

**Report on the Physical Properties and  
Durability of Fiber-Reinforced Concrete**

Reported by ACI Committee 544



**American Concrete Institute®**



First Printing  
March 2010

American Concrete Institute®  
*Advancing concrete knowledge*

## **Report on the Physical Properties and Durability of 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. Proper use of this document includes periodically checking for errata at [www.concrete.org/committees/errata.asp](http://www.concrete.org/committees/errata.asp) 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.

**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**  
**U.S.A.**

**Phone: 248-848-3700**  
**Fax: 248-848-3701**

**[www.concrete.org](http://www.concrete.org)**

ISBN 978-0-87031-365-3

# Report on the Physical Properties and Durability of Fiber-Reinforced Concrete

Reported by ACI Committee 544

Nemkumar Banthia  
Chair

Neven Krstulovic-Opapa  
Secretary

Melvyn A. Galinat  
Membership Secretary

Ashraf I. Ahmed	Graham T. Gilbert	Pritpal. S. Mangat*	Venkataswamy Ramakrishnan*
Corina-Maria Aldea*	Vellore S. Gopalaratnam	Peter C. Martinez	Roy H. Reiterman
Madasamy Arockiasamy	Antonio J. Guerra	Bruno Massicotte	Klaus Alexander Rieder*
P. N. Balaguru	Rishi Gupta	James R. McConaghy	Pierre Rossi
Joaquim Oliveira Barros*	Carol D. Hays	Christian Meyer	Surendra P. Shah
Gordon B. Batson*	George C. Hoff	Nicholas C. Mitchell Jr.	Konstantin Sobolev
Vivek S. Bindiganavile	Allen J. Hulshizer	Barzin Mobasher†	Jim D. Speakman Sr.
Peter H. Bischoff	Akm Anwarul Islam	Henry J. Molloy	Chris D. Szychowski
Marvin E. Criswell	John Jones*	Dudley R. Morgan	Peter C. Tatnall
James I. Daniel	Jubum Kim	Antoine E. Naaman*	Houssam A. Toutanji
Xavier Destree	Katherine G. Kuder*	Antonio Nanni	Jean François Trottier*
Ashish Dubey	David A. Lange	Nandakumar Natarajan	George J. Venta
Philip L. Dyer	John S. Lawler*	Jeffrey L. Novak*	Gary L. Vondran*
Gregor D. Fischer	Mark A. Leppert	Mark E. Patton	Robert Wojtysiak
Dean P. Forgeron*	Maria Lopez de Murphy	Max L. Porter	Robert C. Zellers
Sidney Freedman	Clifford N. MacDonald*	John H. Pye	Ronald F. Zollo
Richard J. Frost			

\*Subcommittee members who prepared this report.

†Subcommittee Chair.

*This document addresses the physical properties and durability of fiber-reinforced concrete (FRC). The effects of fiber reinforcement are evaluated for various physical, short-term, and long-term benefits they impart to the concrete mixture. A variety of test methods, conditions, and properties are reported. The various properties listed, in addition to the wide variety of the choices available in formulating matrix systems, allow performance-based specification of concrete materials using fibers to become a viable option. This document provides a historical basis and an overview of the current knowledge of FRC materials for tailoring new, sustainable, and durable concrete mixtures.*

*This document is divided into three sections. The first section discusses the physical properties of FRC in terms of electrical, magnetic, and thermal properties. Rheological properties, which affect fiber dispersion and distribution, are discussed using both empirical and quantitative*

*rheology. Mechanisms of creep and shrinkage and the role of various fiber types in affecting both plastic shrinkage cracking and restrained shrinkage cracking are also addressed. The durability of concrete as affected by the addition of fibers is documented under freezing and thawing, corrosion resistance, and scaling. The durability of FRC systems is also affected as different fibers respond differently to the highly alkaline cementitious microstructure. The durability of alkali-resistant glass and cellulose fibers are studied by an in-depth evaluation of long-term accelerated aging results. Degradation and embrittlement due to alkali attack and bundle effect are discussed. Recent advances for modeling and design of materials with aging characteristics are presented. Literature on the use of FRC materials under aggressive environments, extreme temperatures, and fire is presented. The final sections list a series of applications where the use of FRC has resulted in beneficial durability considerations.*

ACI Committee Reports, Guides, Manuals, and Commentaries are intended for 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.

**Keywords:** aging; chloride permeability; corrosion; cracking; creep; diffusion; degradation; ductility; durability; electric properties; embrittlement; fiber-reinforced cement-based materials; fiber-reinforced products; fire resistance; flexural strength; freezing-and-thawing; glass; microcracking; permeability; plastic shrinkage; polypropylene; polyvinyl alcohol; reinforcing materials; rheology; shrinkage cracking; steel; sulfate attack; thermal conductivity; toughness; water permeability; wood pulp.

ACI 544.5R-10 was adopted and published March 2010.

Copyright © 2010, 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.

**CONTENTS****Chapter 1—Introduction and scope, p. 544.5R-2**

- 1.1—Introduction
- 1.2—Scope

**Chapter 2—Notation, definitions, and acronyms, p. 544.5R-3**

- 2.1—Notation
- 2.2—Definitions
- 2.3—Acronyms

**Chapter 3—Physical properties of fiber-reinforced concrete (FRC), p. 544.5R-3**

- 3.1—Creep
- 3.2—Shrinkage
- 3.3—Permeability and diffusion
- 3.4—Rheology
- 3.5—Electrical properties
- 3.6—Thermal conductivity

**Chapter 4—Durability of FRC, p. 544.5R-13**

- 4.1—Extreme temperature and fire
- 4.2—Freezing and thawing
- 4.3—Degradation and embrittlement due to alkali attack and bundle effect
- 4.4—Weathering and scaling
- 4.5—Corrosion resistance

**Chapter 5—Applications and durability-based design, p. 544.5R-23**

- 5.1—Case studies of applications of FRC materials and durability

**Chapter 6—References, p. 544.5R-23**

- 6.1—Referenced standards and reports
- 6.2—Cited references

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

The use of fibers in concrete to improve pre- and post-cracking behavior has gained popularity. Since 1967, several different fiber types and materials have been successfully used in concrete to improve its physical properties and durability. This is supported by an extensive number of independent research results showing the ability of fibers to improve durability and physical properties of concrete. Regardless of origin, cracking, when induced by chemical, mechanical, or environmental processes, results in deteriorated and less-durable concrete. In addition, the increased permeability caused by cracking can accelerate other deterioration processes such as freezing-and-thawing damage, again resulting in less-durable concrete.

This report addresses the physical properties and durability of FRC that includes fibers in concrete. In this report, many structural systems are evaluated for various physical, short-term, and long-term benefits. These effects of using fibers have been determined using various testing methods. Many needed tests are not described by existing ASTM standards and similar standards due to the diverse nature of test methods, conditions, and properties reported. It would be a daunting task to address every project in an effort to develop correlations across the various test results. This report presents a limited collection of the published research results in relevant area. With the exception of a few characteristic responses such as creep, plastic shrinkage cracking, and long-term aging, this report does not address the mechanical properties in detail. The justification for this treatment is that topics such as mechanical properties and testing methods are addressed by subcommittees. The broader category of physical properties is in context to specific chapters.

There are several fiber types on the market intended to address various design requirements and constraints. Table 1.1

**Table 1.1—A compilation of mechanical properties of commonly used fibers in concrete materials\***

Type of fiber	Equivalent diameter, mm	Specific gravity, kg/m <sup>3</sup>	Tensile strength, MPa	Young's modulus, GPa	Ultimate elongation, %
Acrylic	0.02 to 0.35	1100	200 to 400	2	1.1
Asbestos	0.0015 to 0.02	3200	600 to 1000	83 to 138	1.0 to 2.0
Cotton	0.2 to 0.6	1500	400 to 700	4.8	3.0 to 10.0
Glass	0.005 to 0.15	2500	1000 to 2600	70 to 80	1.5 to 3.5
Graphite	0.008 to 0.009	1900	1000 to 2600	230 to 415	0.5 to 1.0
Aramid	0.010	1450	3500 to 3600	65 to 133	2.1 to 4.0
Nylon	0.02 to 0.40	1100	760 to 820	4.1	16 to 20
Polyester	0.02 to 0.40	1400	720 to 860	8.3	11 to 13
Polypropylene (PP)	0.02 to 1.00	900 to 950	200 to 760	3.5 to 15	5.0 to 25.0
Polyvinyl alcohol (PVA)	0.027 to 0.66	1300	900 to 1600	23 to 40	7 to 8
Carbon (standard)	—	1400	4000	230 to 240	1.4 to 1.8
Rayon	0.02 to 0.38	1500	400 to 600	6.9	10 to 25
Basalt	0.0106	2593	990	7.6	2.56
Polyethylene	0.025 to 1.0	960	200 to 300	5.0	3.0
Sisal	0.08 to 0.3	760 to 1100	228 to 800	11 to 27	2.1 to 4.2
Coconut	0.11 to 0.53	680 to 1020	108 to 250	2.5 to 4.5	14 to 41
Jute	0.1 to 0.2	1030	250 to 350	26 to 32	1.5 to 1.9
Steel	0.15 to 1.00	7840	345 to 3000	200	4 to 10

\*Data from Nawy (1996), Kuraray (2007), Saechtling (1987), Sim et al. (2005), Toledo et al. (2000), and Balaguru and Shah (1992).

Notes: 1 mm = 0.039 in.; 1 kg/m<sup>3</sup> = 0.06 lb/ft<sup>3</sup>; 1 MPa = 145 psi; 1 GPa = 1,450,000 psi.