ADVERTORIAL

Fibre-reinforced concrete: the concrete of the future for sustainable, low-carbon solutions

Benoit de Rivaz, Technical Director for Bekaert BP Underground Solutions, tells us more about how this international group has positioned itself in the world of construction. He tells us about their range of fibres, which are ideal for underground projects in France and abroad.

Benoit de Rivaz, Technical Director

The Bekaert Group was founded in 1880 and now has a presence in 120 countries. We have 25,000 people working for us and we have a combined turnover of around €5 billion. We serve a wide range of industries, including the automotive sector, equipment manufacturers, agriculture, energy and construction.

Every year, 10 million m^3 of concrete are reinforced with Dramix® steel fibres, invented by Bekaert.

Concrete and steel have always complemented each other: concrete resists compression; steel resists tension. Concrete protects steel against corrosion as long as the concrete is alkaline, and it delays the softening of steel during a fire. Concrete expands and contracts in the same way when the temperature changes (they have the same thermal expansion coefficient).

Bekaert has always been a pioneer in steel fibre reinforcement. Bekaert was the first company to recognise the enormous potential that this new technology could offer for the world of construction. We also set up a production platform with a number of factories dedicated to manufacturing Dramix® steel fibres. Since 2010, all Dramix® production sites have been ISO 14001 certified.

With its brand new Dramix® product range, Bekaert has led a revolution in the world of steel fibres for reinforcement. They are now stronger, safer, more durable and even more practical to use. But above all, they open up a whole new world of possibilities for your work in the field of eco-resilient concrete.

Steel fibre reinforced concrete (SFRC) arrived in the European market in the late 1970s. At that time, there were no standards or guidelines, which slowed the acceptance of this new technology. However, SFRC was already beginning to be used in a variety of public works projects, including tunnel linings, mines, paving, pile-supported slabs, prefabricated elements, and more. Initially, metal fibres were used to replace secondary reinforcement, or to limit cracking in the least critical sections of structures. Today, metal fibres are widely used as the main and only reinforcement for industrial slabs and precast concrete products.

The move towards structural applications is mainly due to advances in SFRC technologies, and research carried out at a number of universities and technical institutes to better understand and measure the material's properties. In the early '90s, the first recommendations for the design of steel fibre-reinforced concrete were developed once the Rilem TC 162-TDF design methods and Model Code 2010 (the basis for the EC2 revision) were made available. The use of precast segments is now a standard solution throughout the world, with over 200 projects already completed (metros, trains, water treatment tunnels, roads, etc.), and is covered by a number of guidelines (ITA, AFTES, ACI, fib).

In France, the Société du Grand Paris studied our fibre-reinforced concrete solution in great detail, and ultimately chose it for an iconic project in the French capital.

Grand Paris 16.1 (Eiffage)

The Grand Paris line 16 (lot 1) (Eiffage, Bonna Sabla) is the first major project in France where we used fibre-reinforced concrete as the sole reinforcement for prefabricated segments, completely replacing traditional reinforcement. The performance classes of fibre-reinforced concrete are based on Model Code 2010 and fib bulletin 83, the reference documents for precast segments reinforced with metal fibres. Today, this solution has also been chosen for the Toulouse Metro, where the segments are also reinforced solely with Dramix high-performance metal fibres.

Strict quality control

Glued Dramix fibre

To improve the fR1 (ELS) and fR3 (ULS) values according to the Model Code 20210 performance classes, a strength of more than 2,200 N/mm^2 (4D 80/60BGP fibre) is usually used for precast segments. The tensile strength of a steel fibre must increase in parallel with the strength of its anchorage (hook shape, concrete matrix). Only in this way can the fibre withstand the forces exerted on it. A high L/D (length to diameter) ratio of 80 is also a crucial factor in this choice.

Fibres that are 60mm long (maximum 20mm in diameter) and relatively thin (0.75mm in diameter) allow the aggregates to be embedded perfectly, **resulting in a matrix of 11.6km of fibres/m^3 of concrete**.

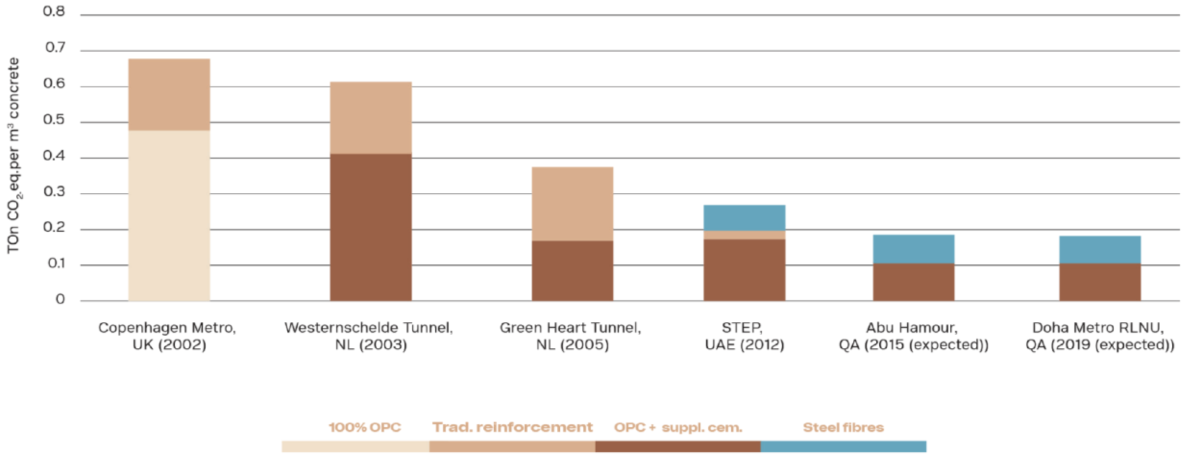
With 4,584 fibre units/kg, customers are assured that fibres are everywhere in the matrix, and especially in traditionally weak points of the segment, such as the corners and edges. Finally, the fact that fibres are glued was also an important factor in choosing this product, as this lowers the risk of balling during the industrial production phase. This balling poses a risk of pockets of rocks and segregations being created, as well as differences in the fibre ratios within the segment, which are detrimental to the homogeneity of the matrix and therefore to the intrinsic strength of the concrete structure.

A significant environmental impact

- Reducing the fibre ratio compared with the reinforcement ratio leads to a reduction in CO_2 emissions during transport. If we compare the 85kg/m^3 of reinforcement with the 40kg/m^3 of fibre, there is a saving of more than 50% in materials.
- This is due to the optimised loading of the fibres. 22 x 1,100/kg big bags per lorry = 24.2t of load for fibre delivery, compared with 60 equivalent segments per lorry = 17.85t for deliveries of standard concrete reinforcement.
- The small diameter of the fibres means that toxic emissions from the primary steel industry can be further limited, as primary coils have a wire diameter of no more than 1mm. The wire-drawing technology itself has low emissions.
- Fewer lorries on the road and optimised waste management in a major city like Paris are important factors to consider. In ecological terms, the carbon footprint is therefore very good. To this end, Bekaert has very recently obtained its EPD (Environmental Product Declaration) Type III ITB certificate number 215/2021, and we are constantly working to improve the carbon footprint of our fibres.

There are also ongoing developments in shotcrete for use as a final coating.

Thanks to improvements in equipment such as spray robots, the quality of control and design methods, and calculation standards, it is now possible to envisage even more use of shotcrete for ‘permanent’ use. Rethinking the design of tunnels makes it possible to reduce the thickness of the concrete and the section excavated, thereby saving time and money. The space saved can also be kept available to facilitate subsequent repair work. By reducing the thickness of the concrete and replacing reinforcement bars with steel fibre-reinforced concrete, a more sustainable and low-carbon structure can be achieved. An important issue is determining the mechanical properties of fibre-reinforced shotcrete using a three-point notched plate bending test in accordance with the new European standard (EN 14 488-3). The new AFTES guidelines (GT6RIFI) deal specifically with permanent wet-sprayed fibre-reinforced shotcrete. In fact, many countries use shotcrete to ensure the long-term stability of underground spaces; this solution has been developed to meet current concerns about saving time and money whilst minimising the environmental impact.



Developments in the design of low-carbon precast segments
(ref Edvardsen, C., 'The Consultant's View on Service Life Design', WTC Congress, COWI A/S)

Hardened post-cracking behaviour (3-point bending tests) provides crack control (ELS) and structural ductility (ULS). What is known as 'service cracking' (crack openings not normally exceeding 300µm) is a very important accelerator for the penetration of aggressive liquids (water containing aggressive ions), both for the concrete and for the reinforcement present in load-bearing structures, such as the passive reinforcement of concrete. Metal fibres with a high unit of elasticity allow for crack control. When the matrix an MFRC is not cracked, it is the durability of the matrix that determines the durability of the composite material. **There is a consensus within the scientific community regarding the improved durability of uncracked metal fibre-reinforced concrete exposed to chlorides and carbon dioxide, compared with standard reinforcement. Corrosion damage to steel fibres is limited to the outer 1 to 5mm for the most aggressive exposures, and damage is only aesthetic. Most of these statements are covered by the main standards and guidelines (fib bulletin 83).** In situations where service stress leads to cracking, fibres are protected from corrosion by the phenomenon of crack healing. The load-bearing capacity of MFRC is not significantly altered for crack openings of 500µm or less.

MFRC affects the tensile behaviour of cracked concrete and adds ductility to a brittle material. It is the excellent crack control performance and the durability of MFRC compared with standard reinforced concrete that are responsible for the development of this material and its economic success. The Life Cycle Assessment (LCA) is a standardised report. It quantifies the environmental impact of a material throughout its life cycle, from the extraction of the raw materials required for its manufacture to the product's end-of-life. This approach and the search for low-carbon solutions will give a fresh boost to MFRC.

Bekaert's global sustainable development strategy is centred on four main pillars: our responsibility in the workplace, in the marketplace, towards the environment and towards the society in which we operate. For example, Bekaert is providing its expertise and support to the innovative Cargo Sous Terrain (CST) logistics system project in Switzerland. CST reinforces and systematises the sustainability aspects already inherent in the system. In addition to the fact that CST offers emission-free and therefore climate-neutral deliveries, a working group is already preparing the construction in compliance with recognised sustainability standards.

Achieving decarbonisation in tunnel construction is not just possible, it is crucial from a sustainability perspective. Currently, almost 70% of the carbon used in tunnels is attributable to the concrete lining. To achieve this, we need to consider

- concrete that uses low-carbon steel binders,
- high-performance metal fibres,
- optimised dimensioning and design by employing digital models based on non-linear finite element analysis.

Dramix could play an important role in this global approach to low-carbon linings in underground works.

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