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The 13th International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures

Editors:
Raafat El-Hacha, Lijuan (Dawn) Cheng,
Maria Lopez de Murphy, William J. Gold

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The 13th International Symposium on Fiber-Reinforced Polymer Reinforcement for Concrete Structures

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Preface

Fiber-reinforced polymer (FRP) composite materials been widely used in civil engineering new construction and repair of structures due to their superior properties. FRP provides options and benefits not available using traditional materials. The promise of FRP materials lies in their high-strength, lightweight, noncorrosive, nonconducting, and nonmagnetic properties. ACI Committee 440 has published reports, guides, and specifications on the use of FRP materials for may reinforcement applications based on available test data, technical reports, and field applications. The aim of these document is to help practitioners implement FRP technology while providing testimony that design and construction with FRP materials systems is rapidly moving from emerging to mainstream technology.

The first International Symposium on Fiber-Reinforced Polymer Reinforcement or reinforced Concrete Structures (FRPRCS) conference was sponsored by the American Concrete Institute (ACI) and held in conjunction with ACI Spring convention in Vancouver, British Columbia, Canada in 1993. Since 1993, FRPRCS has become a prestigious and reputable international conference, and the symposia have been held in Ghent, Belgium (1995); Sapporo, Japan (1997); with ACI in Baltimore, USA (1999); Cambridge, England (2001); Singapore (2003); with ACI in Kansas City, USA (2005); Patras, Greece (2007); Sydney, Australia (2009); with ACI in Tampa, USA (2011); Guimarães, Portugal (2013); and Nanjing, China (2015).

FRPRCS continued the success of the previous conferences and the 13th International Symposium on Fiber-Reinforced Polymer Reinforcement of Concrete Structures (FRPRCS-13) was organized by ACI Committee 440 and held on October 14 and 15, 2017 at the ACI Fall 2018 convention in Anaheim, CA, USA. FRPRCS-13 attracted interest from researchers, practitioners, and manufacturers involved in the use of fiber-reinforced polymers (FRPs) as reinforcement for concrete masonry structures. This includes the use of FRP reinforcement in new construction and FRP for strengthening and rehabilitation of existing structures. The papers/presentations not only emphasized the experimental, analytical, and numerical validations of using FRP composites but also aimed at providing insights needed for improving existing guidelines. New frontiers of FRP research were explored that provide information on emerging materials, systems, and applications for extreme events such as fire and earthquakes. The technical papers also featured discussions on sustainability, novel applications, new technologies, and long-term field data that will result in greater acceptance and use of FRP composites technology by practitioners. Attendees were able to:

a) Understand many of the critical topics of research related to the use of FRP reinforcement in new construction and FRP systems for strengthening and rehabilitating existing structures.
b) Develop knowledge on existing international codes and guidelines on these materials and systems.
c) Exposure to new FRP material technologies as they relate to reinforcing and strengthening concrete and masonry structures.
d) Learn practical aspects of FRP reinforcement materials and systems in field applications for new construction and rehabilitation of existing concrete and masonry structures.

This Special Publication consists of a total of 54 accepted papers out of 63 submissions from 18 countries. 65 presentations were presented over made two days in sixteen special technical sessions. These sessions provided a worldwide state-of-the-art forum for researchers, civil/structural engineers, contractors, consultants, practitioners, and regulatory authorities to exchange recent advances in both research and practice, and to share information, experience, and knowledge in the implementation of FRP technology. The technical papers presented at the sessions and published in this volume included the most recent analytical and experimental research work as well as selected field applications, design, and construction guidelines. The sessions were well attended and generated substantial technical discussion and exchange of new technology. The sessions held included:

FRPRCS A1 —Bond and Anchorage of FRP Bars, Grids, and Laminates to Concrete -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of the bond and anchorage behavior of FRP bars, plates, and tendons to concrete.

FRPRCS B1—Strengthening of Concrete Structures Using FRP Systems -> 5 Presentations
This session emphasized the experimental, analytical, and numerical validations of using FRP composites for the strengthening of reinforced concrete structures.

FRPRCS A2 —Bond and Anchorage of FRP Bars, Grids, and Laminates to Concrete -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of the bond behavior of different FRP-concrete systems.

FRPRCS B2—Testing of FRP Material Characteristics -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of FRP material characteristics.

FRPRCS A3—Emerging FRP Systems -> 5 Presentations
This session emphasized the experimental, analytical, and numerical validations of using emergent FRP systems in concrete infrastructure.

FRPRCS B3—Strengthening of Concrete Structures Using FRP Systems-> 5 Presentations
This session emphasized the experimental, analytical, and numerical validations of using FRP composites for the strengthening of reinforced concrete structures.

FRPRCS A4—Global Codes and Standards -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of using FRP-reinforced or -strengthened concrete structures and will be aimed at providing insights needed for improving existing design guidelines.

FRPRCS B4—Advances in Uses of FRP in Concrete and Masonry -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of using FRP in concrete and masonry structures.

FRPRCS A5—Seismic Resistance of Concrete Structures Using FRP Materials -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of using FRP composites in seismic structural applications.

FRPRCS B5—Strengthening of Concrete Structures Using FRP Systems -> 4 Presentations

This session emphasized the experimental, analytical, and numerical validations of using FRP composites for the strengthening of reinforced concrete structures.

FRPRCS A6—FRP Reinforcement of Concrete and Masonry Walls -> 3 Presentations
This session emphasized the experimental, analytical, and numerical validations of using FRP composites for the reinforcement of concrete and masonry walls.

FRPRCS B6—Field Applications and Case Studies -> 4 Presentations
This session emphasized field applications and case studies of using FRP composites for internal reinforcement of concrete.

FRPRCS A7—Effects of Extreme Events on FRP-Reinforced/Strengthened Structures -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of extreme events on FRP-reinforced or -strengthened concrete.

FRPRCS B7—Effect of Environment on Durability -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of the effects of the environment on the durability of FRP-reinforced or –strengthened concrete structures.

FRPRCS A8—Design and Performance Under Long-Term Loading and Environmental Exposure -> 3 Presentations
This session emphasized the experimental, analytical, and numerical validations of FRP-reinforced or strengthened concrete structures under long term loading and environmental exposure.

FRPRCS B8—Advances in Uses of FRP in Concrete and Masonry -> 4 Presentations
This session emphasized the experimental, analytical, and numerical validations of using FRP composites for concrete and masonry structures.

In accordance with the standard review procedures established by ACI, all papers were reviewed by at least two experts in the subject area and approved for publication. All submitted papers were given serious consideration before a decision regarding publication was made.

This volume represents the thirteen in the symposium series and could not have been put together without the help, dedication, cooperation, and assistance of many volunteers and ACI staff members. First, we would like to thank the authors for meeting our various deadlines for submission, providing an opportunity for FRPRCS-13 to showcase the most current work possible at the symposium. Second, the International Scientific Steering Committee, consisting of many distinguished international researchers, including chairs of past FRPRCS symposia, many distinguished reviewers and members of the ACI Committee 440 who volunteered their time and carefully evaluated and thoroughly reviewed the technical papers, and whose input and advice have been a contributing factor to the success of this volume.

Editors of this volume and chairs of the FRPRCS-13 international Symposium
Raafat El-Hacha
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Maria Lopez de Murphy
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TABLE OF CONTENTS

SP-327—25
Enhancing FRP-to-Concrete Bond Behavior by Epoxy Ribs
Authors: Cheng Jiang, Baolin Wan and John Omboko

SP-327—26
Testing and Finite Element Analysis of GFRP Reinforced Concrete Frame Joints
Authors: Nader Sleiman, Ryan Barrage, Graeme J. Milligan and Maria Anna Polak

SP-327—27
Size Effect in FRP RC Beams with and without Shear Reinforcement
Authors: Szymon Cholostiakow, Matteo Di Benedetti, Maurizio Guadagnini and Emanuele Zappa

SP-327—28
Strengthening of Damaged Reinforced Concrete Beams Using Externally Bonded Fiber Reinforced Polymer
Authors: Salah Altoubat, Abdul Saboor Karzad and Mohamed Maalej

SP-327—29
Development of a Photovoltaic Integrated Insulated Concrete Sandwich Panel
Authors: Mostafa Yossef, An Chen and Austin Downey

SP-327—30
Behavior of Beams Strengthened with Fabric Reinforced Cementitious Mortar in Bending
Authors: Trevor N. S. Billows and Ahmad Rteil

SP-327—31
Shear Strengthening of RC Beams with NSM FRP — Influencing Parameters and A Theoretical Model
Authors: Amir Mofidi, Lijuan Cheng, Omar Chaallal and Yixin Shao

SP-327—32
Evaluation of FRP and FRCM Composites for the Strengthening of Reinforced Masonry Walls
Authors: Zuhair A. Al-Jaberi, John J. Myers and Mohamed A. ElGawady

SP-327—33
A Hybrid FRP-Reinforced Slab-on-Truss Girder System for Short and Medium Span Bridges
Authors: Mamdouh El-Badry, Mohammad Moravvej and Parham Joulani

SP-327—34
Case-Specific Parametric Analysis as Research-Directing Tool for Analysis and Design of GFRP-RC Structures
Authors: Marco Rossini, Eleonora Bruschi, Fabio Matta, Carlo Poggi and Antonio Nanni

SP-327—35
Evaluation and Classification of Anchorage Systems Used to Enhance the Flexural Performance of FRP Strengthened Concrete Members
Authors: Robin Kalfat, Jeremy Gadd, Riadh Al-Mahaidi and Scott T. Smith

SP-327—36
Bond Behaviour of CFRP Bars Prestressed in Self-Consolidating Concrete Beams
Authors: Slamah S. Krem and Khaled A. Soudki

SP-327—37
Meso-Scale Concrete Model for Failure Simulation in Glass FRP Reinforced Concrete Structures
Authors: Sina Khodaie and Fabio Matta

SP-327—38
Review of FRCM Strengthening Solutions for Structural Wall Panels
Authors: Cristian Sabau, Cosmin Popescu, Gabriel Sas, Thomas Blanksvärd and Björn Täljsten

SP-327—39
Column-Footing Connection Evaluation of Hollow-Core Composite Bridge Columns
Authors: Mohanad M. Abdulazeez, Ahmed Gheni, Omar I. Abdelkarim and Mohamed A. ElGawady

SP-327—40
Flexural Behavior of GFRP-UFC Composite Beams under Moderately High Temperature
Authors: Isuru Sanjaya Kumara Wijayawardane and Hiroshi Mutsuyoshi

SP-327—41
Effect of Surface Characteristics of FRP Bars on Bond Behavior in Concrete
Authors: Sándor Sólyom, Matteo Di Benedetti and György L. Balázs

SP-327—42
Durability of GFRP Reinforcement in Seawater Concrete
Authors: Morteza Khatibmasjedi and Antonio Nanni

SP-327—43
Shear Strengthening of Concrete Bridges using CFRP Strips and Anchors and Quality Control Procedures
Authors: Wassim M. Ghannoum, Nawaf K. Alotaibi, Jose Garcia, Chang Hyuk Kim, Yungon Kim, Douglas Pudleiner, Kevin Quinn, Neil Satrom, William Shekarchi, Wei Sun, Helen Wang and James O. Jirsa

SP-327—44
Influence of EB-CFRP on Cracks for Reinforced Concrete Beams Strengthening
Authors: Emmanuel Ferrier, Carmelo Caggegi and Laurent Michel

SP-327—45
State-of-the-Practice of Global Manufacturing of FRP Rebar and Specifications
Authors: Alvaro Ruiz Emparanza, Raphael Kampmann and Francisco De Caso y Basalo

SP-327—46
Quantitative Image Analysis of Concrete-Epoxy Interface Fracture
Authors: Yoseok Jeong, Maria M. Lopez and Charles E. Bakis

SP-327—47
Investigation of CFRP Torsional Strengthening of RC Beams using DIC Photogrammetry
Authors: Ghaidak Al-Bayati, Riadh Al-Mahaidi and Robin Kalfat

SP-327—48
Shear Strengthening of Reinforced Concrete Beams Using Externally Bonded Small-Diameter Carbon Strands
Authors: Judy M. I. Soliman, Tarek K. Hassan and Sami H. Rizkalla

ADVANTAGES OF PREPREG FRP SYSTEMS FOR EXTENDING SERVICE LIFE OF CONCRETE MEMBERS IN WET ENVIRONMENTS

Erblina Vokshi

SYNOPSIS: The use of wet lay-up fiber-reinforced polymers (FRPs) in the construction industry continues to grow. Their lightweight, durability, and good material properties makes them very desirable in the concrete repair industry. Research has shown that these products greatly improve the strength of repaired corroded members and reduce the rate of post-repair corrosion. There is a lack of research, however, in understanding how curing of these systems in the presence of moisture or underwater may affect their ability to strengthen and protect reinforced concrete. In this paper, data on material properties of a prepreg system, cured in laboratory conditions and under-water is presented and compared. The results show that there is a very small drop in tensile material properties when the system is cured underwater. Compression of concrete cylinders strengthened with one layer of the system and cured underwater is shown to be in agreement with ACI 440.2R-08's confinement equations. Durability testing of the bond between the system and reinforced concrete using dolly pull-off test shows a 90% bond strength retention after 1,000hr exposure to various aggressive environments.

Click here to download accompanying video

Keywords: under-water repairs, underwater CFRP, pile strengthening, confinement, under-water cure, corrosion, bond durability,

Erblina Vokshi

ACI member Eri Vokshi is a structures rehabilitation engineer at NRI. Her roles and responsibilities include ensuring all current products are in compliance with current codes and guidelines, acting as a liaison between NRI's sales and R&D department, managing all third party testing for FRP materials, and performing design calculations in accordance with ACI 440. Eri holds a Master's degree in Material Science from Arizona State University and is a professional engineer in the state of Florida. She has been working at NRI for 6 years. She is also an active member of ACI 440 and a voting member of ACI 440F.

INTRODUCTION

Application of wet lay-up Fiber reinforced polymer (FRP) systems in the repair industry is well accepted. These applications include structural strengthening of structures such as parking garages, buildings, bridges, etc. which have experience some form of structural deficiency, many due to corrosion. Emergence of new resin chemistries is allowing these technologies to find new types of applications, such as reinforcement of piles submerged underwater, where corrosion of steel rebar is the major cause of damage.

Research by Suh, et al.[1] investigated a prepreg (water activated resin) technology as well as an existing epoxy technology in understanding effectiveness of FRP wraps in corrosion reduction in submerged piles. This study included laboratory testing as well as two field tests. The authors also studied short term and long term bond strengths when these products were applied on two bridge piles. Finally, eccentric testing on submerged and dry columns was performed. The results show that both systems slow down the corrosion rate, irrespective of whether carbon or glass is used. The bond strength and failure mode of these systems in wet conditions was low and the author suggests that improvements in bond strength are necessary to make these wraps more desirable. Also, though eccentric column testing was performed on these systems, the studies do not clearly show how the underwater wraps compare to applications in dry conditions.

In another paper by Mullins, et.al.[2] the materials used, application experience, and bond data for the two field projects mentioned above[1] are summarized. The authors do not provide any data on material properties of these products when fully cured under water. Also, though the author mentions that interaction diagrams can be developed for column strengthening, no correlation is offered to show how experimental data of columns wrapped underwater compare to theoretical calculations.

Other work, which demonstrate how composites protect reinforced concrete from corrosion of steel, was done by Gadve, et al[3] and includes a pull-out testing of a 330mm rebar was placed inside a concrete cylinder with induced corrosion using NaCl and a current. The results show that rebar corrosion drastically slowed down when concrete cylinders were wrapped with both CFRP and GFRP. Another paper by Masoud and Soudki[4] focus on the results of evaluation of the corrosion activity in unrepaired and FRP repaired specimens, using non-destructive and destructive techniques. The data shows that corrosion potential decreased with the progress of corrosion, and the FRP repair caused a higher rate of decrease of the corrosion potential with time than that observed for the unrepaired specimens. Another research by Spainhour and Wootton[5] show that the type of resin used in the FRP can affect the resistance of the reinforced member from corrosion.

Repairs with FRPs were shown to greatly improve the strength and ductility of repaired corroded members and reduced the rate of post-repair corrosion in work completed by Bonacci, et al[6]. Moreover, subjecting the repaired column to extensive, postrepair corrosion resulted in no loss of strength or stiffness and only a slight reduction in the ductility of the repaired member[7].

Not much research however has been done in understanding how curing process underwater of wet lay-up systems may affect their ability to strengthen and protect reinforced concrete from rebar corrosion. Since underwater pilings require continuous corrosion maintenance at the water to air interface caused by cyclic wet and dry exposure of these areas with tidal height change and large marine organic growth, FRP solutions are a desirable option to asset owners. FRP jackets have been successfully used in many projects to protect concrete and wood pilings in these types of environments. However, the issue with these jackets is that they are size specific and require multi step process.

Research data in this report is presented for a new prepreg, wet lay-up carbon FRP (CFRP) product and epoxy primer, which cure in the presence of moisture and are UV resistant. The CFRP system provides a great advantage to FRP jackets since they are easy to handle and non-size specific. The product is saturated in a moisture-free, controlled environment using specialized saturating machines, which ensure continuous levels of fiber to resin ratios. The prepreg rolls are hermetically sealed and opened when ready to be applied/laid-up for field application. The epoxy primer has a high viscosity and tack and is applied on concrete surface by heavily saturating a polyester felt fabric, which acts as a carrier of the primer and makes it easy to be applied underwater.

The intent of this paper is to show the material properties of this system when fully cured under-water, confinement strengthening effectiveness when the product is applied and cured underwater, while meeting existing ACI 440's[8] design equations, and bond degradation when exposed to various harsh environments.

EXPERIMENTAL PROCEDURE

Tensile coupon testing

Tensile testing of the uniaxial carbon prepreg material was completed in accordance ASTM D3039. Panels were made by pressing two layers of fabric unto each other and letting them cure underwater and in laboratory conditions for 7 days before cutting them into 10in X 0.75in (250mm X 20mm) strips for testing. Figure 1 shows the panel fully submerged underwater while curing. A total of 8 samples were tested.

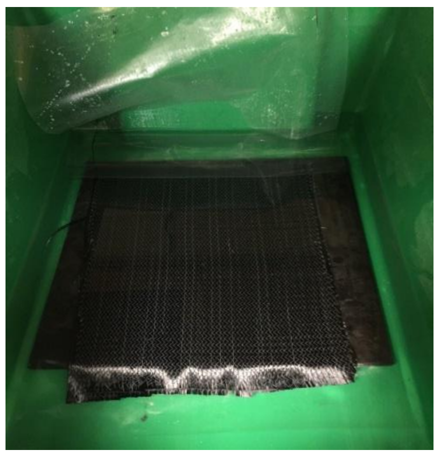

Figure 1 - Panels curing under-water

Concrete cylinder testing

This portion of the experimental study focused on confining 6in X 12in (150mm X 300mm) cylinders with the prepreg CFRP system loaded monotonically under axial compression to failure. In addition to concrete control samples, three additional configurations of the CFRP system were tested with the concrete cylinders, summarized in Table 1.

Table 1 – Testing Matrix for Confinement Testing

	Primer layer	FRP system	Curing environment
Configuration 1	Commercially available epoxy primer – not suitable for underwater applications	Pre-saturate CFRP system	Laboratory conditions
Configuration 2	Polyester felt saturated with epoxy primer – suitable for underwater applications	Pre-saturate CFRP system	Laboratory conditions
Configuration 3	Polyester felt saturated with epoxy primer – suitable for underwater applications	Pre-saturate CFRP system	Under-water

Concrete mix was poured into individual cylinders and was left to cure for 28 days prior to wrapping them with the CFRP system. The surface of concrete specimens was smoothed by grinding away any surface imperfections. Holes >1/4in (6mm) were filled with an epoxy filler. After, the samples to be wrapped with CFRP were prepared by applying the epoxy primer to the concrete surface, followed by wrapping the prepreg CFRP system with the fibers oriented in the hoop direction. On overlap length of 3in was applied at all the termination points of the wrap. While still wet, the