment for handling loads.

Fig. 9: Illustration of a typical CladRack system

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 methods. Because of its unique capabilities, the 5D series provides utmost strength and durability to preserve the integrity of the clad rack structure from downward, uplift from wind loads and seismic forces. The elimination of traditional reinforcement can achieve significant savings.

Raft foundations

Steel fibre reinforced concrete has been used since years for foundation slabs of residential buildings. The legal possibility to design this kind of load bearing structures was supported by local general approvals. However the possibly foundation slabs have been limited to certain loads and size measurements. Due to recent codes (e.g. German Guideline) there is no limitation, neither of applicable loads nor to the size measurement. As such raft foundations of multi storey buildings of any kind can be executed with SFRC, combined reinforcement respectively. Since these are in most cases heavy loaded rafts, big in size measurement and subject to a stringent crack width limitation combined reinforcement is mostly applied. As a rule of thumb about 50% of the traditional reinforcement gets replaced. This is clearly depending on the SFRC performance wherefore the use of Dramix® 4D or 5D fibres are particularly favourable and will generate bigger savings.

Fig. 10: Raft foundation of a multi storey building, Combined reinforcement

The raft foundation of the building illustrated in figure 10 was carried out in combined reinforcement. One main reason for the decision towards SFRC was to get rid of the plenty of shear studs and shear reinforcement. With the solution of a combined reinforcement both has been achieved. Bending reinforcement and reinforcement for crack width requirement has mainly been reduced. On top most of basically foreseen shear studs and shear reinforcement have been completely skipped by the combined solution. As such cost saving, time saving and constructability have been main reason for this solution. The key applications of the extended application area for SFRC are illustrated in figure 6. Different elements than mentioned herein are certainly also supposable.

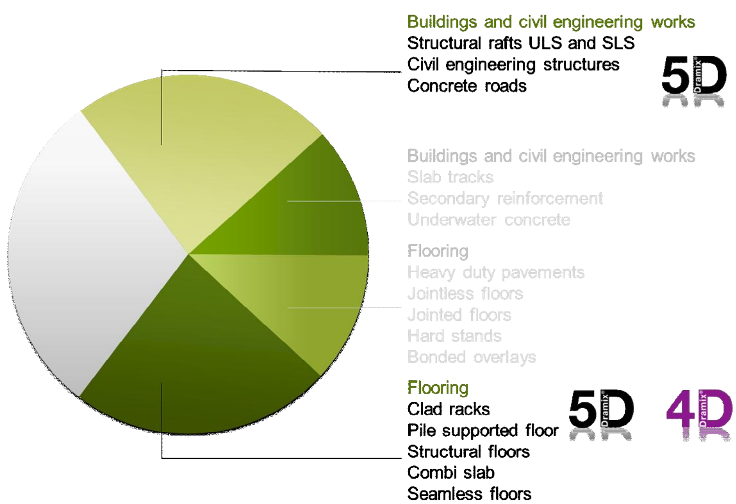

Fig. 11: New application range for SFRC

6. Conclusions and perspective

The application area for SFRC and especially for combined reinforcement is multisided than ever. Thanks to widely gained experience, proven economic feasibility and validation in terms of codes and standards the way into new applications is cleared for. With the development of new steel fibre products an essential element has been complemented. All puzzle parts are assembled in order to cover the extended possibilities for steel fibre reinforced concrete in the well-known manner of an economic, durable and time saving construction art.

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