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A Detailed Overview of Steel Fiber Reinforced Concrete

Introduction

Concrete is one of the oldest and most widely used construction materials known to man. As early as 600BC, ancient Romans used mass concrete for the design of numerous monumental structures, some of which still stand today. While this material had been in use for centuries, it was well known that concrete possessed certain limitations.

One of the most undesirable characteristics of concrete is its brittleness, low tensile strength, and low strain capacity. It wasn't until the mid-1800s that reinforcing bars were added to concrete to compensate for its lack of tensile strength and ductility. While steel bars have historically been the material of choice for concrete reinforcement, steel fiber reinforcement has emerged as a viable alternative.

After almost 50 years of technical development and research, steel fiber reinforced concrete (SFRC) is no longer considered as novel. During this time, construction professionals have gained considerable experience in the use of steel fibers as a reinforcement alternative in numerous projects.

Engineers, in particular, have continued to study the physical, mechanical, and chemical properties of SFRC, further driving the development of design formulas and analysis techniques. These developments have helped to increase the confidence in SFRC as a building material, leading to the publishing of several national and international recommendations, guidelines, and standards.

What is Steel Fiber Reinforced Concrete (SFRC)

Steel fiber reinforced concrete, as its name suggests, is concrete that has been reinforced with steel fibers. Unlike conventional reinforcement, which consists of steel bars or mesh, steel fibers are relatively short, discontinuous elements that are randomly distributed throughout the concrete member. As such, the fibers become part of the concrete matrix, turning it into a composite material.

The steel fibers distribute strain across the cracks in the composite matrix. In other words, the steel fibers are only engaged once cracks are initiated in the concrete. When these cracks occur, the mechanical properties of the fiber come into play as they attempt to hold the matrix together.

In contrast to traditional reinforcement, which is provided at distinct locations, steel fibers form a homogeneous reinforcing network across the entire concrete cross-section, thus providing increased strength, ductility and post-crack properties throughout the entire structure. The synergistic relationship between the steel fiber/concrete matrix is also more resistant to the negative effects of cracking and resists spalling of cover concrete under high compressive loading.

When adequately distributed in the concrete mix, the steel fibers act as flexural, shear, and shrinkage reinforcement in the same way that longitudinal rebar and stirrups do in conventional reinforced concrete structures.

In addition to steel, concrete can also be reinforced with other fibrous materials, including glass, polymers, or organic materials. Steel fibers, however, tend to offer superior reinforcing properties and performance characteristics compared to other fibers.

How Current Codes and Standards Deal With SFRC Structural Members

The International Building Code (IBC), which serves as the model building code for the United States and other regions, references the ACI 318 *Building Code Requirements for Structural Concrete*, for the design and analysis for reinforced concrete structures.

However, the ACI 318 focuses primarily on concrete reinforced with conventional deformed reinforcing bars and does not adequately cover SFRC components. Instead, the American Concrete Institute consists of several sub-committees who develop various reports, recommendations, and design guides to address concrete reinforced with steel fibers.

The ACI 544.4R-18, for example, is a state of the art consensus document which gives general design guidelines for fiber reinforced concrete members. It is, unfortunately, not a comprehensive design standard. The document itself lacks the design equations and analysis procedures necessary for compliance with ACI 318 design standards.

Another document which recognizes SFRC is the ACI 360R-10. However, this guide primarily deals with the design of slabs-on-ground rather than overall structures. In addition to the lack of comprehensive design guidance, the documents developed under the ACI 544 and 360 sub-committees do not carry any legal status as a design code.

Recognizing the shortcomings of the current ACI design guidelines, Bekaert, a Belgium-based global supplier of Dramix® steel fibers, has pursued code approval for the structural and non-structural use of SFRC with the IAPMO-UES alternative product evaluation service (International Association of Plumbing and Mechanical Officials).

How New Code Approvals Are Set to Change the Way We Use SFRC

Although the IBC refers to the ACI for the design of reinforced concrete structures, the International Code Council (ICC) has made it clear that *"The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the* *proposed design is satisfactory and complies with the intent of the provisions of this code…"* - **IBC 2015 [A] 104.11**

The IAPMO UES is an ANSI accredited evaluation service based in Ontario, CA. For over 90 years, they have coordinated with government and industry officials to develop and implement international codes and standards for various systems. For the purposes of **IBC 2015 [A] 104.11**, the IAPMO-UES service provides building officials the confidence that the alternative product has been critically reviewed against the intent of the code and, if accepted by IAPMO-UES, the building official may rely on their review to approve the alternative product for use in a structure.

IAPMO's evaluation of Bekaert's Dramix® steel fibers insurance of evaluation report ER-465 demonstrate compliance with IBC and ACI 318 requirements. The IAPMO UES report for Bekaert's Dramix fibers is the most significant development for steel fibers in the US and represents a milestone for the steel fiber industry.

One of the main features of the IAPMO-UES is its coverage of SFRC in structural or non-structural applications with or without other continuous steel reinforcement such as rebar, mesh or prestressing strands.

The IAPMO report consists of two evaluation reports: IAPMO UES ER 465 and IAPMO UES ER 497. The IAPMO UES ER 465, valid for design in seismic design categories A and B, details methods and analysis techniques for using structural and non-structural SFRC in strength and serviceability in accordance with the latest editions of IBC, CBC, FBC, NYBC, ACI 318, ACI 360.

The IAPMO UES ER 497, on the other hand, details guidelines for the use of Dramix® as shrinkage and temperature reinforcement as per IBC, CBC, FBC, ACI 318 and SDI-C, and non-structural applications per ACI 360.

One of the most exciting prospects of the IAPMO evaluation report, particularly ~~the~~ ER 465, is that it opens a range of possibilities for SFRC applications beyond slabs-on-ground and non-structural applications. In contrast to the ACI 360 and 544 suite of guidelines, ER 465 addresses the analysis and design of crucial structural elements, such as beams, columns, walls, foundations, etc. using Dramix® steel fibers as *supplemental to conventional reinforcement as well as* the primary reinforcement.

SFRC Analysis and Design Software

To address the existing deficiencies, Bekaert has collaborated with software manufacturers to align their SFRC analysis modules in accordance with the new IAPMO UES ER 465/497 code approval. Bekaert offers its own proprietary software, Dramix® Pro, for the analysis and design of specific elements, such as slabs-on-grade and slabs-on-piles. For the design and analysis of other structural elements, Bekaert has consulted with reputable North-American based software firm, ADAPT, whose structural engineering analysis and design software tools are used to design reinforced concrete buildings, bridges, and other structures.

ADAPT has an integrated steel fiber module which is fully compliant with the IAPMO UES ER 465/497 code approval. This allows for a broader range of design functionality, making it possible to design complex structural elements reinforced with Dramix® steel fibers, with or without conventional steel reinforcement. These include, but are not limited to slabs-on-ground, mat foundations, floors on piles, and elevated floors.

Like traditional structural analysis programs, ADAPT facilitates ultimate limit state and serviceability limit state checks, for flexural capacity, shear capacity, crack widths, and stress limits. Other notable features of these software tools include the ability to design and optimize the steel fiber dosage based on capacity requirements using linear or non-linear analysis. These tools also have built-in material libraries allowing designers to select various Dramix® fiber types to assess their performance under different design conditions.

Conclusion

Advancements in the field of SFRC have made it possible to improve the performance of fiber reinforced structures to previously unattainable levels. While SFRC applications continue to expand and are now considered to be a proven reinforcing method, its use in some markets has been paltry due to lack of education and international code support.

New IAPMO code approvals have allowed for further expansion in the possible applications of SFRC structures and also further validates this composite material. These code approvals, together with code-compliant software, provides engineers with the technical and legal framework to offer innovative and cost-efficient solutions to their customers using Dramix® reinforced concrete. As a result, Dramix® steel fibers have become a fully mature building product, taking its place next to reinforcing steel.

Company profile

Bekaert (www.bekaert.com) is a world market and technology leader in steel wire transformation and coating technologies. We pursue to be the preferred supplier for our steel wire products and solutions by continuously delivering superior value to our customers worldwide. Bekaert (Euronext Brussels: BEKB) is a global company with almost 30 000 employees worldwide, headquarters in Belgium and € 4.8 billion in combined revenue.