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Bulletin 95

Fibre Reinforced Concrete: From Design to Structural Applications

Proceedings of the ACI-*fib*-RILEM International Workshop - FRC2018

ACI SP-343
Technical report

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International Workshop - FRC2018

August 2020

Approval for this bulletin

Subject to priorities defined by the Technical Council and the Presidium, the results of the *fib*'s work in commissions and task groups are published in a continuously numbered series of technical publications called *bulletins*. The following categories are used:

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Model code	General Assembly

Any publication not having met the above requirements will be clearly identified as a preliminary draft.

fib Bulletin 95 is published as a technical report and is a collection of contributions to a workshop that was co-sponsored by the *fib* and the American Concrete Institute (ACI). The authors have presented their individual views. Although these contributions have not been discussed in any of the *fib*'s working bodies, the subject matter is highly topical and believed to be of general interest to members of the *fib*.

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Foreword

This bulletin presents a compilation of the papers presented at the 3rd International workshop on Fibre-Reinforced Concrete, "FRC2018, from Design to Structural Applications". The workshop was a joint ACI - Rilem - *fib* event, which expresses inter-federation collaboration and broad expertise.

The aim of the workshop was to provide state-of-the-art information on recent progress in term of specifications development, actual applications, and to expose users and researchers to tomorrow's challenges in the design and construction of a wide variety of structural applications. The topic is thus fitting and is a clear supplement to the work of *fib* TG4.1 "Fibre-reinforced concrete". The aim of TG4.1 is to make theoretical and practical developments in the field of fibre-reinforced concrete materials technology, rheology and materials characterisation and modelling and to present these developments in code-type formulations.

Recently, it was decided to merge the work of TG4.1 and TG4.2 "Ultrahigh performance fibre reinforced concrete" to prepare one joint bulletin. At the time of writing, this bulletin is being finalised. Also, a framework bulletin for the *fib* Model Code MC2020 will be prepared.

I'm very grateful to Fausto Minelli (University of Brescia, Italy), for making the colossal effort to convert this collection of papers into an *fib* bulletin. And many thanks to Corinne Bottollier-Dépois for formatting this bulletin.

Tor Arne Martius-Hammer
Deputy chair of Commission 4: *Concrete and Concrete Technology*

Preface

The first international FRC workshop supported by RILEM and ACI was held in Bergamo (Italy) in 2004. At that time, a lack of specific building codes and standards was identified as the main inhibitor to the application of this technology in engineering practice. The workshop aim was placed on the identification of applications, guidelines, and research needs in order for this advanced technology to be transferred to professional practice.

The second international FRC workshop, held in Montreal (Canada) in 2014, was the first ACI-*fib* joint technical event. Many of the objectives identified in 2004 had been achieved by various groups of researchers who shared a common interest in extending the application of FRC materials into the realm of structural engineering and design. The aim of the workshop was to provide the State-of-the-Art on the recent progress that had been made in term of specifications and actual applications for buildings, underground structures, and bridge projects worldwide.

The rapid development of codes, the introduction of new materials and the growing interest of the construction industry suggested presenting this forum at closer intervals. In this context, the third international FRC workshop was held in Desenzano (Italy), four years after Montreal. In this first ACI-*fib*-RILEM joint technical event, the maturity gained through the recent technological developments and large-scale applications were used to show the acceptability of the concrete design using various fibre compositions.

The growing interests of civil infrastructure owners in ultra-high-performance fibre-reinforced concrete (UHPFRC) and synthetic fibres in structural applications bring new challenges in terms of concrete technology and design recommendations. In such a short period of time, we have witnessed the proliferation of the use of fibres as structural reinforcement in various applications such as industrial floors, elevated slabs, precast tunnel lining sections, foundations, as well as bridge decks. We are now moving towards addressing many durability-based design requirements by the use of fibres, as well as the general serviceability-based design. However, the possibility of having a residual tensile strength after cracking of the concrete matrix requires a new conceptual approach for a proper design of FRC structural elements.

With such a perspective in mind, the aim of FRC2018 workshop was to provide the State-of-the-Art on the recent progress in terms of specifications development, actual applications, and to expose users and researchers to the challenges in the design and construction of a wide variety of structural applications.

Considering that at the time of the first workshop, in 2004, no structural codes were available on FRC, we have to recognize the enormous work done by researchers all over the world, who have presented at many FRC events, and convinced code bodies to include FRC among the reliable alternatives for structural applications. This will allow engineers to increasingly utilize FRC with confidence for designing safe and durable structures.

Many presentations also clearly showed that FRC is a promising material for efficient rehabilitation of existing infrastructure in a broad spectrum of repair applications. These cases range from sustained gravity loads to harsh environmental conditions and seismic applications, which are some of the broadest ranges of applications in Civil Engineering.

The workshop was attended by researchers, designers, owner and government representatives as well as participants from the construction and fibre industries. The presence of people with different expertise provided a unique opportunity to share knowledge and promote collaborative efforts. These interactions are essential for the common goal of making better and sustainable constructions in the near future.

The workshop was attended by about 150 participants coming from 30 countries. Researchers from all the continents participated in the workshop, including 24 Ph.D. students, who brought their enthusiasm in FRC structural applications.

For this reason, the workshop Co-chairs sincerely thank all the enterprises that sponsored this event. They also extend their appreciation for the support provided by the industry over the last 30 years which allowed research centers to study FRC materials and their properties, and develop applications to making its use more routine and accepted throughout the world. Their important contribution has been essential for moving the knowledge base forward.

Finally, we appreciate the enormous support received from all three sponsoring organizations of ACI, *fib* and Rilem and look forward to paving the path for future collaborations in various areas of common interest so that the developmental work and implementation of new specifications and design procedures can be expedited internationally.

June 2018

Bruno Massicotte, Fausto Minelli, Barzin Mobasher, Giovanni Plizzari

Contents

1) MECHANICAL CHARACTERIZATION

Round-Robin Test on Various Test-Methods for Flexural Behavior of Steel Fiber Reinforced Sprayed Concretes

Sven Plückelmann[1], Rolf Breitenbücher[1]

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Abstract

According to the actual European standard EN 14487-1 the potential of steel fiber reinforced sprayed concrete is characterized by flexural strength tests (first peak, ultimate and residual). In most cases, this is performed by a four-point bending test on beam specimens, specified in EN 14488-3. As an alternative test method, a three-point bending test on square panels with notch is recommended by EFNARC. It is argued as main benefit of the latter test method, that the geometry and dimensions of the panels are equal to those of specimens used for measuring the energy absorption capacity according to EN 14488-5. Hence, the specification of the ductility of fiber reinforced concretes according to EN 14487-1 in terms of residual strength and energy absorption capacity can be achieved preparing only one type of specimen. Furthermore, the EFNARC guideline points out a smaller scatter of test results, compared to the beam tests according to EN 14488-3.

Before the EFNARC method will be considered in EN 14487-1, the relevant CEN TC 104/WG10 requests for adequate proofs. These were performed within a round-robin test (RRT) on testing the flexural behavior of steel fiber reinforced sprayed concrete by the standardized EN 14488-3 method as well as by the proposed EFNARC method. The aim of this RRT was to investigate the comparability and correlation between the two test methods. Furthermore, the scatter of both methods was assessed. The RRT has been organized by Ruhr University Bochum, in whose labs the steel fiber reinforced sprayed concrete specimens (beams according to EN 14488-3 and square panels according to EFNARC guideline) were produced using a robotic spraying machine. The specimens were then tested in five independent laboratories Europe-wide. The results of this RRT are presented in detail. With regard to the residual strength, the relevant material parameter for steel fiber reinforced sprayed concrete, a tendency towards a slightly lower scatter was detected for the EFNARC test method.

Keywords

Sprayed concrete, steel fibers, round-robin test, flexural behavior

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1 Introduction

The specification of the ductility of fiber reinforced sprayed concrete according to EN 14487-1 is ascertained by the classification of its residual strengths and/or energy absorptions capacity. In most cases, the residual strengths will be determined if the concrete characteristics are used in a structural design model. According to EN 14487-1, the determination of flexural strengths has to be performed by a four-point bending test on beam specimens specified in EN 14488-3. The residual strengths are classified by a minimum strength level defined for specific intervals of deflection according to EN 14487-1.

With regard to the main field of application of fiber reinforced concrete (i.e. rock stabilization in tunneling) further information concerning the concrete's energy absorption capacity can be essential. The energy absorption capacity has to be determined by performing a bending test on square panels, which are supported on their four edges and loaded centrically with a point load. This test method is specified in EN 14488-5 and was developed by the “National Rail-way Company (SNCF)” in order to simulate the typical loading scenario in terms of biaxial bending. By analogy to the classification of residual strengths, the energy absorption classes are also defined in EN 14487-1.

In EN 14487-1 it is explicitly pointed out that a direct comparison between the two different methods for the specification of ductility by means of residual strengths and energy absorption capacity is not feasible. Depending on project-specific requirements related to the quality of the concrete it could be necessary to perform both test methods. Consequently, in this case, two different types of specimens have to be prepared and tested under different testing conditions.

As an alternative test method to the four-point bending test on beams according to EN 14488-3, a three-point bending test on square panels with notch is recommended by EFNARC. The respective guideline was published in 2011. In this guideline, a series of arguments for performing the EFNARC method instead of the EN 14488-3 method are indicated. As an example, it is argued as main benefit of the EFNARC test method, that the geometry and dimensions of the panels are equal to those of specimens used for measuring the energy absorption capacity according to EN 14488-5. Hence, only one type of specimen has to be prepared for the determination of both material characteristics. Moreover, the EFNARC guideline points out a smaller scatter of test results compared to the beam tests according to EN 14488-3. However, if the scatter of results within the EFNARC test method is lower compared to the EN 14488-3 method remains to be examined, particular as in both guidelines it is noted that there is a lack of information in terms of precision. Even though it is a matter of fact, before the EFNARC test method will be considered in EN 14487-1, the relevant CEN TC 104/WG10 requests for adequate proofs. These were performed within a round-robin test (RRT) on testing the flexural behavior of steel fiber reinforced sprayed concrete by the standardized EN 14488-3 method as well as by the proposed EFNARC method. The aim of this RRT, that was organized and coordinated by the Institute for Building Materials of the Ruhr University Bochum, was to investigate the comparability and correlation between the two test methods. Furthermore, the scatter of both methods was assessed.