

## Durability of CFRP strengthened concrete structures under accelerated or environmental ageing conditions

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**ABSTRACT:** The durability of concrete slabs strengthened by bonded composite materials has been investigated in the framework of an international cooperation between two French and Japanese research institutes. Time evolution of the concrete/composite adhesive bond strength was studied under both controlled and environmental ageing conditions, by using different mechanical characterization methods. The first results of this ongoing experimental campaign are presented.

### 1 INTRODUCTION

Composite materials are commonly used worldwide for the strengthening and repair of civil structures. In Japan for instance, strengthening methods based on fibre reinforced polymer (FRP) have been intensively used for the seismic retrofit of bridge columns after the 1995 Kobe earthquake (Saito 2002), whereas in France, such methods are increasingly applied to the rehabilitation or upgrading of damaged concrete structures (Luyckx 1999). If the effectiveness of FRP strengthening techniques has been clearly demonstrated and is now commonly accepted, the durability of the adhesive bond at the concrete/composite interface is still a matter of investigation (Karbhari 2007, Marouani et al. 2008).

Several authors have reported substantial decreases in the adhesive bond strength of FRP strengthened concrete specimens submitted to accelerated ageing conditions, such as freeze-thaw/dry-heat cycles, immersion in salt solutions or exposure to humid environments (Karbhari 2007, Grace & Singh 2005). Saturated humidity was often found to be the most detrimental factor to the adhesive bond properties (Grace & Singh 2005). Beside the abundant laboratory studies, there are only few available data on the effect of long-term environmental ageing. Moreover there is still no reliable method to assess the field degradation rate on the basis of controlled laboratory exposures.

In this paper, the first results of two ongoing studies conducted by the French and Japanese Public Works Research Institutes (LCPC and PWRI, respectively) are presented. On the French side, concrete slabs strengthened by carbon fibre reinforced polymer (CFRP) have been exposed to accelerated laboratory ageing in saturated humidity. Time evolution of the adhesive bond strength was monitored by using either pull-off or shear loading tests. On the Japanese side, similar kind of specimens have been exposed to environmental ageing in the Tokyo City area for 14 years, and the residual adhesive strength was then evaluated by pull-off or peeling tests.

Data provided by these two complementary studies will offer a unique opportunity to compare the effects of laboratory and environmental ageing on the properties of the concrete/composite interface, and to discuss the validity of the various adhesive test methods.

### 2 EFFECTS OF ACCELERATED AGEING

The French Public Works Research Institute (LCPC) has selected specific laboratory ageing conditions for the durability assessment of adhesive joints: specimens are exposed to 95% relative humidity at a temperature of 40°C in a climatic chamber. Such a humid environment is supposed to be detrimental for the concrete/composite interface, since it may induce both plasticization

# Durability Of Cfrp Strengthened Concrete Structures Under

**Xiuli Du,Liu Jin**



## **Durability Of Cfrp Strengthened Concrete Structures Under:**

Durability of Composites for Civil Structural Applications Vistasp M. Karbhari, 2007-07-25 Given the increasing use of fibre reinforced polymer FRP composites in structural civil engineering there is a vital need for critical information related to the overall durability and performance of these new materials under harsh and changing conditions Durability of composites for civil and structural applications provides a thorough overview of key aspects of the durability of FRP composites for designers and practising engineers Part one discusses general aspects of composite durability Chapters examine mechanisms of degradation such as moisture aqueous solutions UV radiation temperature fatigue and wear Part two then discusses ways of using FRP composites including strengthening and rehabilitating existing structures with FRP composites and monitoring techniques such as structural health monitoring Durability of composites for civil and structural applications provides practising engineers decision makers and students with a useful and fundamental guide to the use of FRP composites within civil and structural engineering Provides a thorough overview of key aspects of the durability of composites Examines mechanisms of degradation such as aqueous solutions moisture fatigue and wear Discusses ways of using FRP composites including strengthening and rehabilitating existing structures

**10th International Conference on FRP Composites in Civil Engineering** Alper Ilki, Medine Ispir, Pinar Inci, 2021-11-26 This volume highlights the latest advances innovations and applications in the field of FRP composites and structures as presented by leading international researchers and engineers at the 10th International Conference on Fibre Reinforced Polymer FRP Composites in Civil Engineering CICE held in Istanbul Turkey on December 8 10 2021 It covers a diverse range of topics such as All FRP structures Bond and interfacial stresses Concrete filled FRP tubular members Concrete structures reinforced or pre stressed with FRP Confinement Design issues guidelines Durability and long term performance Fire impact and blast loading FRP as internal reinforcement Hybrid structures of FRP and other materials Materials and products Seismic retrofit of structures Strengthening of concrete steel masonry and timber structures and Testing The contributions which were selected by means of a rigorous international peer review process present a wealth of exciting ideas that will open novel research directions and foster multidisciplinary collaboration among different specialists

**Building for the Future: Durable, Sustainable, Resilient** Alper Ilki, Derya Çavunt, Yavuz Selim Çavunt, 2023-07-04 This book presents the proceedings of the fib Symposium Building for the future Durable Sustainable Resilient held in Istanbul Turkey on 5 7 June 2023 The book covers topics such as concrete and innovative materials structural performance and design construction methods and management and outstanding structures fib The International Federation for Structural Concrete is a not for profit association whose mission is to develop at an international level the study of scientific and practical matters capable of advancing the technical economic aesthetic and environmental performance of concrete construction

**Concrete Solutions 2011** Michael Grantham, Viktor Mechtcherine, Ulrich Schneck, 2011-09-08 The Concrete Solutions series of International Conferences on Concrete Repair

began in 2003 with a conference held in St Malo France in association with INSA Rennes followed by the second conference in 2006 with INSA again at St Malo France and the third conference in 2009 in Padova and Venice in association with the University of Padova Now in 2011 the event is being held in Dresden in Germany and has brought together some 112 papers from 33 countries Whereas electrochemical repair tended to dominate the papers in earlier years new developments in structural strengthening with composites have been an increasingly important topic with a quarter of the papers now focusing on this area New techniques involving Near Surface Mounted NSM carbon fibre rods strain hardening composites and new techniques involving the well established carbon fibre and polyimide wrapping and strengthening systems are presented Seventeen papers concentrate on case studies which are all important in such conferences to learn about what works and what doesn't work on real structures Thirteen papers are devoted to new developments in Non Destructive Testing NDT Other topics include service life modelling fire damage surface protection methods and coatings patch repair general repair techniques and whole life costing This book is essential reading for anyone engaged in the concrete repair field from engineers to academics and students and also to clients who as the end user are ultimately responsible for funding these projects and making those difficult decisions about which system or method to use

FRP Composites in Civil Engineering - CICE 2004 R. Seracino, 2004-12-15 The range of fibre reinforced polymer FRP applications in new construction and in the retrofitting of existing civil engineering infrastructure is continuing to grow worldwide Furthermore this progress is being matched by advancing research into all aspects of analysis and design The Second International Conference on FRP Composites in

Repair, Rehabilitation, and Retrofitting Mr. Rohit Manglik, 2024-09-24 This book offers a detailed exploration of repair rehabilitation and retrofitting focusing on key concepts methodologies and practical implementations relevant to modern engineering and technology practices

*Quality Assurance of Reinforced Concrete Structures Strengthened by Externally Bonded CFRP Strips* Markus Huber, 2010-01-18 Inhaltsangabe Zusammenfassung Im Dezember 2002 wurde die erste österreichische Richtlinie bezüglich Stahlbetonverstärkungen mit aufgeklebten CFK Lamellen veröffentlicht Das vorrangige Ziel der vorliegenden Diplomarbeit ist die Durchführbarkeit der neuen Richtlinie mit speziellem Augenmerk auf Qualitätssicherung anhand Europas grüner CFK Baustelle die Wiener Marxerbrücke zu überprüfen Die Diplomarbeit enthält eine Übersicht über Eigenschaften und Anforderungen an CFK deren häufigste Anwendungen als Verstärkung und eine Beschreibung des Hauptbezugsobjekts Marxerbrücke Die Methoden der Qualitätssicherung nach der neuen Richtlinie werden erklärt und Resultate aus der Qualitätssicherung auf der Marxerbrücke inklusive einer Analyse von Fehlstellen und Sanierungsmethoden werden präsentiert Anschließend werden die Resultate aus der Qualitätssicherung auf der Marxerbrücke mit denen von vier anderen CFK verstärkten Bezugsobjekten verglichen Abschließend werden Veränderungen bezüglich der Methoden der Qualitätssicherung vorgeschlagen und Empfehlungen für eine zukünftige Ausgabe der österreichischen Richtlinie werden gegeben

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**Recent Advances in Durability Improvement and Low-Carbon Strategy of Engineering Materials and Structures** Zhongya Zhang, Anbang Li, Zhidong Zhang, 2024-08-28

Global warming caused by a significant increase in the concentration of greenhouse gases GHGs such as CO<sub>2</sub> has become a concern all over the world. The whole process carbon emissions of the civil engineering industry account for nearly 40% of global energy and process related CO<sub>2</sub> emissions more than half of which come from the process of producing using constructing and dismantling in civil engineering materials and structures resulting in the embodied carbon emissions. With the acceleration of global warming warmer and uncertain climates will make engineering materials and structures subject to more severe environmental conditions. A series of durability issues will occur more frequently such as the significant variations of humidity in air, the chloride induced corrosion caused by the severe chloride ingress, concrete cracking caused by the expansion of rusts and more severe carbonation of concrete structures due to the increase in CO<sub>2</sub> concentration. The adoption of positive measures to address climate change has become a global consensus as global warming has led to serious threats and challenges to the survival and development of humankind.

Principles of Chemical Engineering Processes Nayef Ghasem, Redhouane Henda, 2008-09-19

Written in a clear concise style Principles of Chemical Engineering Processes provides an introduction to the basic principles and calculation techniques that are fundamental to the field. The text focuses on problems in material and energy balances in relation to chemical reactors and introduces software that employs numerical methods to solve these problems. Upon mastery of this material readers will be able to:

- Understand basic processing terminology: batch, semibatch, continuous, purge and recycle, and standard operations: reaction, distillation, absorption, extraction, and filtration.
- Draw and fully label a flowchart for a given process description.
- Choose a convenient basis for calculation for both single and multiple unit processes.
- Identify possible subsystems for which material and energy balances might be written.
- Perform a degree of freedom analysis for the overall system and each possible subsystem.
- Formulating the

appropriate material and energy balance equations Apply the first law of thermodynamics calculate energy and enthalpy changes and construct energy balances on closed and open systems Written as a text to fully meet the needs of advanced undergraduate students it is also suitable as a reference for chemical engineers with its wide coverage across the biochemical and electromechanical fields Each chapter of the text provides examples case studies and end of chapter problems and the accompanying CD ROM contains software designed for solving problems in chemical engineering

Advanced Optimization Applications in Engineering Ahmad, Afaq,Camp, Charles V.,2024-05-20 In the ever evolving landscape of engineering a pressing challenge looms large the need to navigate the complexities of modern problems with precision and efficiency As industries grapple with an array of intricate issues from sustainable materials to resilient infrastructure the demand for optimal solutions has never been more pronounced Traditional approaches are often inadequate prompting the search for advanced optimization techniques capable of unraveling the intricacies inherent in engineering systems The problem at hand is clear how can engineers researchers and practitioners harness cutting edge methodologies to address the multifaceted challenges shaping our technological future Advanced Optimization Applications in Engineering is a definitive guide poised to revolutionize problem solving in civil engineering This book offers a comprehensive exploration of state of the art optimization algorithms and their transformative applications By delving into genetic algorithms particle swarm optimization neural networks and other metaheuristic strategies this collection provides a roadmap for automating design processes reducing costs and unlocking innovative solutions The chapters not only introduce these advanced techniques but also showcase their practical implementation across diverse engineering domains making this book an indispensable resource for those seeking to stay at the forefront of technological advancements **Guide for**

**Strengthening of Concrete Structures** FIB – International Federation for Structural Concrete,2022-05-01 The idea of preparing a technical document for the repairs and interventions upon concrete structures goes back to the former fib COM 5 Structural Service Life Aspects being the goal of the then TG 5 9 After a long period of reduced activity and taking into account the reorganization of fib commissions that meanwhile took place on June 2017 a different approach was proposed to push forward the task of TG 8 1 formerly TG 5 9 The new goal of TG 8 1 was to deliver a how to do guide gathering together protection repair and strengthening techniques for concrete structures Chapters are intended to provide both guidelines and case studies serving as support to the application of fib MC 2020 pre normative specifications Each chapter was written by an editorial team comprising desirably at least a researcher a designer and a contractor Templates have been prepared in order to harmonize the contents and the presentation of the different methods Following the writing process chapters were reviewed by experts and after amendments by the authors they underwent a second review process by COM 8 and TG 3 4 members as well as by different practitioners For each protection repair and strengthening method addressed in this guide readers have a description of when to adopt it which materials and systems are required which techniques are available and

what kind of equipment is needed It then presents a summary of stakeholders roles and qualifications design guidelines referring to most relevant codes and references the intervention procedure quality control measures and monitoring and maintenance activities Due to the extent of the guide it was decided to publish it as bulletin 102 addressing protection and repair methods and bulletin 103 addressing strengthening methods We would like to thank the authors reviewers and members of COM 8 and TG 3 4 for their work in developing this fib Bulletin which we hope will be useful for professionals working in the field of existing concrete structures especially those concerned with life cycle management and conservation activities As noted above this Bulletin is also intended to act as a background and supporting document to the next edition of the fib Model Code for Concrete Structures which is currently under development under the auspices of TG10 1 with the working title of fib Model Code 2020

*Advanced Polymer Composites for Structural Applications in Construction* L C Hollaway,2004-04-22 Over the past three decades advanced polymer composites have emerged as an attractive construction material for new structures and the strengthening rehabilitation of existing buildings and bridges The techniques associated with the technology analysis and design of polymer composites in construction are continually being researched and the progress made with this exciting material will continue at an ever increasing rate to meet the demands of the construction industry This volume of proceedings is from the Second ACIC 2004 International Conference which focused on the application and further exploitation of advanced composites in construction The conference allowed practising engineers asset managers researchers and representative of regulatory bodies to promote the active exchange of scientific and technical information on the rapidly changing scene of advanced composites in construction This volume focuses on the presentation of new concepts techniques and case studies which will lead to greater exploitation of advanced polymer composites and FRP materials for civil engineering infrastructure rehabilitation and renewal Presents new concepts techniques and case studies

**Advances in FRP Composites in Civil Engineering** Lieping Ye,Peng Feng,Qingrui Yue,2012-02-01 Advances in FRP Composites in Civil Engineering contains the papers presented at the 5th International Conference on Fiber Reinforced Polymer FRP Composites in Civil Engineering in 2010 which is an official conference of the International Institute for FRP in Construction IIFC The book includes 7 keynote papers which are presented by top professors and engineers in the world and 203 papers covering a wide spectrum of topics These important papers not only demonstrate the recent advances in the application of FRP composites in civil engineering but also point to future research endeavors in this exciting area Researchers and professionals in the field of civil engineering will find this book is exceedingly valuable Prof Lieping Ye and Dr Peng Feng both work at the Department of Civil Engineering Tsinghua University China Qingrui Yue is a Professor at China Metallurgical Group Corporation

Maintenance, Safety, Risk, Management and Life-Cycle Performance of Bridges Nigel Powers,Dan Frangopol,Riadh Al-Mahaidi,Colin Caprani,2018-07-04 Maintenance Safety Risk Management and Life Cycle Performance of Bridges contains lectures and

papers presented at the Ninth International Conference on Bridge Maintenance Safety and Management IABMAS 2018 held in Melbourne Australia 9-13 July 2018. This volume consists of a book of extended abstracts and a USB card containing the full papers of 393 contributions presented at IABMAS 2018 including the T Y Lin Lecture, 10 Keynote Lectures and 382 technical papers from 40 countries. The contributions presented at IABMAS 2018 deal with the state of the art as well as emerging concepts and innovative applications related to the main aspects of bridge maintenance, safety, risk management and life cycle performance. Major topics include new design methods, bridge codes, heavy vehicle and load models, bridge management systems, prediction of future traffic models, service life prediction, residual service life, sustainability and life cycle assessments, maintenance strategies, bridge diagnostics, health monitoring, non-destructive testing, field testing, safety and serviceability assessment and evaluation, damage identification, deterioration modelling, repair and retrofitting strategies, bridge reliability, fatigue and corrosion, extreme loads, advanced experimental simulations and advanced computer simulations among others. This volume provides both an up-to-date overview of the field of bridge engineering and significant contributions to the process of more rational decision making on bridge maintenance, safety, risk management and life cycle performance of bridges for the purpose of enhancing the welfare of society. The Editors hope that these Proceedings will serve as a valuable reference to all concerned with bridge structure and infrastructure systems including students, researchers and engineers from all areas of bridge engineering.

#### **Size Effect in Concrete Materials and Structures**

Xiuli Du, Liu Jin, 2020-12-31. The present book gathers a large amount of the recent research results on this topic to provide a better understanding of the size effect by giving a quantitative description of the relationship between the properties of engineering concrete making material, e.g. the nominal strength and the corresponding structure size. To be precise, this is about to explore the new static and dynamic unified size effect laws for concrete materials as well as size effect laws for concrete components. Besides presenting clear and accurate descriptions that further deepen our fundamental knowledge, this book provides additionally useful tools for the scientific design of concrete structures in practical engineering applications.

*Mechanics of Structures and Materials XXIV* Hong Hao, Chunwei Zhang, 2019-08-08. *Mechanics of Structures and Materials: Advancements and Challenges* is a collection of peer-reviewed papers presented at the 24th Australasian Conference on the Mechanics of Structures and Materials (ACMSM24) Curtin University Perth Western Australia 6-9 December 2016. The contributions from academics, researchers and practising engineers from Australasia, Asia Pacific region and around the world cover a wide range of topics including Structural mechanics, Computational mechanics, Reinforced and prestressed concrete structures, Steel structures, Composite structures, Civil engineering materials, Fire engineering, Coastal and offshore structures, Dynamic analysis of structures, Structural health monitoring and damage identification, Structural reliability analysis and design, Structural optimization, Fracture and damage mechanics, Soil mechanics and foundation engineering, Pavement materials and technology, Shock and impact loading, Earthquake loading.



Traffic and other man made loadings Wave and wind loading Thermal effects Design codes Mechanics of Structures and Materials Advancements and Challenges will be of interest to academics and professionals involved in Structural Engineering and Materials Science *CIGOS 2021, Emerging Technologies and Applications for Green Infrastructure* Cuong Ha-Minh, Anh Minh Tang, Tinh Quoc Bui, Xuan Hong Vu, Dat Vu Khoa Huynh, 2021-10-28 This book highlights the key role of green infrastructure GI in providing natural and ecosystem solutions helping alleviate many of the environmental social and economic problems caused by rapid urbanization The book gathers the emerging technologies and applications in various disciplines involving geotechnics civil engineering and structures which are presented in numerous high quality papers by worldwide researchers practitioners policymakers and entrepreneurs at the 6th CIGOS event 2021 Moreover by sharing knowledge and experiences around emerging GI technologies and policy issues the book aims at encouraging adoption of GI technologies as well as building capacity for implementing GI practices at all scales This book is useful for researchers and professionals in designing building and managing sustainable buildings and infrastructure

**Non-Metallic (FRP) Reinforcement for Concrete Structures** L. Taerwe, 2004-06-02 Dealing with a wide range of non metallic materials this book opens up possibilities of lighter more durable structures With contributions from leading international researchers and design engineers it provides a complete overview of current knowledge on the subject

**Proceedings fib Symposium in Tel-Aviv Israel** FIB - International Federation for Structural Concrete, 2013-04-01

**Creative Systems in Structural and Construction Engineering** Amarjit Singh, 2017-11-22 An examination of creative systems in structural and construction engineering taken from conference proceedings Topics covered range from construction methods safety and quality to seismic response of structural elements and soils and pavement analysis

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