Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures

Reported by ACI Committee 440

John P. Busel
Chair

Carol K. Shield
Secretary

Tarek Alkhrdaji
Charles E. Bakis
P. N. Balaguru
Lawrence C. Bank
Abdeldjelil Belarbi
Brahim Benmokrane
Gregg J. Blaszak
Timothy E. Bradberry
Gordon L. Brown, Jr.
Vicki L. Brown
Raafat El-Hacha
Garth J. Fallis
Amir Z. Fam
Edward R. Fyfe
Russell Gentry
Janos Gergely
William J. Gold
Nabil F. Grace
Mark F. Green*
Zareh B. Gregorian
Doug D. Gremel
H. R. Trey Hamilton III
Isaam E. Harik
Kent A. Harries
Mark P. Henderson
Bohdan N. Horeczko
Vistasp M. Karbhari
James G. Korff
Michael W. Lee
Ibrahim M. Mahfouz
Orange S. Marshall
Amir Mirmiran
Ayman S. Mosallam
John J. Myers
Antonio Nanni
Kenneth Neale
John P. Newhook
Max L. Porter
Mark A. Postma
Andrea Prota
Hayder A. Rasheed
Sami H. Rizkalla
Morris Schupack
Rajan Sen
Khaled A. Soudki
Samuel A. Steere III
Gamil S. Tadros
Jay Thomas
Houssam A. Toutanji*
J. Gustavo Tumialan
Milan Vatovec
Stephanie L. Walkup
David White

*Subcommittee co-chairs responsible for preparing the report.
Several voting members of the committee contributed chapters or made other substantial contributions to the report. In addition, the committee would like to acknowledge the contribution of associate members T. Ivan Campbell and Luke A. Bisby.

Applications of fiber-reinforced polymer (FRP) composites as reinforcement for concrete structures have been growing rapidly in recent years. ACI Committee 440 has published design guidelines for internal FRP reinforcement, externally bonded FRP reinforcement for strengthening, prestressed FRP reinforcement, and test methods for FRP products. Although these guidelines exist, new products and applications continue to be developed. Thus, this report summarizes the current state of knowledge on these materials and their application to concrete and masonry structures. The purpose of this report is to act as an introduction to FRP materials in areas where ACI guides exist, and to provide information on the properties and behavior of concrete structures containing FRP in areas where guides are not currently available. If an ACI guide is available, the guide document supersedes information in this report, and the guide should always be followed for design and application purposes. ACI Committee 440 is also in the process of developing new guides and thus the current availability of guides should be checked by the reader. In addition to the material properties of the constituent materials (that is, resins and fibers) and products, current knowledge of FRP applications, such as internal reinforcement including prestressing, external strengthening of concrete and masonry structures, and structural systems, is discussed in detail. The document also addresses durability issues and the effects of extreme events, such as fire and blast. A summary of some examples of field applications is presented.

Keywords: aramid fibers; blast; bridges; buildings; carbon fibers; composite materials; corrosion; design; dowels; ductility; durability; external reinforcement; fatigue; fiber-reinforced polymer (FRP); fibers; fire; glass fiber; masonry; mechanical properties; polymer resin; prestressed concrete; seismic; stay-in-place forms; structural systems; test methods.

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.

CONTENTS

Chapter 1—Introduction and scope, p. 2
1.1—Introduction
1.2—Historical perspective of FRP composites

ACI 440R-07 supersedes ACI 440R-96 and was adopted and published September 2007.
Copyright © 2007, 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

Chapter 2—Notation and definitions, p. 4
2.1—Notation
2.2—Definitions

Chapter 3—Codes and standards, p. 8
3.1—Materials
3.2—Internal FRP reinforcement
3.3—External FRP reinforcement

Chapter 4—Composite materials and processes, p. 11
4.1—Introduction
4.2—Polymer matrix: resins
4.3—Reinforcing fibers
4.4—Types of reinforcement
4.5—Additives and fillers
4.6—Core materials for sandwich structures
4.7—Adhesives
4.8—FRP manufacturing processes

Chapter 5—Properties, test methods, and nondestructive evaluation, p. 18
5.1—Introduction
5.2—Typical properties of currently available products
5.3—Test methods for mechanical properties
5.4—Durability testing methods
5.5—Nondestructive inspection techniques for FRP materials

Chapter 6—Performance of concrete members with internal FRP reinforcement, p. 24
6.1—Strength
6.2—Serviceability
6.3—Bond and development of reinforcement
6.4—Fatigue performance
6.5—Members reinforced with FRP grating systems
6.6—Members reinforced with FRP grids
6.7—Pavement applications

Chapter 7—Prestressed concrete members, p. 30
7.1—FRP tendons
7.2—Anchorages
7.3—Flexural behavior
7.4—Fatigue behavior
7.5—Time-dependent behavior
7.6—Ductility and deformability
7.7—Transfer and development length
7.8—Shear behavior
7.9—External tendons
7.10—Prestressed poles

Chapter 8—Repair, strengthening, and retrofitting, p. 35
8.1—Flexural strengthening with non-prestressed FRP
8.2—Flexural strengthening with prestressed FRP
8.3—Shear strengthening
8.4—Axial strengthening of columns
8.5—Seismic strengthening and retrofitting
8.6—Mechanically fastened fiber-reinforced polymer (MF-FRP) laminates
8.7—Strengthening using near-surface-mounted FRP reinforcement
8.8—Design procedures

Chapter 9—Structurally integrated stay-in-place FRP forms, p. 43
9.1—Introduction
9.2—Advantages and limitations of system
9.3—Structural composition of FRP forms
9.4—Fabrication processes of FRP structural forms
9.5—Concrete component
9.6—Construction considerations
9.7—Behavior of axial members
9.8—Behavior of flexural and axial/flexural members

Chapter 10—Masonry applications, p. 51
10.1—Introduction
10.2—FRP strengthening techniques
10.3—FRP repair and strengthening of masonry
10.4—Design and application considerations

Chapter 11—Durability of FRP used in concrete, p. 56
11.1—Definition of durability
11.2—Durability of FRP composites
11.3—Internal reinforcement
11.4—External reinforcement
11.5—Structurally integrated stay-in-place (SIP) forms

Chapter 12—Fire and blast effects, p. 63
12.1—Introduction
12.2—Fire
12.3—Blast effects

Chapter 13—Field applications, p. 68
13.1—FRP as internal reinforcement
13.2—Prestressing applications
13.3—External reinforcement
13.4—Masonry applications
13.5—Stay-in-place FRP forms

Chapter 14—Research needs, p. 76
14.1—Introduction
14.2—Key research needs
14.3—Conclusions

Chapter 15—References, p. 78
15.1—Referenced standards and reports
15.2—Cited references

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

The purpose of this report is to present the current state of knowledge with regard to applications of fiber-reinforced polymer (FRP) materials in concrete. This report summarizes the fundamental behavior, the most current research, design codes, and practical applications of concrete and masonry structures containing FRP. This document is intended to complement other reports (for example, standards and design guidelines) produced by ACI Committee 440, either

American Concrete Institute Copyrighted Material—www.concrete.org