

Currently in preview, click buy full version

ACI 544.9R-17

Report on Measuring Mechanical Properties of Hardened Fiber- Reinforced Concrete

Reported by ACI Committee 544



American Concrete Institute
Always advancing



Report on Measuring Mechanical Properties of Hardened Fiber-Reinforced Concrete

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at <http://concrete.org/Publications/DocumentErrata.aspx>. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided "as is" without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

Report on Measuring Mechanical Properties of Hardened Fiber-Reinforced Concrete

Reported by Committee 544

Barzin Mobasher*, Chair
Neven Krstulovic-Opara, Secretary

Clifford N. MacDonald*, Membership Secretary

Corina-Maria Aldea
Emmanuel K. Attiogbe
Mehdi Bakhshi
Nemkumar Banthia
Joaquim Oliveira Barros*
Amir Bonakdar*
Amanda C. Bordelon
Jean-Philippe Charron
Xavier Destree*

Ashish Dubey
Mahmut Ekenel
Liberato Ferrara†
Gregor D. Fischer
Dean P. Forgeron*
Emilio Garcia Taengua
Rishi Gupta
Heidi Helmink
George C. Hoff

Marco Invernizzi
John Jones
David A. Lange
Michael A. Mahoney
Bruno Massicotte
James Milligan
Nicholas C. Mitchell, Jr.
Jeffrey L. Neale
Giovanni A. Plizzari

Klaus Alexander Rieder
Pierre Rossi
Steve Schaefer
Surendra P. Shah
Flavio de Andrade Silva
Luca Sorelli
Thomas E. West
Kay Wille
Robert C. Zellers

Consulting members

P. N. Balaguru
Hiram Price Ball Jr.
Gordon B. Batson

Arnon Bentur
Andrzej M. Brandt
James I. Daniel

John J. Fredman
Christopher Meyer
Henry J. Molloy

Antoine E. Naaman‡
Venkataswamy Ramakrishnan

*Members of subcommittee who contributed to this report.

†Chair of the subcommittee that developed this report.

‡Consulting members who contributed to this report.

The committee would like to thank H. Aoude and F. Vessingh for their contributions to this report.

This report provides a synopsis of the existing testing methodologies for the determination of mechanical properties of hardened fiber-reinforced concrete (FRC). This report applies to the mechanical properties of conventionally mixed and placed FRC, including fiber-reinforced self-consolidating concrete (FRSCC), or fiber-reinforced shotcrete (FRS) using steel, glass, polymeric, and natural fibers.

The objective is to enable manufacturers to characterize the mechanical properties of hardened FRC and encourage researchers and testing laboratories to adopt common and unified test methods to build a meaningful database of mechanical properties of hard-

ened FRC materials and products. Test results from the test procedures used in this report are not intended for the design of FRC structures, but to gain a better understanding of factors influencing the determination of their mechanical properties and of FRCs and FRC products.

Keywords: compressive strength; fiber pullout; fiber-reinforced concrete; flexural fatigue resistance; flexural strength; impact resistance; multiaxial behavior; shear and torsion; tensile strength; toughness.

CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

1.1—Introduction, p. 2

1.2—Scope, p. 2

CHAPTER 2—NOTATION AND DEFINITIONS, p. 2

2.1—Notation, p. 2

2.2—Definitions, p. 3

ACI 544.9R-17 was adopted and published January 2017.

Copyright © 2017, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

ACI Committee Reports, Guides, and Commentaries are intended to provide guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

CHAPTER 3—SAMPLING AND SPECIMEN PREPARATION, p. 4

- 3.1—General, p. 4
- 3.2—Test specimens, p. 4
- 3.3—Sample size, p. 4

CHAPTER 4—COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY, AND POISSON'S RATIO, p. 4

- 4.1—General, p. 4
- 4.2—Compressive stress-strain curve, p. 5

CHAPTER 5—TENSILE BEHAVIOR, p. 6

- 5.1—General, p. 6
- 5.2—Direct tension tests, p. 6
- 5.3—Indirect tension tests, p. 10

CHAPTER 6—FLEXURAL BEHAVIOR: STRENGTH, TOUGHNESS, AND CLOSED-LOOP TESTS, p. 14

- 6.1—General, p. 14
- 6.2—Flexural strength, p. 15
- 6.3—Flexural toughness and residual post-cracking strength, p. 15

CHAPTER 7—INTERFACE, BOND SLIP, AND FIBER PULLOUT, p. 20

- 7.1—General, p. 20
- 7.2—Pullout tests, p. 21

CHAPTER 8—HIGH STRAIN RATE TESTING, p. 24

- 8.1—General, p. 24
- 8.2—High-speed tension tests, p. 25
- 8.3—Split Hopkinson (pressure) bar test, p. 26

CHAPTER 9—IMPACT PERFORMANCE TESTING, p. 27

- 9.1—General, p. 27
- 9.2—Noninstrumented impact tests, p. 27
- 9.3—Instrumented impact tests, p. 27

CHAPTER 10—FATIGUE RESISTANCE, p. 35

- 10.1—General, p. 35
- 10.2—Uniaxial compression fatigue, p. 37
- 10.3—Biaxial compression fatigue, p. 38
- 10.4—Tensile fatigue, p. 38
- 10.5—Flexural fatigue, p. 39

CHAPTER 11—SHEAR AND TORSION, p. 40**CHAPTER 12—BIAXIAL/MULTIAXIAL BEHAVIOR, p. 41****CHAPTER 13—CONCLUSIONS, p. 41****CHAPTER 14—REFERENCES, p. 42**

- Authored documents, p. 43

CHAPTER 1—INTRODUCTION AND SCOPE**1.1—Introduction**

The use of fiber-reinforced concrete (FRC) has evolved from small-scale applications to routine factory and field applications that involve the global use of tens of millions of cubic yards (meters) annually. This growth of application, in conjunction with new fibers, admixtures, and mixture designs, has created an urgent need to review existing test methods and, where necessary, develop new methods for determining the fresh and hardened properties of FRC.

1.2—Scope

This report documents the determination of mechanical properties of hardened FRC. The objective is to characterize these mechanical properties and evaluate common and unified test methods. This objective builds a meaningful database of mechanical properties of hardened FRC materials and products. Further, the results should not be taken out of the context presented for illustrating the tests and not for comparing fibers out of context. The results from the tests and procedures used in this document are not intended to be used for the design of FRC structures. The purpose of this document is to gain a better understanding of the many factors influencing tests for the determination of mechanical properties of FRC and FRC products.

Although most of the test methods described in this report were developed initially for steel FRC (SFRC), they are applicable to concretes reinforced with glass, synthetic/polymeric, and natural fibers, except when noted. In Fig. 1.2, an example of different types of fibers commonly employed in FRC is provided.

This report applies to the mechanical properties of conventionally mixed and placed FRC or fiber-reinforced shotcrete (FRS) using steel, glass, synthetic/polymeric, and cellulose/natural fibers.

Some newer test methods and evaluation procedures under development are not included in this report. Examples of this are tensile creep and flexural creep of concrete where the section has cracked and the bridging fibers are carrying loads.

This report does not discuss test methods for thin glass FRC or mortar products produced by the spray-up process. The Prestressed Concrete Institute (PCI MNL 128) and the International Glassfibre Reinforced Cement Association (2016a,b) have prepared recommendations for test methods for these spray-up materials.

CHAPTER 2—NOTATION AND DEFINITIONS**2.1—Notation**

- a, b = dimensions, in. (mm)
- b = width, in. (mm)
- d = depth, in. (mm)
- d_f = fiber diameter, in. (mm)
- f_1 = first cracking nominal stress (as from results of flexural tests according to ASTM C1609/C1609M), psi (MPa)