Bulletin 79

Fibre-reinforced concrete:

From design to structural applications

FRC 2014: ACI-*fib* International Workshop

fib CEB-FIP aci

ACI SP-310
ACI-*fib* workshop proceedings

fib CEB-FIP Bulletin 79

Fibre-reinforced concrete:
From design to structural applications

American Concrete Institute
Always advancing

Technical report

Proceedings of a workshop held in Montreal, Canada,
on 24 and 25 July 2014

Edited by Bruno Massicotte, Jean-Philippe Charron,
Giovanni Plizzari and Barzin Mobasher

May 2016

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:

Category:	**Draft to be approved by:**
Technical report	Task group and chairpersons of the commission
State-of-the-art report	Commission
Manual / Guide to good practice / Recommendation	Technical council
Model code	General assembly

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

fib Bulletin 79 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*.

This bulletin is also published as an ACI Symposium Publication, ACI SP-310.

Cover images:

Front cover: Illustration based on a photograph of UHPFRC precast segments for the 100-metre-span box girder Batu 6 Bridge, crossing Sungai Perak, Malaysia. Photograph courtesy of Stephen Foster, University of New South Wales, Australia.

Back cover: Illustration based on a photograph of a full-scale 5-metre-long prototype of the 43.5-metre-span UHPFRC truss footbridge over the Ovejas ravine in Alicante, Spain. Photograph courtesy of Pedro Serna, Universitat Politècnica de Valencia, Spain.

ISSN 1562-3610
ISBN 978-2-88394-119-9
Printed by DCC Document Competence Center Siegmar Kästl e.K., Germany

Preface

The FRC-2014 Workshop, *Fibre-reinforced concrete: From design to structural applications*, was the first ever ACI-*fib* joint technical event. The workshop, held at Polytechnique Montreal, Canada, on July 24 and 25, 2014, was attended by 116 participants from 25 countries and four continents.

The first international FRC workshop was held in Bergamo, Italy, in 2004. At that time, the lack of specific building codes and standards was identified as the main inhibitor to the application of this technology in engineering practice. Ten years after Bergamo, many of the objectives identified at that time have been achieved. The use of fibre-reinforced concrete (FRC) for designing structural members in bending and shear has recently been addressed in the *fib* Model Code for Concrete Structures 2010. Steel-fibre-reinforced concrete (SFRC) has also been used structurally in several building and bridge projects in Europe and North America. SFRC has been widely used in segmental tunnel linings all over the world. Members of ACI 544 and *fib* TG 4.1 have been involved in writing code-based specifications for the design of FRC structural members.

Although fibres have been used by the construction industry for several decades, their use in structural applications is still very modest if one considers the gigantic potential of concrete structures around the world and the benefits expected of their mechanical behaviour and durability. However, recent technological developments and large scale applications have demonstrated that FRC has reached a level of maturity such that these innovative materials can be used by engineers with confidence. From that perspective, the aim of the FRC 2014 workshop was to provide the state-of-the-art on the recent progress attained in terms of specifications and actual applications. Presentations covered several design guidelines adopted worldwide illustrating the progress made in the last ten years, and also a wide spectrum of FRC applications such as beams, elevated floors, tunnel linings, slabs, pavements, precast elements, bridge elements, and many others.

More than fifty papers were presented at the workshop, from which 44 were selected for this joint ACI-*fib* publication. The papers are organised into six themes:

- design guidelines and specifications,
- material properties for design,
- behaviour and design of beams and columns,
- behaviour and design of slabs and other structures,
- behaviour and design of foundations and underground components, and finally,
- applications in structure and underground construction projects.

The papers cover a wide range of applications and illustrate the maturity of FRC as the choice material for improving the serviceability, sustainability, and performance of concrete structures. The workshop chairs would like to express their sincere recognition to all authors and reviewers who contributed to the quality of the document. Special thanks to both ACI and *fib* officers and staff who supported the organisation of the workshop, editorial support, and dissemination of the workshop proceeding as an ACI Symposium Publication and an *fib* Bulletin.

While significant progress has been made in the introduction of FRC in codes and structures, the current accomplishment should be viewed as the beginning, and significant follow up work is still needed. Indeed, introducing new technologies and new materials in structural applications brings technical and scientific challenges and responsibilities. The necessity to achieve the objectives set worldwide for sustainable development requires that 21st century concrete structures meet higher performances than those of the previous one, a role that FRC can definitely help achieve. It is the responsibility of all actors to move forward in that direction.

The recently published codes and design guidelines, available worldwide, constitute a first step into the implementation of FRC in the construction industry. However, before the structural use of FRC becomes a common practice, several benchmarks need to be accomplished. The numerous factors that still inhibit the use of FRC in structural applications should be viewed as challenges that could only be solved through a joint effort of all key players. Professor Sidney Mindess, a pioneer of FRC research, indicated in his opening speech at the Montreal Workshop four challenges to increase the structural use of FRC: education and training, performance specifications, more appropriate testing methods, and comprehensive research programs focused on the combined use of FRC and continuous reinforcement. Without claiming to provide an exhaustive list of actions, the following presents some challenges that need to be addressed by the scientific community, fibre producers, structural design community, construction industry, and stakeholders to achieve the objective of building more durable concrete structures. These challenges are inspired by Professor Mindess' remarks.

The scientific community should contribute to the elimination of artificial divisions between different types of FRC based on the compressive strength and type of fibres. They should put the emphasis on the benefits brought by fibres on the performance of concrete structures and present FRC as a continuum of materials with different characteristics and performances. Approaching research on FRC more holistically with the emphasis on applications is essential for the sound development of the scientific knowledge.

Fibre producers would certainly be the first ones to benefit from a wider use of fibre concrete. Considering that about 1% of the concrete used worldwide contains fibres, they should combine their efforts for developing new applications and expanding the spectrum of the conventional uses, rather than working against each other for the same market. Addressing the replacement of alternative reinforcement solutions should evolve toward adopting a strategy based on the vision that fibres should be used along with other types of reinforcement to make better constructions at both service and ultimate limit states.

The structural design community has always adopted conservatism that is justified in many instances for safety and professional responsibility. The evidence of enhanced performances of FRC structures and the need to build more durable and safer structures only justifies a more extensive use of FRC. Being at the decision central point, designers should be more proactive in proposing the implementation of FRC in structures. They should contribute to the writing of design guidelines, they should ask to get appropriate training, and they should promote the improvement of the expertise level of the engineering profession.

Being driven by the necessity of profit, the construction industry has always been resistant to changes unless motivated by economic advantages. Problems associated with the use of FRC, especially at high dosages, have often and justifiably discouraged their broader use. Today's technological knowhow and availability of products are such that past technical

problems have been overcome. Changing traditional ways of building with FRC will need some effort and modification of the current practice. However, members of the construction industry with the vision of tomorrow's concrete structures will make the appropriate changes because survival often requires evolution. A better and more modern image of the construction industry would certainly be beneficial to all.

Stakeholders with long-term vision will implement the needed change, as clear evidence of better, safer, and more durable structures with FRC is needed. Combined with the maturity of the scientific knowledge on FRC, stakeholders can now require a wider use of FRC. When only short-term economic considerations prevail, FRC is not always competitive. However, when better service performances, higher longevity and enhanced quality become important issues, FRC utilisation often becomes inevitable. Therefore, those who decide the quality of concrete should be able to defend their choice to those they represent. The onus is on them to justify not using FRC considering all benefits brought by their appropriate use in structures.

Not all challenges have been discussed here and several technical and scientific issues still have to be resolved. Adding fibres into a concrete mix is not magical and the challenges remain high. Despite the obstacles that need to be crossed and the long journey ahead, the path appears more clearly. It requires more research, open minds, visions and close collaboration between all actors. Forums such as the FRC workshops are essential events that bring together participants of various technical geographical origin. They are one component of the collaborative effort that is needed to achieve the objective of building better structures.

FRC is a remarkable material, and so far we have only scratched the surface of the contributions it can make to structural concrete design. Although fibres themselves are relatively expensive, they lead to real economic benefits in the design of concrete structures, and can expand the range of structures that can be constructed using concrete. It is hoped that some of the suggestions presented above can lead to the more rapid introduction of this material into everyday engineering practice.

Bruno Massicotte, Jean-Philippe Charron, Giovanni Plizzari and Barzin Mobasher

Contents