IIFC

FRP INTERNATIONAL

the official newsletter of the International Institute for FRP in Construction

Vol. 10, No. 1, January 2013

Editor's Note

Welcome to the 20th year of *FRP International* and the 10th anniversary of the formation of IIFC and its adoption of *FRP International* as its official newsletter.

January 1993, Vol.1, No. 1

May 2004, Vol. 1, No. 1 as official IIFC newsletter

July 2012, Vol. 9, No. 3

In this issue, we take a brief look back at 20 and 10 years ago in the FRP community and a look forward at one of the issues – durability – that continues to bedevil FRP researchers, manufacturers and specifiers.

Once again, I want to stress the importance of our readers to the success of *FRP International* and the IIFC as a whole. ***Get involved!*** Write an article, case study or product report for *FRP International*. *FRP International* is delivered electronically to the inboxes of all IIFC members – arguably, this may be the best venue to have your work, project or product seen by a highly focused and interested target audience. Please also be sure to complete the newsletter and website utility survey (below).

Kent A. Harries, Editor
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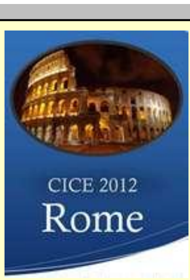


The complete Proceedings of CICE 2012 are now available on the IIFC website: www.iifc-hq.org.

IIFC requests your input...

In an effort to better serve IIFC membership, the IIFC Executive Committee is asking all IIFC members and readers of *FRP International* to complete a brief survey addressing the utility of FRP International and the IIFC website: www.iifc-hq.org. We ask that you take three minutes of your time to complete the online survey located at:

http://www.surveymonkey.com/s/FB8WBV7

20th Anniversary of *FRP International*
10th Anniversary of IIFC

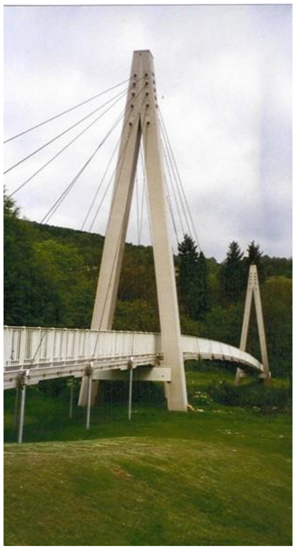
Twenty years ago, in January 1993, Volume 1, Number 1 of *FRP International* appeared. Edited by Prof. Sami Rizkalla, then at the University of Manitoba, *FRP International* began as one of the technical activities of the American Concrete Institute (ACI) Committee 440 to achieve advancement through knowledge. Professor Rizkalla was supported by Associate Editors representing the four professional organisations particularly active with FRP materials at the time: Prof. Tony Nanni (representing ACI), Prof. Larry Bank (representing ASCE), Prof, Marie-Anne Erki (representing CSCE) and Hiroshi Mutsuyoshi (representing JCI). Professor Rizkalla served as Editor for ten years. In May 2004, Volume 1, Number 1 *of FRP International* appeared again, recast as the official newsletter of the nascent International Institute for FRP in Construction (IIFC). Prof. Vistasp Karbhari served as the editor through 2006; Dr. Rudolf Seracino was editor from 2007 to 2010; and finally Dr. Kent Harries took over as Editor in January 2011. This issue marks the 20th volume of *FRP International*, the 10th as the official newsletter of the IIFC. To celebrate this milestone, a few statistics are in order:

Over 20 years, the 56 issues of *FRP International* have contained 194 research articles and 283 case studies or product reports. Articles have originated from 29 countries. Interestingly, articles focusing on external FRP reinforcement have outnumbered those addressing either internal FRP reinforcement or FRP structures and shapes by about 2 to 1. A complete index of all *FRP International* articles is maintained on the IIFC website.

Considering the milestone anniversaries of both *FRP International* and IIFC, over the course of this year we will feature a few items from twenty and ten years ago… The use of FRP in Construction has come a long way in a very short time. Why it only seems like yesterday…

Twenty Years Ago…

The January 1993 *FRP International* was introduced by Prof. Raymond M. Measures of the Institute of Aerospace Engineering at the University of Toronto. "Dr. Measures, a pioneer and world renowned researcher, succeeded in demonstrating that the marriage of fibre optic sensors, lasers, micro-electronics, integrated fibre optics, and artificial intelligence with the use of new advanced composite materials permits these materials to be made into ***Smart Structures***."



Also in January 1993, the completion of the "World's First Major FRP Bridge" was announced [later described in Vol. 1, No 3]. The 64 m long cable-stayed Aberfeldy Footbridge over the River Tay (pictured) was designed by Peter Head of Maunsell and constructed by students of the University of Dundee. The structure has remained iconic to the FRP industry and is now becoming subject of renewed studies on FRP durability. Recently Dr. Tim Stratford published an article *The Condition of the Aberfeldy Footbridge after 20 Years in Service* in the Proceedings of Structural Faults and Repair 2012.

Ten Years Ago…

The inaugural IIFC-sponsored *FRP International* contained a thorough review of the international state-of-the-art in FRP for construction. Articles described the first FRP road bridge in Australia; the development of the first 'all composite' bridge deck in Europe – the ASSET bridge deck; the strengthening of the West Gate Bridge in Melbourne, Australia [see West Gate Bridge, *FRP International*, Vol. 8, No. 3, July 2011]; field applications of Prof. Measures' concepts of smart structures by ISIS Canada; and FRP methods for repairing cast and wrought iron and steel structures in the UK [see FRP Repair of Steel and Cast Iron Structures in Great Britain, *FRP International*, Vol. 8, No. 3, July 2011]. Other articles featured bridge structures in Denmark, Canada, USA and building structures in Japan and Switzerland.

Report from CECOM 2012

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The 1st International *Conference on Civil Engineering Infrastructure Based on Polymer Composites*, CECOM 2012 organized by Lodz University of Technology, Mostostal Warszawa S.A., Targi w Krakowie Ltd and Rzeszow University of Technology was held in conjunction with the 3rd International Kompozyt-Expo® Trade Fairs on 22–23 November 2012 in Krakow, Poland.

Three research projects: TULCOEMPA, Trans-IND [see *FRP International* Vol. 9, No. 2] and PANTURA co-supported this international forum which allowed the almost 70 participants to exchange recent advances in both research and practice. Participation of civil engineers, manufacturers of composite materials, designers, and researchers from around the world enabled interesting and inspiring technical discussions.

The latest worldwide applications of composite materials in the construction industry and civil engineering infrastructure were presented in six sessions over two days in the following areas:

- Flexible methods for manufacturing FRP for construction;
- Concrete structures reinforced or prestressed with FRP;
- FRP strengthening of concrete, steel, masonry and timber structures; and,
- Hybrid and other FRP structures.

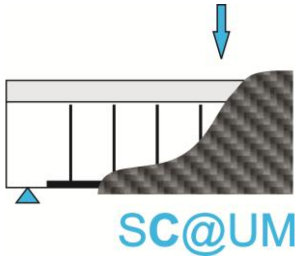
Four invited Keynote lecturers: Ane de Boer (Holland), Bjorn Taljsten (Sweden), Jin-Guang Teng (China) and Renata Kotynia (Poland) inspired the FRP audience.

The Chair of the IIFC Advisory Committee Prof. J.G. Teng represented IIFC at the CECOM2012 conference with an official lecture reviewing IIFC history, benefits of membership and worldwide activity.

The CECOM2012 proceedings organized by Lodz University of Technology will be available to all IIFC members through the IIFC website in the near future.

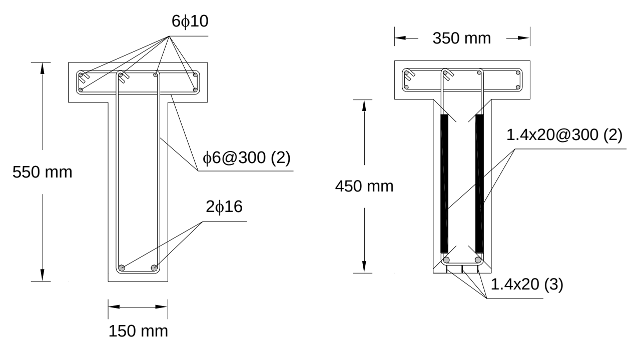
As a chair of the conference, I am deeply thankful to the members of the Organizing Committee for their efforts and valuable contributions that have led to the success of this conference.

SCatUM: CFRP Strengthening Challenge at FRPRCS-11



A competition to accurately predict the load deflection response of a CFRP-strengthened reinforced concrete tee-beam will be held in conjunction with FRPRCS-11 (June 26-28, 2013, Guimarães City, Portugal. www.frprcs11.uminho.pt).

A prototype reinforced concrete tee-beam will be subjected to initial loading causing a mid-span deflection of L/350, which will introduce an initial damaged state representative of service conditions. Subsequently, the beam will be strengthened for both shear and flexure with near-surface mounted (NSM) CFRP strips. Following strengthening, the beam will be reloaded to failure.



prototype tee-beam *NSM-CFRP strengthening*

Participants are challenged to present an accurate model of the nonlinear load-deflection response of the NSM-CFRP strengthened prototype tee-beam through failure. The accuracy of the predicted responses, the innovative character of the proposed model, the creativity and theoretical soundness of the model principles will be evaluated by the competition scientific committee.

The results of the competition will be presented in a special session at FRPRCS-11 giving visibility and emphasising the most creative and innovative aspects of the proposed models. Three prizes of €1000, €500, and €250 will also be awarded.

The competition is open to teams of up to three students. Applicants must register by February 1, 2013.

Competition rules and entry packages are available at:

http://www.frprcs11.uminho.pt

JEC Construction and Building Forum

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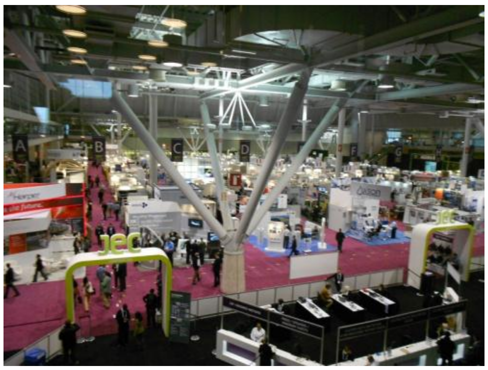
IIFC President Larry Bank represented IIFC at the Construction & Building Forum held at the recent JEC Innovative Composites Summit held at the Boston Convention and Expo Center November 7-9, 2012.



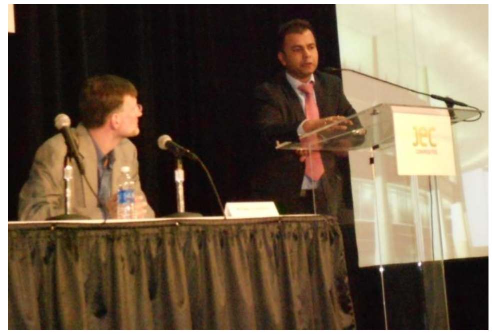
JEC Expo Floor

The forum which was billed as intending to "… Advance the understanding and application of composites in construction and building," was well attended with 50-70 attendees mostly from industry. Question and answer periods followed each speaker.

IIFC President Bank was the first speaker and reviewed the history of IIFC and explained the many benefits of participating in IIFC to the attendees. He then gave a quick overview of key activities in FRP Composites for Construction over the last 25 years.

He was followed by Professor Nicholas Dempsey who gave a very informative talk on FRP Design with the 2009/2012 International Building Code (IBC). He emphasized to the audience that FRP materials are now recognized as construction materials by the IBC allowing for easier use in building construction. He also indicated that with appropriate design and testing many FRP products could pass mandatory fire testing standards for use in buildings.

Mr. Anurag Bansal, Head of the Manufacturing Process Department Innovation and Development at Acciona Infraestructuras, Madrid, Spain spoke next. Mr. Bansal gave an overview of a number of pedestrian and highway bridges constructed in Spain in recent years using FRP composite girders and elements. He then described the construction of a carbon fiber cable stressed-ribbon pedestrian bridge and the lessons learned from this project. [see FRP Girder Bridges: Lessons Learned in Spain in the Last Decade, *FRP International* Vol. 9, No. 4, October 2012]



Anurag Bansal of Acciona Infraestructuras addressing a question from forum chair, Nicholas Dembsey of Worcester Polytechnic Institute, Worcester MA USA

The next speaker was a respected industry leader in pultruded composites in the US, Mr. Glenn Barefoot, Vice President, Business Development & Marketing at Strongwell in Bristol, VA. Mr. Barefoot reviewed the history of pultrusion and discussed some new developments in the industry especially the move toward die-infusion processing systems as an alternative to conventional open-bath processing.

The final talk in the informative session was by Dr. Woodrow Holley of KaZaK Composites, Woburn, MA. Mr. Holley spoke about the development of an innovative building panel that incorporates Phase Change Materials (PCMs) in the core that his company hopes can increase market penetration due to HVAC energy savings from the PCMs in the panel.

CICE 2012 Proceedings available on IIFC website

The complete Proceedings of CICE 2012 are now available on the IIFC website: www.iifc-hq.org.

All proceedings of IIFC-sponsored conferences presently archived on the IIFC website are:

CICE 2012, Rome, Italy, 13-15 June 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

This article is a technical submission to FRP International *focusing on performance of FRP systems subject to environmental conditioning.*

Environmental Resistance Factors Derived from Experimental Data

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When designing with FRP materials, it is important to distinguish between material resistance factors, load reduction factors, and environmental reduction factors. This paper discusses only the latter, given the notation C_E in ACI 440.2R (2008). The ACI-prescribed C_E values are given in Table 1.

Table 1 C_E values prescribed by ACI 440.2R-08.

Exposure	CFRP	GFRP
interior exposure	0.95	0.75
exterior exposure	0.85	0.65
aggressive exposure	0.85	0.50

Conventionally, the C_E factor is applied to FRP strength (i.e., $C_E F_u$) and strain capacity ($C_E \varepsilon_u$) but not modulus. The results of the present study call into question this convention, and demonstrate that strength and modulus are affected while strain capacity is not significantly affected by environmental conditioning. Additionally, the C_E factor is typically only applied to material properties and not when determining bond capacity. This study shows that environmental exposure has a greater effect on bond behaviour than on FRP strength or modulus. Finally, this study also indicates a difference in performance between preformed and hand layed-up FRP with the preformed FRP demonstrating superior durability. This difference between manufactured and hand lay-up materials reflects issues of quality control and should not be surprising. Nonetheless, existing ACI 440.2R guidance does not acknowledge this difference, effectively penalizing the use of preformed materials.

The objective of this work is to establish a basis for recommending environmental reduction factors suitable for design of externally bonded FRP materials. This goal is achieved based on the results of a database having 64 permutations of FRP material, test method, and environmental conditioning (Cromwell *et al.* 2011) described in the following sections.

FRP Material Systems Considered

Three commercially available FRP systems were included in this study: 1) a preformed unidirectional CFRP plate; 2) a unidirectional carbon fibre fabric; and 3) a unidirectional glass fibre fabric. The carbon and glass fabrics were hand layed-up into their CFRP and GFRP forms using a compatible two-part saturating resin. When bonded to concrete, a layer of resin was used to prime the concrete surface prior to adding the saturated fabric sheets. The CFRP plate was bonded to the concrete using a compatible two-part structural epoxy. Experimentally determined material properties of all three systems are given in Table 2. FRP modulus and strength are given in terms of force per unit width of FRP (N/mm). This approach is consistent with that now promulgated by ASTM D7565 and normalizes for FRP thickness which varies for a hand layed-up fabric system. In essence, the values reported are E x t and F_u x t, respectively.

Table 2 FRP material properties.

Property	CFRP plate	CFRP fabric	GFRP fabric
material thickness (mm)	1.14	varies with lay-up	
ASTM D3039 tensile strength, F_u x t (N/mm)	2550	650	330
ASTM D3039 modulus of elasticity, E x t (kN/mm)	142	58	18
ASTM D3039 ultimate strain, ε_u (%)	1.88	1.06	1.87
ASTM E831 CTE @ 20°C (10^{-6}/°C)	1.48	3.94	13.77
ASTM D4065 glass transition temperature, T_g (°C)	150	52	45

Experimental Program

An extensive experimental program investigating the behaviour of the three FRP systems (Table 2) subjected to nine environmental conditioning protocols (Table 3) was conducted. The effect of environmental conditioning was assessed using four standard test methods:

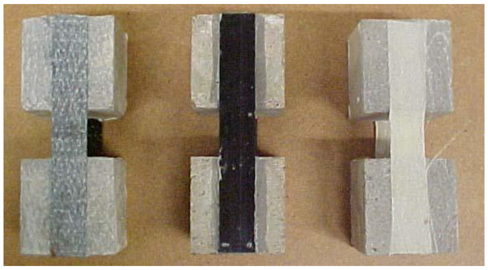
Tension Test: Tension capacity parallel to the fibre was determined using ASTM D3039. Baseline and conditioned specimens were cut using a water-cooled diamond blade into coupons 254 mm long by 25.4 mm. 50 mm long fiberglass gripping tabs were adhered to each end. Tension tests on the baseline specimens also provided fundamental material properties reported in Table 2.

Table 3 Environmental exposures tested.

Exposure	Duration	Description
Baseline	all	22°C @ 70%RH
ASTM D2247 Water	1000, 3000 & 10000h	100% RH @ 38°C
ASTM D1141 Salt Water	1000, 3000 & 10000h	Immersion in salt water @ 22°C
Alkaline	1000, 3000 & 10000h	Immersion in pH 9.5 $CaCO_3$ solution @ 22°C
ASTM D3045 Dry Heat	1000 & 3000h	60°C
ASTM C581 Diesel	4h	Immersion in diesel fuel @ 22°C
ASTM G23 Weathering	1000 cycles (4000h)	2h of UV @ 63°C followed by 2h @ 100% RH
Freeze-Heat	20 cycles (480h)	9h @ -18°C followed by 15h @ 100% RH @ 38°C
[1]ASTM C666 Freeze-Thaw	360 cycles (1583h)	70min @ -18°C followed by 70 min @ 4.5°C and UV

Short Beam Shear Test: ASTM D2344 short beam shear (SBS) test provided interlaminar shear strength for the preformed CFRP plate material only. Specimens were cut using a water-cooled diamond blade into coupons 19 mm long by 6.4 mm wide. The specimens were loaded in three-point flexure over a span of 12.7 mm.

Bond to Concrete: Bond test specimens (Fig. 1) consisted of two 51 mm concrete cubes spaced 25 mm apart bonded together using 19 mm wide by 127 mm long FRP strips on opposing faces. The bonded length of FRP on both cubes was 38 mm. The average 56-day compressive strength for all 192 cubes was 30 MPa. Custom-made U-shaped collars were used to grip opposing cubes in a universal test machine and tension was applied in displacement control at a rate of 2.2 mm/min.



CFRP fabric CFRP plate GFRP fabric

Figure 1 FRP bond test specimens.

Beam Flexure: Sixteen concrete beams 154 mm deep by 203 mm wide by 2440 mm long reinforced internally with two #3 (9.5 mm) bars, top and bottom, and U shaped W2.9 (4.9 mm) deformed wire stirrups at 152 mm centres were fabricated and tested in three-point flexure over a span of 2288 mm. The concrete compressive strength determined at the age of testing was 38 MPa. A single 2130 mm long layer of FRP was applied to each beam: for the CFRP plate, a 102 mm wide plate was bonded to the beam soffit; the CFRP fabric repair was 152 mm wide and the GFRP fabric was 305 mm wide resulting in it extending 51 mm up each side of the beam. The FRP details were not comparable in terms of strengthening effect (nor were they intended to be); the objective of this study was only to draw comparisons between similar beams subjected to different environmental conditioning. Beam tests were only subject ASTM C666 freeze-thaw exposure.

Results of Experimental Program

A summary of the performance of all specimens subject to environmental conditioning is provided in Table 4. Reported values are normalized by those obtained from the companion baseline tests.

CFRP Plate

The preformed CFRP plate material was relatively unaffected by the environmental conditioning conducted. As a performed product, the CFRP plate system has better consistency and quality and has cured since its manufacture. Additionally, a resin-rich outer layer protects the underlying carbon tows from exposure. Of note is the consistent improvement in modulus and strength with increased exposure to water at 38°C. This observation is likely indicative of continued post-cure. Due to the relatively low CTE of the CFRP plate (Table 2), few potentially damage-causing residual stresses are likely to develop due to elevated post-cure temperature; therefore, few detrimental effects are observed. These results, and the relatively inert behaviour when exposed to salt water, demonstrate that the resin-rich outer layer of the CFRP plate inhibits water absorption and is resistant to combined exposure (weathering).

CFRP Fabric

The hand layed-up CFRP fabric also performed relatively well under the environmental conditioning conducted. The greater variation compared to the CFRP plate can be partially attributed to the hand lay-up process. Some improvement in performance is evident in the conditioning methods that involved elevated temperature; this increase may be attributed the post-cure. However, there is also evidence of water absorption that negatively affects the system performance. For instance, the tension properties of the CFRP fabric are improved following 1000h exposure to 38°C water (attributed to post-cure); however, the performance degrades at longer exposures indicating eventual absorption. In this case, the elevated post-cure temperature may result in some microcracking associated with temperature-induced residual stress allowing absorption to take place. The additional detrimental effects of salt are also apparent in the behaviour of the CFRP fabric.

GFRP Fabric

The GFRP fabric was less durable than the CFRP products. No post-cure resulting from elevated temperature was evident, and the detrimental effects of absorption are readily apparent. As may be expected, the GFRP was particularly affected by exposure to an alkaline environment. Glass fibre in GFRP applications is known to degrade in an alkaline environment; for this reason the integrity of the surrounding resin matrix is critical to good performance. A relatively high CTE can lead to matrix cracking allowing absorption of concrete pore water with its incumbent alkalinity. The GFRP also indicated deterioration under both elevated temperature environments. This decline may be an indication that these environments exposed the specimens to temperatures greater than their glass transition temperature, T_g. If this is the case, deterioration is expected to be due to the phase change in the polymer matrix. This effect was not seen in the CFRP fabric specimens that did have a marginally greater value of T_g.

Glass Transition Temperature and Water Absorption

Single specimens of all three FRP materials from each conditioning regime were tested to assess any shift in T_g (Pack 2003). In no case was a significant change in T_g recorded. However, in those specimens where absorption was suspected, distinctive peaks at 0° and 100°C were noted, corresponding to the freezing and boiling points (phase changes) of the absorbed water. This confirmed the hypothesis that absorption was present in both FRP fabrics although not in the CFRP plate material.

Table 4: Average measured properties normalized to those obtained for baseline exposure.

		Exposure														
		Water 1000h	Water 3000h	Water 10000h	Salt Water 1000h	Salt Water 3000h	Salt Water 10000h	Alkaline 1000h	Alkaline 3000h	Alkaline 10000h	Heat 1000h	Heat 3000h	Diesel	Weathering	Freeze-Heat	Freeze-Thaw[e]
CFRP Plate	**E x t**[a]	**0.96**	0.97	1.06	1.01	1.00	1.03	1.02	**0.96**	1.03	1.01	1.05	1.02	0.99	0.99	-
	F_u x t[a]	1.05	1.09	1.15	1.02	1.07	1.12	1.02	1.04	1.13	1.06	1.06	1.03	1.02	1.03	-
	ε_u[a]	1.02	1.04	1.09	**0.84**	1.02	1.07	0.97	0.95	1.02	1.01	1.00	0.96	1.02	0.97	-
	F_{SBS}[b]	1.01	1.02	0.98	1.05	1.03	0.98	1.01	1.00	1.01	1.04	1.07	1.03	**0.94**	0.97	-
	bond[c]	1.07	1.14	1.18	1.17	1.30	0.94	1.16	1.18	0.98	**0.91**	0.98	1.00	-	1.15	-
	flex[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.94
CFRP fabric	**E x t**[a]	1.12	0.98	1.05	1.10	0.98	1.14	1.09	1.02	**0.90**	0.98	1.10	1.00	1.03	1.12	-
	F_u x t[a]	1.26	**0.92**	1.08	1.22	0.97	0.97	1.22	0.97	0.97	1.17	1.18	**0.92**	1.20	1.14	-
	ε_u[a]	1.14	1.01	1.13	1.22	0.99	**0.84**	1.17	1.06	1.09	1.06	1.16	1.13	1.30	1.19	-
	bond[c]	0.91	1.26	1.16	1.29	1.29	1.13	1.13	1.40	1.44	0.61	**0.60**	1.00	-	1.28	-
	flex[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.02
GFRP fabric	**E x t**[a]	1.00	1.00	1.00	1.06	**0.94**	**0.94**	1.00	1.00	1.00	1.06	1.00	1.00	**0.94**	1.00	-
	F_u x t[a]	0.91	**0.82**	0.97	1.06	0.88	0.94	0.85	0.85	0.91	0.88	0.94	0.94	0.88	1.00	-
	ε_u[a]	0.94	0.83	1.01	0.96	0.89	1.03	0.81	0.96	1.07	**0.79**	0.87	1.01	0.90	0.96	-
	bond[c]	1.09	0.87	1.01	1.10	1.11	0.87	0.90	0.83	**0.52**	1.05	1.01	1.06	-	1.15	-
	flex[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.97

lowest observed values are presented in bold text; all values are average of four tests except freeze-thaw (2 tests)
[a] obtained from D3039 tension test; [b] obtained from D2344 short beam shear test; [c] obtained from bond test
[d] obtained from flexural beam test; [e] unretrofit control beams = 0.92

Bond to Concrete

Bond to concrete is an interface property and not itself affected by the deterioration of the FRP material. Certainly, the FRP may deteriorate to a degree where failure occurs prior to bond strength being developed but this decline does not imply bond failure *per se*. The majority of the reported deterioration of bond capacity associated with environmental conditioning was not bond related but simply reflects the deterioration and failure of the FRP material. The results of the GFRP bond specimens subjected to alkaline environment, for instance, exhibit the same degree of deterioration as the comparable tension tests. Some adhesive failures were noted at the FRP or concrete interfaces of the bond line. These failures may be attributed to environmental induced degradation of the adhesive layer.

Deteriorated bond capacity of the CFRP plate system subjected to heating conditions (60^{o}C) may be attributed to the elevated temperature approaching the T_g value of the adhesive epoxy used. While this value was not determined in the present study, a typical value would be on the order of 50^{o}C.

In situ Performance – Beam Flexure Tests

The degree of strengthening provided varied considerably. The CFRP plate, CFRP fabric and GFRP fabric-retrofit beams had capacities 218%, 157% and 149% of their companion unretrofit beam capacities, respectively. The effect of 360 freeze-thaw cycles on the unretrofit concrete beam was to reduce its capacity approximately 8%. This reduction is consistent with results expected from good quality concrete and indicates little damage to the substrate concrete resulting from the freeze-thaw conditioning. The reductions associated with freeze-thaw exposure of the CFRP plate and GFRP fabric retrofit beams are only 6% and 4%, respectively. The beams having CFRP fabric subjected to freeze-thaw exposure had no apparent strength loss. The reduced degree of environmental-induced degradation associated with the presence of FRP may result from the FRP actually protecting the concrete from freeze-thaw damage. With the FRP in place, a large region of soffit concrete is protected from water ingress and, therefore, the effects of freeze-thaw cycles on the concrete substrate are diminished.

Primary failure of the retrofit beams was associated with loss of the FRP strengthening effect. The CFRP plate system exhibited typical intermediate crack-induced (IC) debonding in all cases. This observation is consistent with the expected mode of flexural failure and was apparently unaffected by the freeze-thaw conditioning. The behaviour of the CFRP fabric-reinforced beams changed from one controlled by adhesive failure of the bond between FRP and concrete to IC debonding for the conditioned beams. This shift is counterintuitive and may reflect poor quality lay-up or surface preparation of the unconditioned specimens. Nonetheless, the fact that the conditioned beams performed admirably is an indication that little freeze-thaw induced deterioration occurred.

The GFRP fabric retrofit beams had such a small FRP reinforcement ratio that the fabric ruptured prior to debonding. In all cases, the FRP rupture resembled a ‘brooming’ type of failure typical of tension specimens. Such a failure is indicative of a good quality FRP having a sound matrix and good fibre continuity. The extent of the rupture (brooming) area was reduced for the conditioned beam specimens indicating that there may be some degradation of the GFRP system present.

Recommendations

Based on the extensive experimental program described, the following environmental exposure factors for design of externally bonded FRP materials are proposed (Table 5):

Table 5 Reduction factors for environmental exposure.

<table>
<tr><th></th><th>CFRP Plate</th><th>CFRP Fabric</th><th>GFRP Fabric</th></tr>
<tr><td colspan="4">Lowest values observed in this study</td></tr>
<tr><td>tension modulus, E x t</td><td>0.96</td><td>0.90</td><td>0.94</td></tr>
<tr><td>tension strength, F_u x t</td><td>1.00</td><td>0.92</td><td>0.82</td></tr>
<tr><td>bond capacity</td><td>0.91</td><td>0.60</td><td>0.52</td></tr>
<tr><td colspan="4">Recommendations</td></tr>
<tr><td>FRP material properties</td><td colspan="2">0.90</td><td>0.80</td></tr>
<tr><td>bond to concrete</td><td>0.90</td><td colspan="2">0.50</td></tr>
</table>

Proposed environmental exposure factors associated with material properties are 0.90 and 0.80 for CFRP and GFRP, respectively. It is proposed that these factors be applied to both FRP strength (i.e., $C_E F_u$) and modulus ($C_E E$) values. Since the linearity of FRP behaviour is unaffected by environmental exposure, strain capacity remains unchanged since the combinatorial effects of reducing both the stress and modulus equally results in unchanged strain (i.e., $\varepsilon_u = C_E F_u / C_E E$). This application to strength and modulus, but not strain, is supported by the present study.

In addition, exposure factors to be applied to bond capacity are proposed (Table 5); these factors are dependent on expected material quality and are proposed as 0.90 for preformed CFRP and 0.50 for fabric systems regardless of material. Based on the conditioning performed in this study, it is deemed that these proposed factors are appropriate for exterior exposure. The factors can likely be relaxed for interior exposure while environment-specific factors need to be developed for specified 'aggressive' environments.

Cited References

ACI Committee 440 (2008) *ACI 440.2R-08 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*, American Concrete Institute, Farmington Hills MI.

Cromwell, J.R. (née Pack), Harries, K.A. and Shahrooz, B.M. (2011) Environmental Durability of Externally Bonded FRP Materials Intended for Repair of Concrete Structures, *Journal of Construction and Building Materials* **25** 2528-2539.

Pack, J.R. (2003) *Environmental Durability Evaluation of Externally Bonded Composites*, MSCE thesis, University of Cincinnati, 289 pp.

ASTM Standard Test Methods Cited

ASTM C581 – 03 (2008) *Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service*

ASTM C666 – 03 (2008) *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*

ASTM D1141 – 98 (2008) *Standard Practice for the Preparation of Substitute Ocean Water*

ASTM D2247 - 02 *Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity*

ASTM D2344 – 00 (2006) *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*

ASTM D3039 - 08 *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*

ASTM D3045 – 92 (2003) *Standard Practice for Heat Aging of Plastics Without Load*

ASTM D4065 - 06 *Standard Practice for Plastics: Dynamic Mechanical Properties: Determination and Report of Procedures*

ASTM D7565 - 09 *Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures*

ASTM E831 - 06 *Standard Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis*

ASTM G23-96 *Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials*

Upcoming Conferences and Meetings

COMPOSITES 2013, January 29-31, 2013, Orlando, USA. www.compositesshow.org.

Early Registration ends January 4, 2013

11th International Symposium on Fiber Reinforced Polymer for Reinforced Concrete Structures (FRPRCS-11), June 26-28, 2013, Guimarães City, Portugal. www.frprcs11.uminho.pt

Revised Papers due: March 31, 2013

2nd Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, September 9-11, 2013, Istanbul, Turkey. www.smar-2013.org

Early Registration ends April 30, 2013

ACIC 2013 *6th Advanced Composites in Construction,* September 10-13, 2013, Belfast, UK. www.acic-conference.com

Papers due: April 1, 2013

APFIS 2013 *4th Asia-Pacific Conference on FRP in Structures,* December 11-13, 2013, Melbourne Australia. www.apfis2013.org

Papers due: May 1, 2013

CICE 2014 *7th International Conference on FRP Composites in Civil Engineering*, August 19-22, 2014, Vancouver, Canada. relhacha@ucalgary.ca

Abstracts due: May 1, 2013

CICE 2016 *8th International Conference on FRP Composites in Civil Engineering*, June 2016, Hong Kong.

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ASCE *Journal of Composites for Construction*

The American Society of Civil Engineers (ASCE) Journal of Composites for Construction (JCC) is published with the support of IIFC. As a service to IIFC members and through an agreement with ASCE, *FRP International* provides an index of ASCE JCC. The ASCE JCC may be found at the following website:

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***ASCE Journal of Composites for Construction*, Volume 16, No. 5, pp 489-613. October 2012.**

Effective Moment of Inertia Prediction of FRP-Reinforced Concrete Beams Based on Experimental Results

S. Roohollah Mousavi, M. Reza Esfahani

Repair and Strengthening of Reinforced Concrete Beam-Column Joints with Fiber-Reinforced Polymer Composites

Halil Sezen

Effects of Eccentricity on the Seismic Rehabilitation Performance of Nonseismically Detailed Interior Beamwide Column Joints

Bing Li, Qian Kai, Weichen Xue

Normalized Confinement Stiffness Approach for Modeling FRP-Confined Concrete

Veysel Yazici, Muhammad N. S. Hadi

Bond Behavior of the ETS FRP Bar Shear-Strengthening Method

A. Godat, A. L'Hady, O. Chaallal, K. W. Neale

Experimental Tests and Design Model for RC Beams Strengthened in Shear Using the Embedded Through-Section FRP Method

Amir Mofidi, Omar Chaallal, Brahim Benmokrane, Kenneth Neale

Tests on RC Beams Strengthened at the Span with Externally Bonded Polymers Reinforced with Carbon or Steel Fibers

George J. Mitolidis, Thomas N. Salonikios, Andreas J. Kappos

Environment-Assisted Subcritical Debonding of Epoxy-Concrete Interface

Chao Zhang, Jialai Wang, Kenneth J. Fridley

FE Modeling of CFRP-Repaired RC Beams Subjected to Fatigue Loading

Kam Yoke M. Loo, Stephen J. Foster, Scott T. Smith

FRP-Masonry Debonding: Numerical and Experimental Study of the Role of Mortar Joints

Christian Carloni, Kolluru V. Subramaniam

Rapid Strengthening of Masonry Structures Cracked in Earthquakes Using Fiber Composite Materials

Xianglin Gu, Bin Peng, Gonglian Chen, Xiang Li, Yu Ouyang

Flexural Performance and Moment Connection of Concrete-Filled GFRP Tube–Encased Steel I-Sections

Sarah Zakaib, Amir Fam

***ASCE Journal of Composites for Construction*, Volume 16, No. 6, pp 615-755. December 2012.**

Design-Oriented Strength Model for FRP-Confined Concrete Members

Theodoros C. Rousakis, Theodoros D. Rakitzis, and Athanasios I. Karabinis

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Repair Effects and Acoustic Emission Technique–Based Fracture Evaluation for Predamaged Concrete Columns Confined with Fiber-Reinforced Polymers

Gao Ma, Hui Li, and Zhongdong Duan

Axial and Flexural Performance of Square RC Columns Wrapped with CFRP under Eccentric Loading

Muhammad N. S. Hadi and Ida Bagus Rai Widiarsa

Slenderness Limit for Short FRP-Confined Circular RC Columns

T. Jiang and J. G. Teng

Impact Behaviors of CFT and CFRP Confined CFT Stub Columns

Xiao Yan and Shen Yali

Effect of Temperature Variation on the Full-Range Behavior of FRP-to-Concrete Bonded Joints

W. Y. Gao, J. G. Teng, and Jian-Guo Dai

Experimental Investigation of Bond Fatigue Behavior of Concrete Beams Strengthened with NSM Prestressed CFRP Rods

Noran Wahab, Khaled A. Soudki, and Timothy Topper

Retrofitting of Severely Shear-Damaged Concrete T-Beams Using Externally Bonded Composites and Mechanical End Anchorage

Tamer El-Maaddawy and Yousef Chekfeh

Effect of Adhesive Thickness and Concrete Strength on FRP-Concrete Bonds

Julio C. López-González, Jaime Fernández-Gómez, and Enrique González-Valle

Numerical Investigation on the Influence of FRP Retrofit Layout and Geometry on the In-Plane Behavior of Masonry Walls

Gian Piero Lignola, Andrea Prota, and Gaetano Manfredi

Behavior of Full-Scale Railway Turnout Sleepers from Glue-Laminated Fiber Composite Sandwich Structures

Allan Manalo and Thiru Aravinthan

Evaluating the Long-Term Durability of Externally Bonded FRP via Field Assessments

Douglas G. Allen and Rebecca A. Atadero

Axial Behavior of Square Reinforced Concrete Columns Strengthened with Lightweight Concrete Elements and Unbonded GFRP Wrapping

Andrin Herwig and Masoud Motavalli

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FRP International needs your input…

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Recent Dissertations

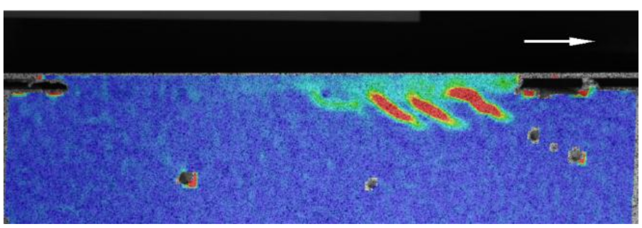
Strengthening of reinforced concrete members by prestressed, externally bonded reinforcement with gradient anchorage

Christoph Czaderski-Forchmann, PhD (2012)
Empa, Structural Engineering Research Laboratory, ETH Zurich, Switzerland

advisor: Professor Peter Marti, ETH Zurich

http://dx.doi.org/10.3929/ethz-a-007569614

The "gradient anchorage method", a pure adhesive anchorage method for highly prestressed strips to strengthen reinforced concrete, was developed at Empa. The aim and motivation for this work was to better understand the bond behaviour of CFRP strips in the region of the gradient anchorage. Detailed insights into the structural behaviour of CFRP strips that were glued on a concrete surface were found in lap-shear, prestress force release and beam tests. Full-field displacements measurements were performed using an optical 3D image correlation measurement system. The relative displacement slip and separation between the CFRP strip and the concrete surface were determined from the measured absolute displacements. The full-field measurements also provided strain patterns which helped to study and describe the load carrying mechanism in the tests. Equations were proposed to estimate the influence of a prestress force release on the anchorage pulling resistance for short or long bond lengths.



Lap-shear test on a CFRP strip bonded on concrete. The arrow shows the loading direction. The cracking behaviour in the concrete under the strip can be observed. The first principal strains, obtained using optical 3D image correlation, are overlaid on the photo.

Fibre Reinforced Polymer Strengthened Masonry Arch Structures

Yi Tao, PhD (2012)
University of Edinburgh, UK

advisors: Drs Jian-Fei Chen and Tim Stratford

This thesis presents an extensive study of the behaviour of FRP strengthened masonry arch bridges. It starts with a laboratory test of a one-third scale two-span masonry arch bridge with sand backfill. The arches were first load tested to near collapse and then repaired by bonding FRP into their intrados before testing to failure. A new concrete damage model is then presented to investigate the bond behaviour of FRP-to-concrete and the debonding process. An extensive finite element investigation was conducted modelling the test arch bridge. A detailed solid model, which is more suitable for modelling both the plain masonry and FRP strengthened structures, was developed. The research showed that it is necessary to consider both loading and construction histories in the numerical modelling to achieve close agreement with test results.

Durability of Bonded Concrete/FRP Interfaces Subjected to Creep and Environmental Ageing

Noureddine HouHou, PhD (2012)
IFSTTAR, Université Paris-Est, France

advisors: Drs Karim Benzarti and Marc Quiertant

www.theses.fr/2012PEST1138

The main objective of this research is to design, implement and validate a methodology for studying the long term behavior of bonded concrete/FRP interfaces, based on the development of an innovative experimental creep device (double shear test configuration) that can be coupled to environmental ageing. A prototype involving three double-shear specimens loaded by flat jacks connected to a hydropneumatic accumulator, was first designed and realized in order to validate the concept. The mechanical behavior of the bonded assemblies was found in fair agreement with numerical and analytical modeling, done either by calculating the instantaneous response using a finite element (FE) approach and Völkersen's analytical model, or by simulating the delayed creep response of the adhesive layer. Finally, a full-scale creep test setup involving fourteen double shear specimens (with two different commercially available FRP systems) was installed in a climatic room (40°C, 95% R.H.). At periodic ageing terms, two specimens were removed from the climatic room and subjected to destructive tests in order to determine the residual capacity of the FRP/concrete interface. Physico-chemical analyses of the polymer adhesive were also performed on these specimens. Preliminary results of this ongoing experimental campaign are discussed in the dissertation. [Dissertation is in French, but an article in English is also available in the Journal of Adhesion Science and Technology (DOI: 10.1080/01694243.2012.697387).]

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