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Steel – and Synthetic Fibre Reinforced Concrete
Which fibre to use for which application and why?

INTRODUCTION

Fibres for concrete, they appear in all colours, shapes, sizes and materials. Today, the majority of the fibres used in concrete can basically be classified into 3 families:

1. Steel fibres
2. Micro synthetic fibres
3. Macro synthetic fibres

Specific technical strengths and weaknesses of the different fibres, are often less well known, and lead to confusion. The main purpose of this brochure is to offer you an insight into the technical performance of the different materials. This brochure seeks to answer a question you might have: "Which fibre to use/specify for which application, and why?

Ann Lambrechts
Head R&D of Bekaert Building Products

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1. WHAT CAN WE LEARN FROM MATERIAL PROPERTIES?

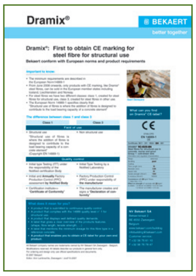
Material	Concrete 	Steel Mesh / Steel fibre  	Micro / Macro Polymer Fibre Extruded polypropylene / polyethylene  
Thermal Expansion coefficient λ	12 x 10^{-6}/°C	12 x 10^{-6}/°C	1.5 x 10^{-4}/°C
(Shrinkage for a temperature decrease of 30°C on a 50 mm long fibre)	0.018mm	0.018mm	0.23 mm
Creep behaviour in tension (Tg glass transition temperature)		+370°C	- 20°C
Melting Point (°C)		1500°C	165°C does not reinforce
Young's Modulus	30 000 MPa	210 000 MPa	3 000 – 10 000 MPa
Tensile strength		500 – 2 000 MPa	200 – 600 MPa
Density	2 400 kg/m³	7 850 kg/m3	910 kg/m³
Resistance to UV light			degradation will occur
Corrosion resistance		in concrete, and cracks < 0.2 mm	
Typical length of fibres		30-60 mm	**micro:** 6 - 20 mm **macro:** 30 – 65 mm
Typical diameter of fibres		0.5 – 1.0 mm	**micro:** 0.015 – 0.030 mm **macro:** 0.5 – 1.0 mm
Bekaert brands		Dramix®, Wiremix®	**micro:** Duomix® **macro:** Synmix®
CE label is compulsory in EU – in accordance with		EN14889-1	EN14889-2

Since June 2008, all fibres in EU must comply with standards EN 14889-1 and 2, and be CE labelled.
Two levels of attestation are defined:

"Structural use is where the addition of fibres is intended to contribute to the load bearing capacity of the concrete element"

Eric Winnepenninckx - Belgian Construction Certification Association (BCCA)

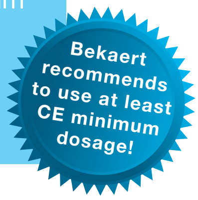
EN 14889-1 in fact states that structural use is where the addition of fibres is designed to contribute to the load bearing capacity of the concrete element. The manufacturing process of fibres for structural use should therefore be audited regularly by a certified body. This is not necessary for fibres for other use (non-structural use). A declaration of the manufacturer is sufficient in this case.



CE info sheet

According to EN 14889, a minimum performance level must be reached. As such for every fibre for structural use, a minimum dosage is required to have CE marking.

Download info sheets at:
http://dramix.bekaert.com



Concrete and steel have always been complementary: concrete is strong in compression; steel is strong in tension. Concrete protects steel against corrosion as long as the concrete is alkaline, and delays softening of the steel during a fire. Concrete and steel expand/contract equally due to temperature changes (equal thermal expansion coefficient).

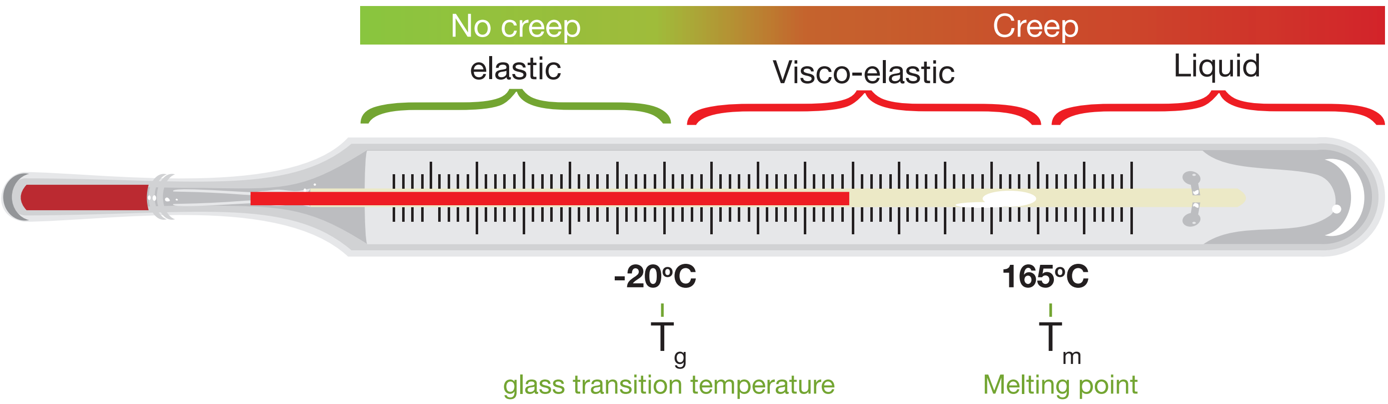
<u>The existence of national and international recommendations on the sizing of the structures or structural elements made up of these materials today perfectly validated for steel fibre only.</u>

Fibre materials with a Young's Modulus which is significantly affected by time and/or thermohydrometrical phenomenon are not covered by International recommendations as Model Code edited by fib, for the following reasons :

1. **<u>Polymer fibres melt at 165°C</u>**; in a fire any "reinforcing" effect of the macro fibres fades away as the temperature rises.

2. The Young's Modulus is 3 - 10 GPa, which is largely **<u>insufficient to reinforce</u>** concrete material with a modulus of 30 GPa.

3. **<u>Macro polymer fibres creep</u>** (further elaborated below) (Fig 1)



Below -20°C, polypropylene/polyethylene are typically elastic with negligible creep.

Between -20°C and 165°C, (at ambient temperature), polypropylene/polyethylene is typically visco-elastic, with significant creep. Creep is the increase in extension of a material under constant load. The deformation of the fibre is not only time-dependent, but also temperature-dependent.

So creep rises with temperature in the range 20°C to 40°C.

Creep of the fibre leads to:
- Unsustainable crack widths (which will widen, over time, under constant loading), thereby adversely affecting the durability of the concrete, serviceability, liquid tightness, ...
- Creep rupture of the fibre, even at stress levels corresponding to the serviceability limit state.

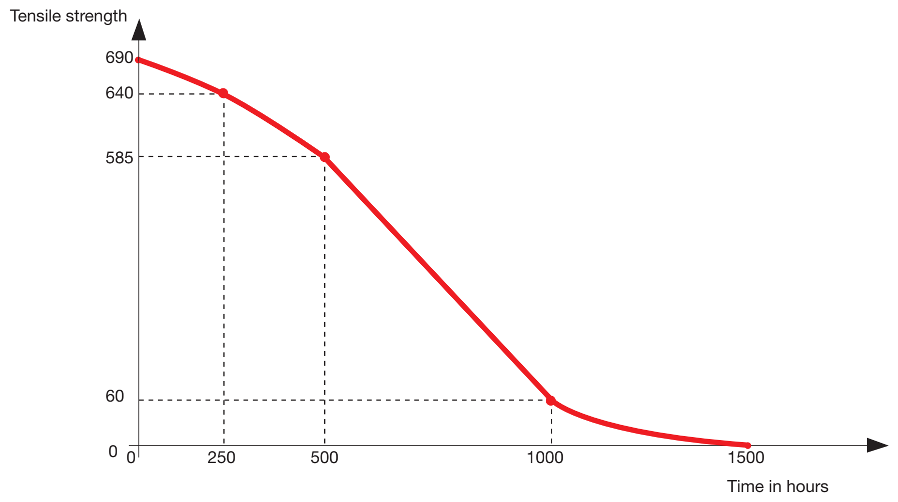
Due to the important creep behaviour, it is therefore mentioned explicitly in the Austrian standard - section 1.2.3 - that macro synthetic fibre concrete is **not covered** by the design rules on load bearing capacity and serviceability.

4 Macro polymer fibres are **not proven to be a durable reinforcement**

No long-term evidence on durability / ageing on polymer fibre concrete is **available**.

UV-degradation of macro-synthetic fibres is another cause for concern.

Tests at the Bekaert lab have shown a complete deterioration of the macro-synthetic fibres: **1500 hrs of UV-light** were sufficient to completely embrittle and break the fibres.



2. REINFORCEMENT

A fibre concrete is a composite material made up of a cement mortar reinforced with a matrix of fibres. In a fibre concrete, the fibres spread the strain across the cracks created in the matrix. In other words, the fibres are only useful if there are cracks in the concrete. No cracks, no effect of the fibres. Cracks, however, can appear at different stages in the life of the material. From the first moments, just after pouring the concrete, up to a very advanced age.

Plastic shrinkage reinforcement

Drying shrinkage reinforcement

Load bearing reinforcement SLS ULS

Long term reinforcement

- Fatigue
- Creep
- Fire
- Ageing

Reinforcement properties of the composite material:

	 Steel Mesh	 Steel fibres Dramix®	 Micro polymer fibres Duomix®	 Macro polymer fibres Synmix®
Plastic shrinkage	○	☺	☺ ☺ ☺	☺
Drying shrinkage	☺	☺ ☺ ☺	○	○
Impact resistance	☺	☺ ☺ ☺	☺	☺ ☺
Crack control (Serviceability limit state)	☺ ☺	☺ ☺ ☺	○	○
Post-crack strength (ultimate limit state)	☺ ☺ ☺	☺ ☺	○	☺
• Temperature dependent	☺	☺	☹	☹
• Time dependent	☺	☺	☹	☹
• No creep rupture	☺	☺	☹	☹
Anti-spalling properties in fire	○	○	☺ ☺ ☺	○
Fatigue resistance	☺	☺ ☺ ☺	○	☺
Fire resistance	☺	☺	☹	☹
No staining (aesthetics)	☺	☺ (*)	☺	☺
Corrosion resistance	☺ in concrete	☺ cracks < 0.2 mm in concrete	☺	☺

○ insignificant effect ☺ positive effect
(*) galvanized ☹ negative effect

2.1 Plastic shrinkage reinforcement

During the first few hours after pouring, the concrete starts to develop its strength and stiffness. At this young age, the compressive strength is of the order of 3 MPa, the tensile resistance only 0.3 MPa and the Young's Modulus less than 5 GPa. Should the concrete start to crack at this point, then both the load in any fibre, and the crack openings, will be small.

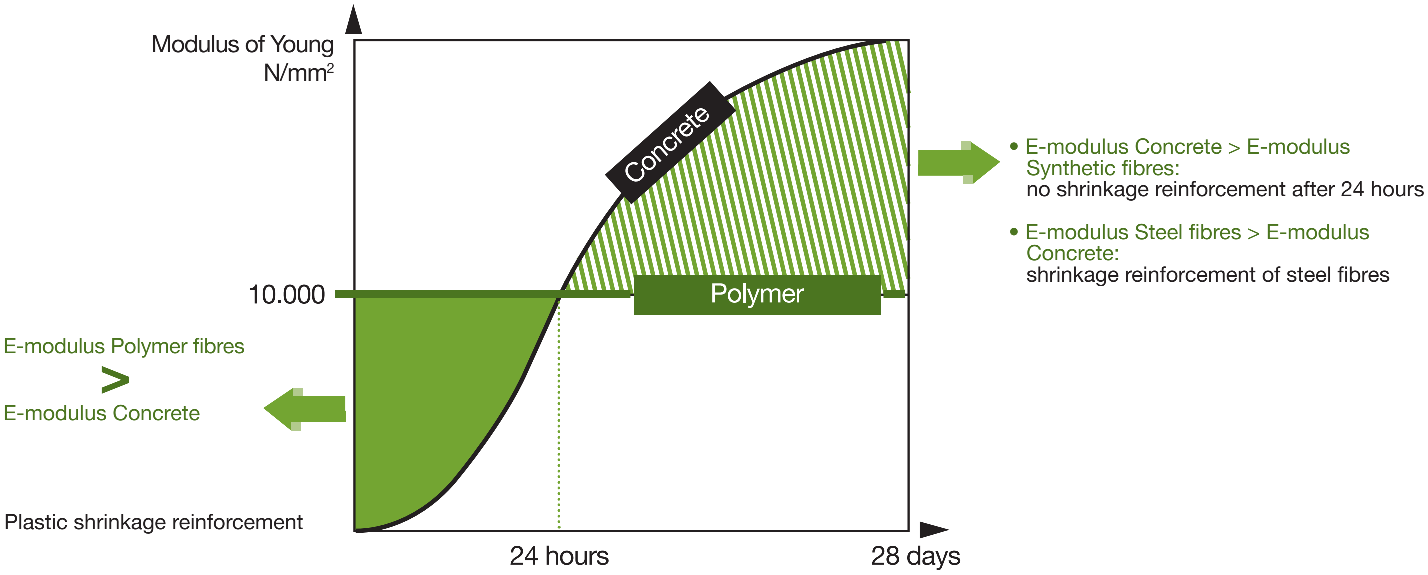
Any crack that might appear will be bridged by millions of micro synthetic fibres. In a composite material such as fibre concrete, a reinforcement effect can only be obtained when the reinforcing material displays a higher Young's Modulus than the basic material to be reinforced such as concrete. Micro polymer fibres reinforce the very young and still plastic concrete with ease, thanks to the dense network of fibres: millions of micro fibres are dispersed throughout the concrete.

Material	Young's Modulus
Concrete	+/- 30 GPa
Micro synthetic fibres	+/- 4 GPa
Macro synthetic fibres	3-10 GPa
Steel fibres	210 GPa

"In a composite material such as fibre concrete, a reinforcement effect can only be obtained when the reinforcing fibre has a higher Young's modulus than the base material."

Thomas Bonamie Concrete lab manager

Polymer fibres have only a plastic reinforcement effect in the first 24 hrs when their Young's Modulus exceeds the fresh concrete Young's modulus.

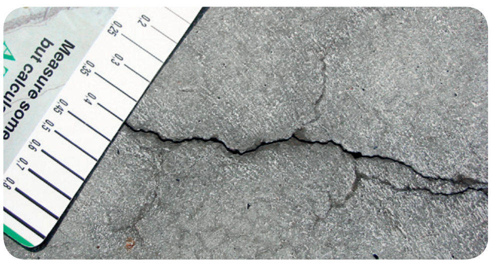


2.2 Drying shrinkage reinforcement & crack control

After 24 hours or more, the mechanical properties of the concrete multiply: compressive strengths now exceed 10 MPa, tensile strengths reach 1 MPa, and Young's Modulus is now well in excess of 15 GPa. Should the concrete crack again, then the loads on the fibre reinforcement are significantly higher. Synthetic fibres become less interesting.

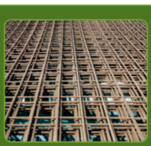
In fact, due to their low Young's Modulus, macro synthetic fibres require large crack widths before they develop any useful stress in tension. "Therefore in aged and cracked structures in concrete with macro-synthetic fibres, crack openings are larger than with steel fibres, and the deformation of the structure may be (too) significant".

"The Young's Modulus of a fibre is responsible for the crack control. The higher the Young's Modulus, the better the control of the cracks in terms of crack length and crack opening."



$\sigma = E \cdot \varepsilon$

E = Young's Modulus
ε = deformation ≈ crack opening

Steel mesh	Steel fibres	Macro synthetic fibres	Micro synthetic fibres
			
Young's Modulus: 210 GPa		E-modulus: max. 10 GPa	

20 X HIGHER

$\sigma = \mathbf{E} \cdot \varepsilon$
small deformations or crack openings

$\sigma = E \cdot \boldsymbol{\varepsilon}$
big deformations or crack openings

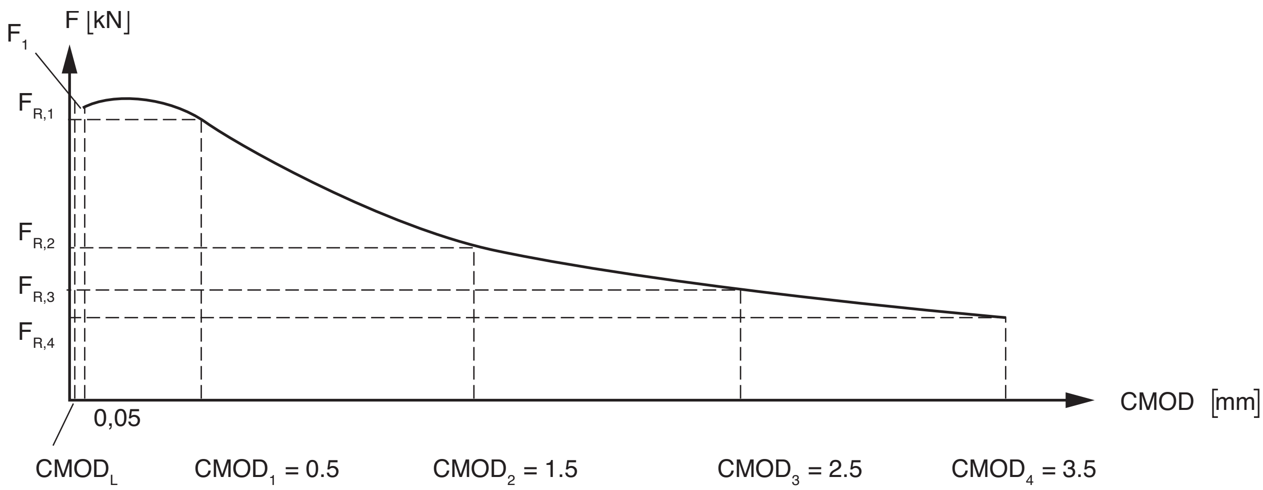
Possible consequences:

1. For the same loads to be taken up => same tension in the fibre concrete, the elongation of the fibres will be much higher for macro synthetic fibres compared with steel fibre concrete.

2. An engineer, considering designing a floor or tunnel lining with macro synthetic fibre concrete (post-crack strength), will be faced to large crack openings, major concrete deformations, or possibly failure depending on the loads.

2.3. Load bearing reinforcement in serviceability limit state (SLS), and ultimate limit state (ULS)

The reinforcing effect of the fibres is measured via standardized test methods, such as EN14651 and ASTM C 1609.



Typically, the post-crack resistance at a low crack width (CMOD = 0.5) is applied in SLS design; and the post-crack strength at CMOD = 3 mm, is used in ULS design.

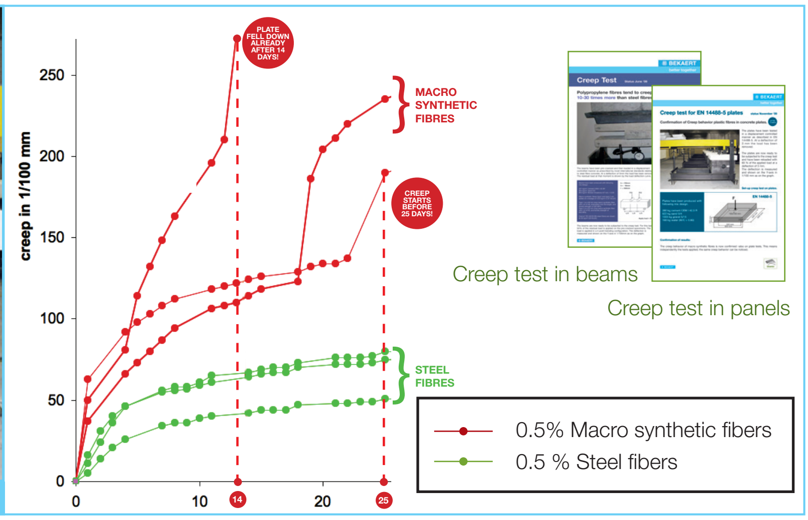
Steel fibres and macro polymer fibres behave differently in the standardized beam test (Micro polymer fibres are too small to have any reinforcing effect, so they will not be discussed any further).
Due to the low Young's Modulus of macro synthetic fibres, crack widths are very significant (> 0.5 mm) before fibres start to work.
Note that the "reinforcing effect" of macro synthetic fibres, observed in the standard beam test, should be treated with caution: indeed the values are obtained after 15' (the time it takes to run one test). For macro synthetic fibres, prone to creep, a still unknown creep factor should be taken into account.

3. CREEP BEHAVIOUR OF THE CONCRETE REINFORCED WITH MACRO POLYMER FIBRES

Since macro polymer fibres appeared on the market (≈ 2000), more and more experience has been gathered on this new material.
Especially the "time dependency" of the performance causes concern. Tests at different labs have shown that creep of macro synthetic fibre concrete is not only considerable, but also leads to creep failure at service loads. Creep failure means that the load bearing capacity is completely lost, which, of course, is unacceptable for load bearing structures.

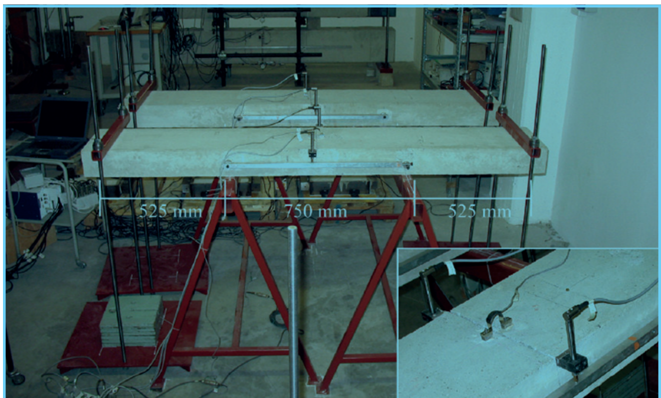
Beginning in 2004, different concrete labs have tested and evaluated the creep behaviour of different fibre concretes. Creep behaviour has been examined using both beams and in "structural" investigations such as the Efnarc panel test.


Creep test set-up

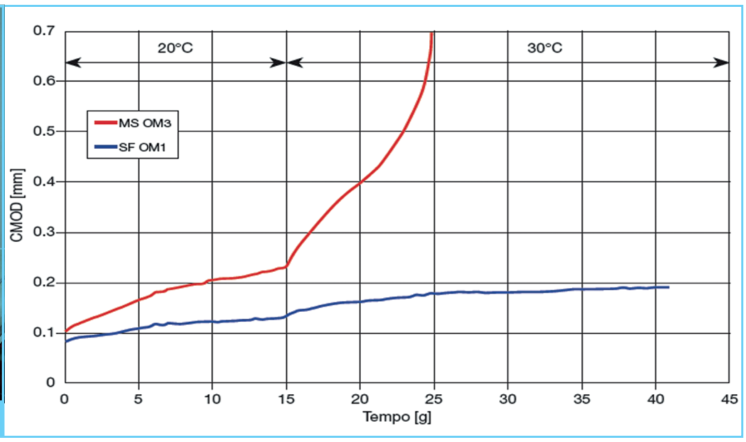


In addition to the research done in 2004 on the creep behavior under load, a follow up research program was done at the University of Bologna to study the influence of temperature on creep behavior. The test specimen were put under load in a temperature controlled chamber. On the graph it is clearly shown that, with a mere increase of 10 °C (from 20 °C to 30 °C), still remaining in serviceability conditions, creep of the macros synthetic fibre increased exponential leading to rupture in a couple of days.

Ask your creep info sheets via: **infobuilding@bekaert.com**



Experimental set-up for the long-term test.



Picture: CMOD (crack mouth opening displacement) increase over time for the beams Steel fibre SF and Macro-synthetic fibre MS

Possible consequences:

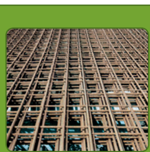
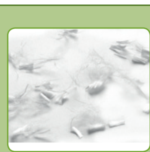
1. Crack openings grow in an uncontrolled way until total failure
2. Designed Fluid tight structures lose their fluid tightness already after a few weeks.


Fluid tight structures

4. FIRE RESISTANCE – DO NOT PLAY WITH FIRE

Metallic fibres have a neutral to positive impact on the fire resistance of structures. Due to a **decreased spalling effect**, a structure in metal fibrous concrete behaves rather better in the presence of fire than a mesh reinforced structure according to tunnelling specialists (segmental lining). **Steel keeps its mechanical performance** up to a temperature of 350-400° C.

Macro **synthetic fibres**, by contrast, start to **lose their mechanical properties as soon as the temperature reaches 50°C** and disappear altogether at 160°C. In a fire, a structure with macro synthetic fibres becomes rather soon unreinforced – with no load bearing capacity left at all – and may result in an unsafe situation from the first hours onwards.
Tests in the Bekaert laboratory have shown a decrease of 40 to 50% in the post-crack strength of macro polymer fibre concrete at 50°C.

	 Steel mesh	 Steel fibres	 Macro synthetic fibres	 Micro synthetic fibres
Loss of mechanical performance	300 °C		50 °C	
Melting point	1.500 °C		160 °C	

Micro polypropylene fibres have a significant positive impact on the spalling behaviour of concrete during a fire (especially for high strength concretes).
This effectiveness can be explained as follows: in case of a fire, prolypropylene fibres disappear at 165°C (they have reached their fusion point) to leave in place a significant network of fine canals (capillaries). These canals act as expansion vessels for the water vapour generated under pressure by the fire (evaporation of the water present in the concrete).

5. CORROSION RESISTANCE

Micro and macro polymer fibres are resistant to most acid & alkaline environments.

Regarding metallic fibres: experience and research allows to conclude the following:

- Steel fibres need only a concrete cover of 1-2 mm compared to 30-40 mm for normal rebar and mesh.
- Corrosion of the fibres at the surface may cause discolorations but does not affect the mechanical properties of the steel fibre concrete reinforced structures.
- Fibres in crack openings smaller than 0.25 mm do not corrode (Brite Euram).
- When no stains are required, galvanized fibres can be applied.

Dramix® Green Galvanized steel fibres

6. THE RIGHT FIBRE FOR THE RIGHT USE

	 Dramix® Steel fibres	 Synmix® macro synthetic fibres	 Duomix® Micro synthetic fibres
Plastic shrinkage reinforcement			✓
Anti-spalling aid at fire			✓
Non load bearing reinforcements Precast: Handling and transportation reinforcement Flooring: Temperature and shrinkage reinforcement	✓	✓	
Temporary linings (such as in mines) allowing large deformations	✓	✓	
Crack controlling reinforcement	✓		
Structural reinforcements	✓		
Heavy impact	✓		
Fatigue	✓		

		 Dramix® Glued steel fibres		 Synmix® Macro synthetic fibres		 Duomix® Micro synthetic fibres	
	Mixability	< 40 kg/m³	★★★	< 5 kg/m³	★★	< 1 kg/m³	★★★
		> 40 kg/m³	★★	> 5 kg/m³	★	> 1 kg/m³	★
	Pumpability	< 40 kg/m³	★★★	< 5 kg/m³	★★	< 1 kg/m³	★★★
		> 40 kg/m³	★★	> 5 kg/m³	★	> 1 kg/m³	★
	Easy to finish	Flooring finish	★★	Flooring finish	★	Flooring finish	★★★
		SCC[1]	★★★	SCC[1]	★	SCC[1]	★★★

[1] Surface appearance in self-compacting concrete

References

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  Fibres for concrete, part 1:
  steel fibres - Definitions, specifications and conformity

- EN 14889-2
  Fibres for concrete, part 2:
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  D. Nemegeer, J. Vanbrabant and H. Stang, Rilem, Proceedings PRO 31
  Test and design methods for Steel Fibre Reinforced Concrete, 20 - 23 March 2003

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ABOUT BEKAERT

Bekaert is active worldwide in selected applications of its two core competences: advanced metal transformation and advanced materials and coatings. The combination of these competences makes Bekaert very unique. Bekaert, headquartered in Belgium, is a technological leader and serves a worldwide customer base in a variety of industry sectors.

BUILDING WITH BEKAERT

Bekaert products are widely used in the construction sector. Dramix® has given Bekaert a leading position in the market of steel fibre concrete reinforcement. In 1979, Bekaert introduced Dramix® steel fibres for concrete reinforcement, designed to offer an easy-to-use alternative for traditional steel mesh and bar reinforcement. Applications of Dramix® steel fibres include industrial floors, precast elements, tunneling and mining, residential applications and public works.

Other Bekaert building products

- Murfor® - masonry reinforcement
- Stucanet® - plastering mesh
- Widra® - corner beads
- Mesh Track - road reinforcement

How can we help you?

Contact us for:
Defining the right reinforcement material
Detailed information on all types of reinforcement

- standards
- CE labels
- Test methods & results

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