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IIFC Webinars

Emmanuel Ferrier, Université Lyon 1
Chair, IIFC Education Task Group
emmanuel.ferrier@univ-lyon1.fr

The objective of the IIFC Education Task Group is to promote education and knowledge transfer of IIFC researcher's to students and industry. The IIFC webinar series consists of short – one hour – online seminars on specialized topics. Students enrol in a virtual classroom and follow the course from their computer. Each webinar contains commentary from the presenting professor, an annotated dashboard, details on calculation methods described and allows participant interaction. The contents of each webinar are approved by the IIFC Education Task Group. All webinars are free to the public.

2015 Webinar Series

8 January 2015 at 1500 UTC - *FRP material for strengthening of structures in the field of construction, mechanical properties and bond*, E. Ferrier, University LYON1, France.
http://spiralconnect.univ-lyon1.fr/b3/join?meetingId=b3_71cf4568-a35c-4ba0-a093-53baecf26602

14 January 2015 at 1500 UTC - *RC beam strengthened for flexure*, E. Martinelli, University of Salerno, Italy.

February 2015 - *RC beam strengthened for shear*, J. Barros, University of Minho, Portugal.

March 2015 - *Field applications of FRP in bridges in Australia*, R. Al-Mahaidi, Swinburne University of Technology, Australia.

March 2015 - *Development of Standard Design Equations for Pultruded GFRP Members Subject to Compression*, K. Harries, University of Pittsburgh, USA.

April 2015 - *Durability of FRP*, B. Benmokrane, University of Sherbrooke, Canada.

April 2015 - *Seismic behavior of structures strengthened by FRP*, T. Triantafillou, University of Patras, Greece.

June 2015 - *Fire behavior of RC structures, case of FRP strengthening*, L. Bisby, University of Edinburgh, UK

Check the IIFC website for updates, dates, times and web links. www.iifc-hq.org.

Please connect to webinars 5 minutes before the scheduled start time. Webinars will be archived and available through the IIFC website.

FRPRCS-12 and APFIS-2015

On behalf of the FRPRCS Steering committee and the International Institute for FRP in Construction (IIFC), it gives us great pleasure to invite you to participate in the Joint Conference of The 12th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures **(FRPRCS-12)** & The 5th Asia-Pacific Conference on Fiber Reinforced Polymers in Structures **(APFIS-2015)** which will take place in Nanjing, China, from December 14-16, 2015. For more information, please contact frprcs-apfis2015@seu.edu.cn or visit the joint conference website at: http://iiuse.seu.edu.cn/frprcs12_apfis2015/

Zhishen Wu, Conference Chair
Gang Wu and Xin Wang, Conference Co-Chairs
International Institute for Urban Systems Engineering/School of Civil Engineering
Southeast University

CICE 2014 Best Paper – Repair Application

Cyclic Interface Behavior of External Composite Reinforcements: A Coupled Damage-Plasticity Model

Pietro Carrara and Laura De Lorenzis
Technische Universität Braunschweig, Germany
p.carrara@tu-braunschweig.de
l.delorenzis@tu-braunschweig.de

Introduction

During the past two decades, fiber reinforced polymers (FRP) in the form of externally bonded or near-surface mounted reinforcement have emerged as one of the most attractive strengthening techniques for civil engineering structures made of a variety of materials (i.e. concrete, steel, masonry or timber). Several studies pointed out that debonding failure mechanisms often control the capacity of the strengthened member. Some of these mechanisms are triggered by the bond shear stresses generated at the interface as a result of the composite action. In the case of concrete substrates, among the possible debonding failure mechanisms (e.g. shear failure of the adhesive, failure of the interface between adhesive and substrate, cohesive failure of the substrate), the most likely to occur when the reinforcement is correctly applied is cohesive failure of the substrate. This failure involves the formation of micro-cracks at the interface level, which gradually coalesce, resulting in a macro-crack that propagates a few millimeters inside the substrate until complete loss of bond of the composite system. Similar processes occur for substrates of other quasi-brittle materials (e.g. masonry and rarely timber); however, the case of concrete is the primary concern of this paper. The aforementioned behavior has been widely studied in the case of monotonic loading (Yuan et al., 2004, Carrara and Ferretti, 2013), and simple cohesive zone models based on a mode-II law have been found to accurately describe the bond mechanics between the FRP and its support (Yuan et al., 2004).

Until recently, little attention has been paid to cyclic loading, despite the significance of this issue e.g. for the strengthening of bridges. Recent studies reporting cyclic pull-out tests on bonded joints (Ko and Sato, 2007, Carloni et al, 2012), demonstrated that fatigue can trigger debonding failure even for an applied force smaller than the bond strength of the joint in monotonic conditions. Failure results from the accumulation of irreversible damage at the interface due to fatigue micro-cracking, which leads to a gradual deterioration of the bond (Roe and Siegmund, 2003 and Martinelli and Caggiano, 2014). Some studies suggest the existence of a load and a displacement threshold under which fatigue failure is prevented (Roe and Siegmund, 2003).

To date, fatigue life assessment is largely based on the Wöhler curve or the Paris law. These methods are empirically based, since the parameters of the evolution laws are typically not defined through mechanically sound rules but rather calibrated following a case-by-case approach. Hence, any deviation from the ideal conditions underlying each theory can lead to a significant mismatch in the predictions (Roe and Siegmund, 2003). An alternative approach is the employment of numerical models. Some of them (e.g. Ko and Sato, 2007) consider, beside classically measured mechanical properties, additional parameters without a direct physical meaning that need a case-by-case experimental calibration similarly to the aforementioned empirical laws. Thus, the accuracy of these models outside the range of variables of the tests used to calibrate the parameters is open to question. A few authors adopted fracture, damage or plasticity theories (either coupled or not) to define the interface law (Roe and Siegmund, 2003, Martinelli and Caggiano, 2014). Here, the local hysteretic response is ruled by internal parameters that should be physically explained. However, some of these models are not necessarily suitable for FRP reinforcements, having been proposed for very different material systems; moreover, they are only amenable to finite element implementation (Roe and Siegmund, 2003). On the other hand, the available simple models proposed for FRP strengthening (Martinelli and Caggiano, 2014) are not formulated in a thermodynamical framework, which opens the question of their energetic consistency.

The present work proposes a new numerical model able to simulate the interface behavior of a bonded joint between an FRP laminate and a quasi-brittle substrate under cyclic loadings. Pure mode-II interface loading conditions are assumed. The interface law is defined by means of an admissible domain coupling linear softening and damage. Under monotonic loading, a mode-II bilinear cohesive relationship is reproduced and well-known results are recovered (Yuan et al. 2004). Post-failure friction and interlocking are neglected. The capability of the model to correctly predict the local and global behavior of an FRP bonded

joint is demonstrated comparing the numerical predictions with available experimental results.

Proposed Model

Hereafter the main characteristics of the proposed model are summarized. The adopted notations and sign conventions are depicted in Fig. 1a. An FRP laminate with cross section $A_f=b_f t_f$, initial bond length l_b and Young's Modulus E_f is considered. The laminate is modeled as linearly elastic, while the supporting substrate is assumed rigid because its stiffness is typically much larger than that of the composite element. A zero-thickness interface layer lumps the interface volume where the non-linear debonding phenomena take place and the interface law presented hereafter rules its behavior.

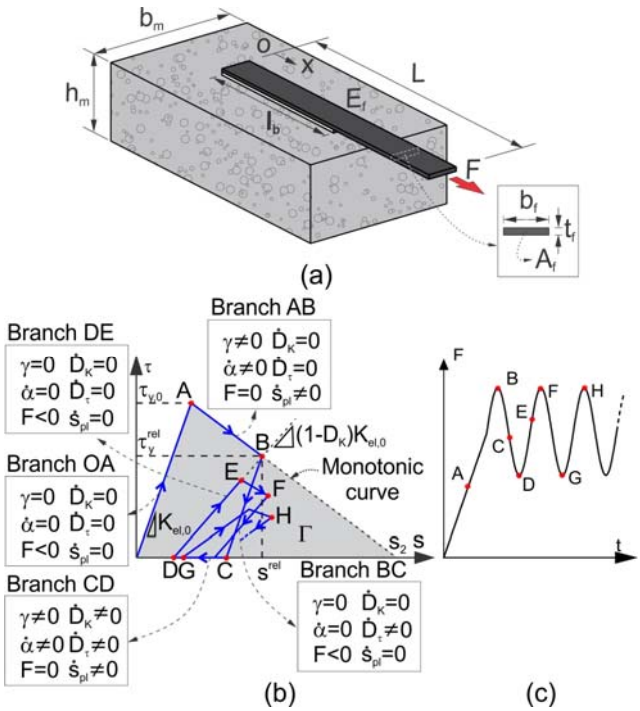

Fig. 1 (a) Scheme of a pull out test, (b) schematic representation of the interface law (c) example of a cyclic load history.

No sign inversion of the applied cyclic load is considered, as this is the situation for which test results are available. The bond shear stresses, τ, are restricted to assume non-negative values coherently with the experimental evidence (Fig. 1b). As mentioned earlier, a bilinear local τ-s law is assumed under monotonic loading, s being the interface relative displacement between FRP and support (slip).

Governing equations

Neglecting bending effects, local equilibrium of a bonded FRP element can be written as

$$\frac{dN}{dx} = \tau(s,t)b_f \tag{1}$$

with N as the FRP axial force and $\tau(s,t)$ as the bond shear stress expressed as a function of the slip s and the time t. Since the support is taken as rigid, the slip s coincides with the FRP displacement u_f. Simple kinematics and the linear elasticity assumption for the FRP lead to

$$\frac{ds}{dx} = \frac{du_f}{dx} = \frac{N}{E_f A_f} \tag{2}$$

Eqs. 1-2 constitute the system governing the debonding process. Provided a constitutive law $\tau(s,t)$ and a proper set of boundary conditions, this system can be solved by means of a finite difference method as done in Carrara and Ferretti (2013).

Interface behavior

As classically done in plasticity theories (e.g. Lemaitre, 1985), the slip decomposition $s=s_{el}+s_{pl}$ is adopted, where s_{el} and s_{pl} are respectively the elastic and plastic portions of the total slip. To reproduce the observed hysteretic behavior, a cyclic interface law coupling damage and plasticity is proposed. The yield criterion reads as follows

$$F(\tau,R) = \left|\tau - q(R)\right| - q(R) \tag{3}$$

with $\tau = (1-D_K)K_{el,0}\left(s - s_{pl}\right)$

$$q(R) = \frac{(1-D_\tau)}{2}\left[\tau_{y,0} + R\right]h(s - s_{pl})$$

where $q(R)$ is a combined kinematic-isotropic hardening function, and R is the hardening thermodynamic force given by $R=K_{pl}\alpha$ with $K_{pl}<0$ as the softening modulus governing the slope of the monotonic softening law, and α as the internal hardening variable conjugate to R (note that "hardening" is here to be intended as "softening"). In term, $K_{el,0}$ is the initial linear elastic stiffness, $\tau_{y,0}$ is the initial (monotonic) bond strength (Fig. 1b) and $h(s-s_{pl})$ is the Heaviside step function $h(\xi)$ equal to 1 for $\xi>0$ and to 0 otherwise. Finally, D_K and D_τ are two damage parameters governing respectively the stiffness degradation and the bond strength reduction due to the cyclic actions (Fig. 1b).

The model thus contains the four internal variables s_{pl}, α, D_K and D_τ for which evolution laws must be defined. Introducing γ as plastic multiplier and assuming associated plasticity, the evolution laws of the plastic

variables α and s_{pl} are defined as $\dot{s}_{pl} = \gamma sign(\tau - q)$ and $\dot{\alpha} = \gamma(1-D_\tau)h(s-s_{pl})$, where $sign(\xi)$ is equal to -1, 0 or +1 respectively if $\xi<0$, $\xi=0$ or $\xi>0^+$. For the damage variables D_τ and D_K the following evolution laws are assumed

$$\dot{D}_\tau = -\frac{\langle \dot{s} \rangle_- \, h(\tau_0 - \tau_y)}{s_{f,u}} \tag{4}$$

$$\dot{D}_K = -\frac{\tau_y^{rel}(\hat{t})\dot{s}_{pl}}{K_{el,0}\left(s^{rel} - s\right)^2} h(-\langle \dot{s}_{pl} \rangle_-) \tag{5}$$

with $\dot{D}_j \geq 0$, $D_j = \min\left[1, \int_0^t \dot{D}_j dt\right]$

and $\dot{D}_K = 1$ if $\dot{D}_K > 1 + \frac{K_{pl}}{K_{el,0}}(1-D_\tau)^2$

where s is the current slip, $<>_-$ are the Macaulay brackets selecting the negative part of a number. $s_{f,u}$ is a fatigue endurance parameter defined as the sum of the unloading displacements prior to fatigue failure, $\tau_y=(1-D_\tau)[\tau_{y,0}+K_{pl}\alpha]$ is the current bond strength, while τ_y^{rel} and s^{rel} are respectively the yield bond stress and the slip at the end of the former loading/reloading phase where a plastic flow occurs (Fig. 1b).

The resulting interface law and the evolution of the main parameters are represented in Fig. 1b for the load history of Fig. 1c. Note that for monotonic load conditions the classical bilinear interface law and the corresponding results are recovered. The proposed model requires calibration of the monotonic bilinear interface law, and of the additional parameter $s_{f,u}$ that controls the fatigue endurance. The physical meaning of this parameter enables its calibration with experimental observations. Finally, the model satisfies the second law of thermodynamics in the form of the Clausius-Duhem inequality, for this proof and for many more details see Carrara and De Lorenzis (2014).

Simulation of Experimental Tests

Experimental data from Ko and Sato (2007) and Carloni et al. (2012) are here used to validate the proposed model. In both studies monotonic tests were also performed. Here, the maximum monotonic debonding force F_{max} is used to obtain the interface fracture energy Γ, while the bond strength $\tau_{y,0}$ and the slip at peak bond strength s_1 are estimated from the published monotonic bond-slip curves. The ultimate slip s_u follows from Γ and $\tau_{y,0}$, whereas the elastic stiffness $K_{el,0}$ is computed from $\tau_{y,0}$ and s_1. In absence of direct measurements, the parameter $s_{f,u}$ is calibrated from the cyclic experimental results. The parameters used for the numerical analyses are summarized in Table. 1.

Table 1 Model parameters used in numerical analyses.

	C14[(a)]	A25[(a)]	DS-F1[(b)]
$K_{el,0}$ (MPa/mm)	364.5	364.5	162.5
τ_0 (MPa)	3.50	2.25	6.50
s_u (mm)	0.286	0.711	0.369
Γ (mJ/mm^2)	0.50	0.80	1.20
K_{pl} (MPa/mm)	-12.25	-3.16	-17.60
$s_{f,u}$ (mm)	3.0	7.0	30.0
[(a)]Ko and Sato (2007); [(b)] from Carloni et al. (2012)			

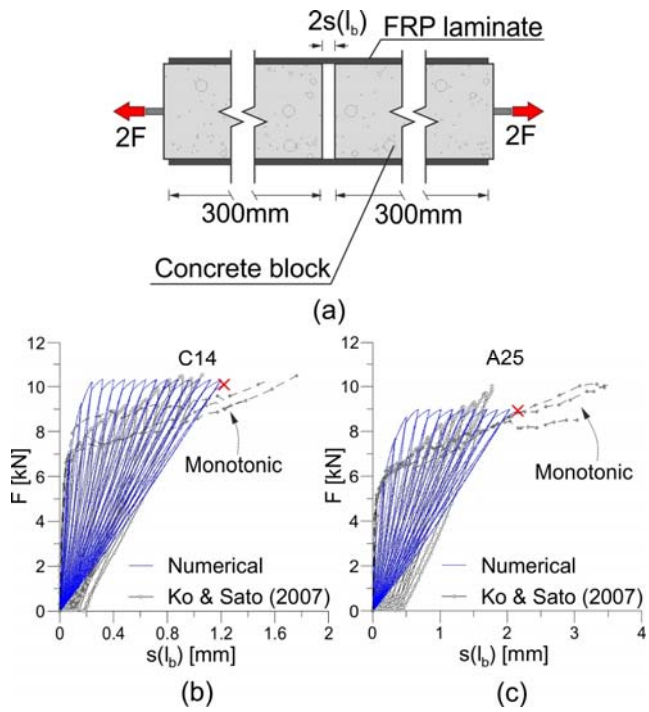

Fig. 2 – Comparison with the experimental results from Ko and Sato (2007): (a) scheme of the specimens, (b) results for the specimen C14 and (c) results for the specimen A25.

Ko and Sato (2007) investigated cyclic loading with variable amplitude on concrete blocks with two symmetrically bonded FRP sheets (Fig. 2a). The geometry and material data are l_b=300mm, b_f=50mm, t_f=0.167mm and E_f=261GPa. Figs. 2b,c show the comparison between numerical and experimental data from the C14 and A25 tests. A satisfactory agreement is observable, although the slip recovery at complete unloading is underestimated. This is because for F=0 a residual slip at the loaded end would imply a constant value of slip along a portion of the plate (i.e. from the loaded end until the first undamaged section) because no strain variation would be present. This residual

displacement applied to the undamaged part of the interface, in absence of friction phenomena, would imply non-zero bond stresses, in contrast with the assumption of zero force in the FRP. Fig. 3 reports the interface laws obtained numerically at the loaded end. The degradation of the interface stiffness is observable as well as a slight reduction of the ultimate slip attained in comparison with the monotonic law.

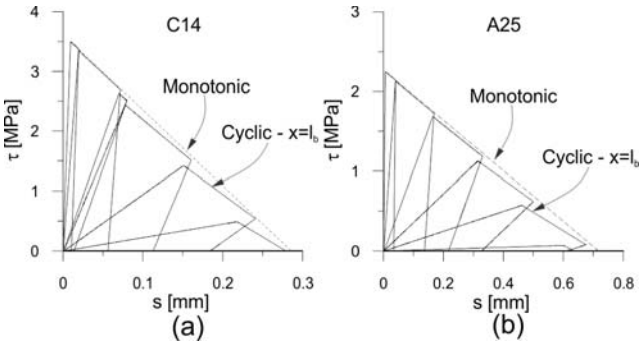

Fig. 3 – Numerical interface relationships for the tests in Ko and Sato (2007): (a) C14, (b) A25.

Carloni et al. (2012) investigated the bond deterioration under constant amplitude loading using the setup sketched in Fig. 4a. The geometry and material parameters are l_b=152mm, b_f=25mm, t_f=0.167mm and E_f=230GPa. A very good agreement between numerical and experimental results for the DS-F1 test is observable for both the global equilibrium curve (Fig. 4b) and the number of cycle to failure (Fig. 4c). Moreover, the trend of the maximum and minimum displacements at the loaded-end with the number of cycles is well reproduced (Fig. 4c). A slight underestimation of the displacement at the end of the unloading branch is still visible (Fig. 4b-c), but is less relevant than the one observed in Figs. 2b-c. In Fig. 5 the numerical local interface laws are depicted at different locations along the bond length (indicated with A-B-C in Fig. 4a). An embrittlement of the local cyclic behavior with respect of the monotonic behavior is observed (Fig. 5), however this does not affect significantly the maximum attained displacement at the loaded end (s_{max}) which is close to the monotonic one (Fig. 4b). Moreover, comparing the three curves for the points A-B-C is it interesting to note that the local interface law is significantly different from the monotonic curve near the loaded end, whereas this difference is less pronounced at a distance from the loaded end and does not vary significantly (i.e. Figs. 5b,c are similar).

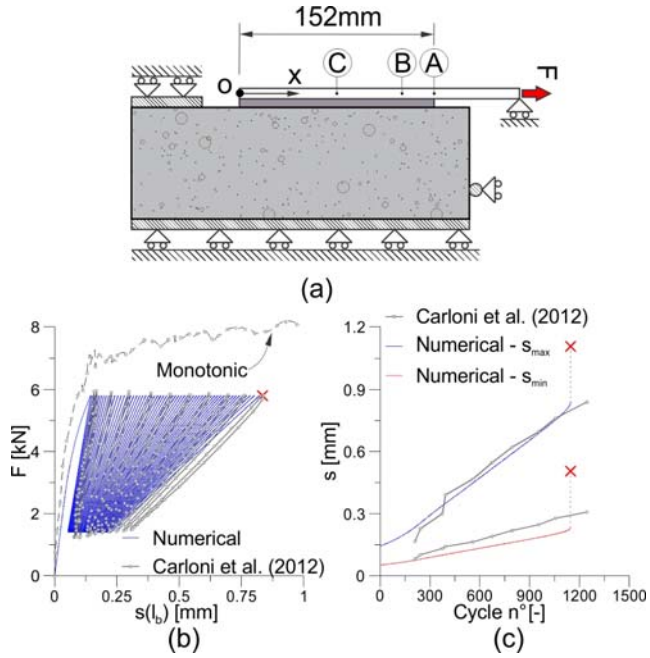

Fig. 4 – Results for the DS-F1 test from Carloni et al. (2012): (a) scheme of the specimens, (b) pull-out curves (1 cycle every 20 is plotted), (c) maximum and minimum displacements at the loaded end vs. number of cycles.

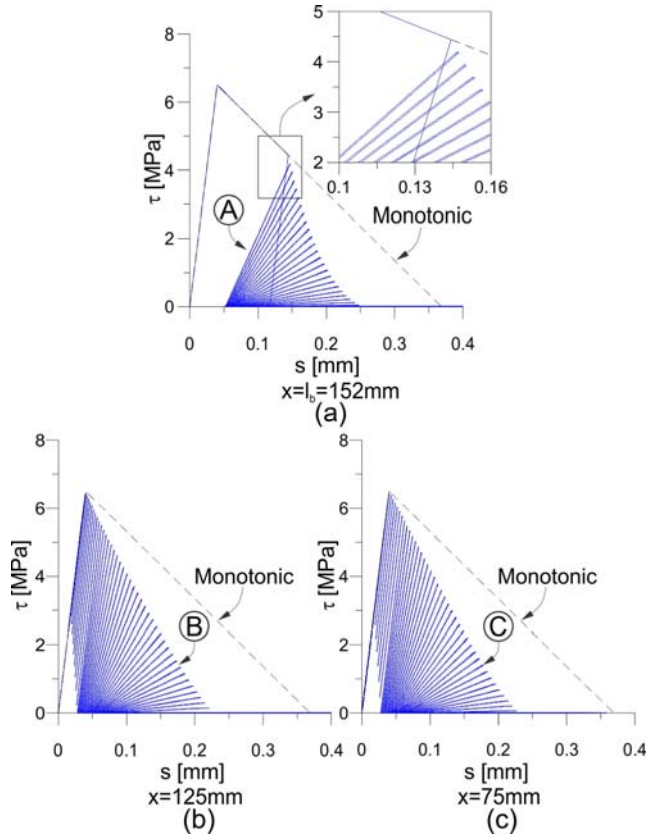

Fig. 5 – Numerical interface relationships for the DS-F1 test from Carloni et al. (2012) for the points highlighted in Fig. 4a (1 cycle every 10 is plotted): (a) point A, (b) point B and (c) point C.

Concluding Remarks

This contribution presents a novel model able to simulate the cyclic behavior of FRP reinforcement externally bonded on quasi-brittle materials. The interface behavior is described by means of a coupled plastic-damage model that degenerates into a bi-linear cohesive law for monotonic loading. The model considers pure mode-II loading with no inversion of the applied force. Damage is assumed to result from two components, one related to the stiffness degradation and the other related to the loss of bond strength. The model is thermodynamically consistent and requires calibration of one parameter, in addition to the monotonic mode-II interface law. The comparison of numerical predictions with experimental data from the literature demonstrates the capability of the model to correctly reproduce the global behavior in case of variable as well as constant amplitude load cycles. In particular, both the number of cycles prior to failure and the evolution of the maximum and minimum displacements at the loaded end are satisfactorily predicted. An effect of embrittlement of the local interface laws with respect to the monotonic law is observed. This however seems to exert a limited influence on the maximum displacement attained. While more analyses are needed to confirm and extend the obtained results, the proposed model appears a very promising tool to study the fatigue behavior of the externally bonded FRP reinforcement.

Acknowledgements

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Upcoming Conferences and Meetings

International Conference on Advances in Composite Materials and Structures, April 13-15, 2015, Istanbul, Turkey.
sites.google.com/site/cacmsistanbul2015/

Abstracts due September 15 2014

Early Registration Deadline November 30 2014

ICCM20 – 20th International Conference on Composite Materials, July 19-24, 2015, Copenhagen, Denmark. www.iccm20.org.

Early Registration Deadline March 15 2015

NOCMAT 2015 – Nonconventional Materials: Construction for Sustainability – Green Materials and Technologies, August 10-13, 2015, Winnipeg, Canada. umanitoba.ca/conferences/nocmat2015/

Abstracts due January 15 2015

SMAR 2015 – Third Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures , 7– 9 September 2015, Antalya Turkey. www.smar2015.org

Abstracts due November 30 2014

ADVANCED COMPOSITES IN CONSTRUCTION

ACIC 2015 – 7th International Conference in the Advanced Composites in Construction, 9–11 September 2015, Cambridge UK. acic-conference.com

Abstracts due November 21 2014

CAMX: Composites and Advanced Materials Expo, October 26-29, 2015, Dallas TX, USA. www.thecamx.org

JOINT CONFERENCE

FRPRCS-12 ***12th International Symposium on Fiber Reinforced Polymer for Reinforced Concrete Structures***, and

APFIS 2015 – 5th ***Asia-Pacific Conference on FRP in Structures***, December 14-16, 2015, Nanjing, China.

http://iiuse.seu.edu.cn/frprcs12_apfis2015/

Abstracts due January 15 2015

Concrete Solutions 2016, 5th International Conference on Concrete Repair, June 20-22, 2016, Thessaloniki, Greece.

7th International Conference on Advanced Composite Materials in Bridges and Structures, August 22-25, 2016 Vancouver, Canada.

CICE 2016 ***8th International Conference on FRP Composites in Civil Engineering***

December 2016, Hong Kong

CICE 2018 ***9th International Conference on FRP Composites in Civil Engineering***

July 2018, Paris

CICE 2014 Proceedings available on IIFC website SOON!

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CICE 2014, Vancouver, 20-22 August 2014

CICE 2012, Rome, Italy, 13-15 June 2012

APFIS 2012, Sapporo, Japan, 2-4 February 2012

CICE 2010, Beijing, China, 27-29 September 2010

APFIS 2009, Seoul, Korea, 9-11 December 2009

CICE 2008, Zurich, Switzerland, 22-24 July 2008

APFIS 2007, Hong Kong, 12-14 December 2007

CICE 2006, Miami, USA, 13-15 December 2006

BBFS 2005, Hong Kong, 7-9 December 2005

Composites Around the World

Pressure Infusion Lining System

Dan Warren, Warren Environmental Inc.
www.warrenenviro.com

As part of its role in providing clean and safe drinking water to the residents and businesses of Mesa Arizona, routine inspection revealed a deteriorated 14 m long segment of 42 in. (1066 mm) diameter prestressed concrete pipe in the line from the Pasadena Reservoir to the Val Vista Treatment Facility. Because the deteriorated segment passes through a developed area with limited clearance from existing homes, the City determined that removal and replacement using open-cut methods was not feasible. Additionally, the depth of the pipeline – about 8 m below ground – increased the cost and disruption of performing repairs by open digging.

An innovative trenchless alternative was adopted. Developed by Warren Environmental of Carver Massachusetts, the Pressure Infusion Lining System combines epoxy and a mandrel-formed carbon fibre lining to create a structural rehabilitation. The unique system was awarded the 2014 Joseph L. Abbott Jr Innovative Product Award based on its elimination of a) wet-out facilities; b) the need to transport weight restricted materials; c) the need for refrigerated storage on site; and d) the need for steam or boiler trucks – all common elements of conventional cured-in-place pipe lining systems. The system is also seamless, not requiring applications of individual plies to build out a desired thickness. For the 42 in. (1066 mm) pipe, the final system was approximately 5 mm thick, providing a structural repair without constricting the pipe diameter.

Mandrel-wound carbon liner inspected prior to installation

Application Steps

1. Prepare the pipeline removing accumulated scale and muck.

2. 'Spincast' using a robotic spray applicator (or human operator in larger pipes) a layer of Warren S-301 epoxy. S-301 is an NSF approved material having a 30 year history in water and wastewater applications.

3. Once the epoxy is applied – and before it cures – the carbon fibre roll is inserted. A bladder is positioned and inflated, forcing the liner into the epoxy layer. Pressure is maintained for about two hours.

During (left) and following (right) liner infusion

4. Once the epoxy cures, the reusable bladder is removed and a top coat of epoxy is applied to protect the liner from abrasion and scour.

Finished product

Spark testing and adhesions tests are conducted to ensure that there are no pinholes or voids behind the liner.

The Mesa project, marking the first installation of the system was completed in five days – within the allotted time to bring the pipeline back into service.

The Pressure Infusion Lining System can be installed in pipes from 100 to 3000 mm diameter and in lengths from 75 to 180 m depending on the diameter.

ASCE *Journal of Composites for Construction*

ASCE Journal of Composites for Construction
Volume 18, No. 5. October 2014.

Buckling of Built-Up Columns of Pultruded Fiber-Reinforced Polymer C-Sections

Giosuè Boscato, Carlo Casalegno, Salvatore Russo, and J. Toby Mottram

Serviceability Analysis of Concrete Beams with Different Arrangements of GFRP Bars in the Tensile Zone

Ronaldas Jakubovskis, Gintaris Kaklauskas, Viktor Gribniak, André Weber, and Mantas Juknys

Fatigue Behavior of GFRP Reinforcing Bars in Air and in Concrete

Martin Noël and Khaled Soudki

Shear Strength of FRP RC Beams and One-Way Slabs without Stirrups

T. Zhang, D. J. Oehlers, and P. Visintin

Prediction of Intermediate Crack Debonding Strain of Externally Bonded FRP Laminates in RC Beams and One-Way Slabs

H. M. Elsanadedy, H. Abbas, Y. A. Al-Salloum, and T. H. Almusallam

Flexural Strengthening of RC Beams with an Externally Bonded Fabric-Reinforced Cementitious Matrix

Saman Babaeidarabad, Giovanni Loreto, and Antonio Nanni

Environmental Aging Effect on Tensile Properties of GFRP Made of Furfuryl Alcohol Bioresin Compared to Epoxy

Amanda Eldridge and Amir Fam

Seismic Behavior of RC Shear Walls with Externally Bonded FRP Sheets: Analytical Studies

Carlos A. Cruz-Noguez, David T. Lau, and Edward G. Sherwood

FRCM Strengthening of Shear-Critical RC Beams

Rizwan Azam and Khaled Soudki

ASCE Journal of Composites for Construction
Volume 18, No. 6. December 2014.

Durability of Concrete Cylinders Wrapped with GFRP Made from Furfuryl Alcohol Bioresin

Amanda Eldridge and Amir Fam

Unified Design Method for Flexure and Debonding in FRP Retrofitted RC Beams

G. X. Guan and C. J. Burgoyne

Strength and Ductility Trends for Concrete Members Strengthened in Flexure with Carbon Fiber-Reinforced Polymer Reinforcement

Joseph Robert Yost and Robert E. Steffen

Mechanical Performance of the Wet-Bond Interface between FRP Plates and Cast-in-Place Concrete

Pu Zhang, Gang Wu, Hong Zhu, Shao-ping Meng, and Zhi-shen Wu

Strength of Hollow Concrete Masonry Reinforced with Sprayed Glass-Fiber-Reinforced Polymer

Guilherme A. Parsekian, Fernando S. Fonseca, and Nigel G. Shrive

Effect of Reinforcement Ratio on Transverse Early-Age Cracking of GFRP-RC Bridge Deck Slabs

Amir Ghatefar, Ehab El-Salakawy, and M. T. Bassuoni

Predicting Stress and Strain of FRP-Confined Square/Rectangular Columns Using Artificial Neural Networks

Thong M. Pham and Muhammad N. S. Hadi

Parametric Study of FRP Plate Debonding Using Global Energy Balance

G. X. Guan, C. J. Burgoyne, and M. Achintha

FRP Slab Capacity Using Yield Line Theory

Shobeir Pirayeh Gar, John B. Mander, Monique Head, and Stefan Hurlebaus

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Tel: (613)533-6000 (Ext. 79359) • Fax: (613)533-2128
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By submitting this application you agree to share your contact information with fellow IIFC members and any conference/organization associated with IIFC.

FRP INTERNATIONAL

the official newsletter of the International Institute for FRP in Construction

FRP International needs your input…

As IIFC grows, we seek to expand the utility and reach of *FRP International*. The newsletter will continue to report the activities of IIFC and focus on IIFC-sponsored conferences and meetings. Nevertheless, we also solicit short articles of all kinds: research or research-in-progress reports and letters, case studies, field applications, book reviews or anything that might interest the IIFC membership. Articles will generally run about 1000 words and be well-illustrated. Submissions may be sent directly to the editor. Additionally, please utilize *FRP International* as a forum to announce items of interest to the membership. Announcements of ***upcoming conferences***, ***innovative research or products*** and ***abstracts from newly-published PhD dissertations*** are particularly encouraged. All announcements are duplicated on the IIFC website (www.iifc-hq.org) and all issues of the *FRP International* are also available in the archive at this site.

FRP International is yours, the IIFC membership's forum. The newsletter will only be as useful and interesting as you help to make it. So, again, please become an *FRP International* author.