IN-LB	Inch-Pound Units
SI	International System of Units

Measuring Shrinkage, Creep, and Transport Properties of Fiber-Reinforced Concrete—Report

Reported by ACI Committee 544

ACI PRC-544.11-22

American Concrete Institute
Always advancing

First Printing
July 2022
ISBN: 978-1-64195-181-4

Measuring Shrinkage, Creep, and Transport Properties of Fiber-Reinforced Concrete—Report

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, 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 the ACI Collection of Concrete Codes, Specifications, and Practices.

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

www.concrete.org

ACI PRC-544.11-22

Measuring Shrinkage, Creep, and Transport Properties of Fiber-Reinforced Concrete—Report

Reported by ACI Committee 544

Liberato Ferrara*, Chair — Neven Krstulovic-Opara, Secretary — Clifford N. MacDonald, Membership Secretary

Corina-Maria Aldea*
Salah Ahmed Altoubat
Emmanuel K. Attiogbe
Mehdi Bakhshi*
Nemkumar Banthia*
Joaquim Oliveira Barros
Amir Bonakdar†
Amanda C. Bordelon
Jean-Philippe Charron*
Xavier Destree
Ashish Dubey
Mahmut Ekenel
Alessandro P. Fantilli
Gregor D. Fischer
Dean P. Forgeron
Emilio Garcia Taengua*
Rishi Gupta
Heidi Helmink
David A. Lange
Michael A. Mahoney
Bruno Massicotte
James Milligan
Nicholas C. Mitchell Jr.
Barzin Mobasher*
Verya Nasri
Giovanni A. Plizzari
Klaus Alexander Rieder
Pierre Rossi
Steve Schaef*
Surendra P. Shah
Flavio de Andrade Silva
Luca Sorelli
Hendrik Thooft
Thomas E. West Jr.
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
Sidney Freedman
Christian Meyer
Antoine E. Naaman
Venkataswamy Ramakrishnan

*Members of Task Group who prepared this report.
†Chair of the Task Group who prepared this report.

Fiber-reinforced concrete (FRC) has become a viable choice for many designers and builders for the unique properties and advantages it provides. From slabs-on-ground to underground structures, the use of FRC has been expanding in concrete construction. This growth of applications has created the need to review the existing test methods for FRC and, where necessary, develop new ones. Two reports (ACI 544.2R and ACI 544.9R) have already been published regarding testing fresh properties and mechanical properties of FRC, respectively. This report is the third and final report on testing FRC for its durability properties, including shrinkage, creep, and permeability. Several standard and nonstandard test methods are presented in this report to represent some of the knowledge in this area.

Keywords: creep; durability; fiber-reinforced concrete; shrinkage; testing; transporting.

CONTENTS

ACI PRC-544.11-22 was adopted and published in July 2022.

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Some of the key properties of concrete structures vary as a function of time and the environment. These include, but are not limited to, shrinkage, creep, and transport properties such as permeability and diffusion. Fibers show a positive impact in improving the long-term durability (ACI 544.5R) and sustainability aspects of concrete (Cutright et al. 2013). As described in this report, fibers can help reduce and limit restrained shrinkage cracking, which may occur in concrete with a large, exposed surface such as slabs. These applications are susceptible to rapid changes in temperature and humidity, resulting in high water evaporation and higher potential for shrinkage cracking. Another example is the use of fibers in applications where sustained loads and creep stresses can be critical in the service life of the structure. Bridge deck overlays, environmental structures, and tunnel linings are some of the applications where fiber reinforcement has been used successfully to enhance the long-term performance and durability of concrete (ACI 544.4R). To ensure structural integrity and proper serviceability, most building codes limit the allowable crack widths in the range of 0.006 to 0.015 in. (0.15 to 0.38 mm) for concrete structures exposed to weathering and fibers can be beneficial in maintaining such allowances (ACI 544.10). Fibers bridge cracks in a three-dimensional distributed manner because they are present throughout the body of concrete, whereas reinforcing bars control cracks more locally (Hubert et al. 2015). Cracks may occur as a result of over-stressing or time-dependent stresses such as shrinkage and creep discussed in this report.

Fibers come in different material types, geometries, and sizes and typically range from 1/8 to 2.5 in. (3 to 65 mm) in length and are classified according to ASTM C1116/C1116M. These fiber material types include steel, glass, synthetic, and natural, as well as blended fibers. A subclassification is often used based on the size and functionality of the fibers; hence, fibers can be classified as microfibers or macrofibers with the fiber diameter of 0.012 in. (0.3 mm) as the separating limit as defined by ASTM D7508/D7508M. Adding fibers to concrete can change its post-crack response from brittle to ductile under various types of loads, including compression, tension, flexure, and impact (ACI 544.4R). After cracking, fibers bridge the cracks and start to carry tensile stresses, commonly referred to as post-crack residual strength. More information on the mechanisms of FRC and related design guides can be found in ACI 544.4R. The presence of fibers will help with reducing and controlling the crack width and,

Table 1.1—Summary of the test methods presented in this report and their applicability to FRC

Property	Test	Description	Application to FRC
Shrinkage properties	Unrestrained, ASTM C157/C157M	Free (unrestrained) drying shrinkage of prismatic specimens	Not effective for studying macrofibers, as concrete does not crack*
	Restrained, ASTM C1579	Restrained plastic shrinkage of rectangular panels using stress risers	Effective in studying FRC for crack reduction in a comparative way. Quicker test.
	Restrained, ASTM C1581/C1581M	Restrained drying shrinkage of concrete cast around a steel ring	Effective in studying FRC for crack reduction and time of cracking in a comparative way. Longer test.
	Restrained, other	Restrained plastic shrinkage of square panels using a vacuum system	Effective in studying FRC for crack reduction in a comparative way.
Creep properties	Flexural: Beams	Precracking beams, followed by creep test at a specific percentage of residual stress (ASTM C1399/C1399M, C1609/C1609M, BS EN 14651)	Effective in studying FRC for cracked sections up to a known stress value. Test can take a long time.
	Flexural: Panels	Precracking round panels, followed by creep test at a specific percentage of residual stress (ASTM C1550)	Effective in studying FRC for cracked sections up to a known stress value. Test can take a long time.
	Creep, other	Direct tension test on precracked specimens (prismatic or cylindrical). Compression test. Fiber pullout test under creep load.	Useful in studying FRC if conducted correctly. Proper direct tension test is very difficult to perform for concrete.
Transport Properties	Chloride diffusion, ASTM C1202	Electrical indication of concrete's ability to resist chloride ions ingress using cylinders.	Not effective for studying fibers, as concrete cannot be cracked.
	Chloride diffusion, ASTM C1556	Bulk chloride diffusion profile and coefficient using concrete cylinders. Can precrack cylinders using splitting tensile test.	Useful in studying FRC for precracked specimens and determining the role of fibers in reducing crack width and diffusion.
	Chloride diffusion, other	Bulk chloride diffusion profile and coefficient using concrete beams. Can precrack beams using FRC flexural tests.	Useful in studying FRC for precracked specimens and determining the role of fibers in reducing crack width and diffusion.
	Water permeability	Create water head (pressure) to flow water into a precracked concrete specimen (cylinder, beam, or panel).	Effective in studying FRC for precracked specimens and determining the role of fibers in reducing crack width and water flow rate and permeability.

*Synthetic microfibers may reduce bleeding and therefore can help reduce the plastic shrinkage of concrete. Refer to Section 3.2 for more information.