

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

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12th International Conference on FRP Composites in Civil Engineering (CICE 2025) João R. Correia, Susana Cabral-Fonseca, José Gonilha, João Firmo, Mário Garrido, 2026-02-09 This book composed of two volumes presents the latest advances innovations and applications in fibre reinforced polymer FRP composites and structures as shared by leading international researchers and engineers at the 12th International Conference on FRP Composites in Civil Engineering CICE held in Lisbon Portugal on July 14 16 2025 The volumes cover a broad spectrum of topics including all FRP structures bond and interfacial behaviour concrete filled FRP tubular members FRP reinforced or pre stressed concrete structures confinement design methodologies and guidelines durability and long term performance fire impact and blast resistance FRP as internal reinforcement hybrid FRP systems with other materials new materials and products seismic retrofitting structural strengthening of concrete steel masonry and timber and experimental testing All contributions underwent an international peer review process ensuring both quality and relevance Together they provide a rich source of ideas that not only advance current understanding but also inspire new research directions and foster multidisciplinary collaboration across the field

Concrete Repair, Rehabilitation and Retrofitting II Mark G. Alexander, Hans-Dieter Beushausen, Frank Dehn, Pilate Moyo, 2008-11-13 The Second International Conference on Concrete Repair Rehabilitation and Retrofitting ICCRRR 2005 was held in Cape Town South Africa from 24 26 November 2008 The Conference followed the very successful First International Conference also in Cape Town in 2005 and continued as a collaborative venture by researchers from the South African Research Programme in Concrete Materials based at the Universities of Cape Town and The Witwatersrand and The Construction Materials Sections at Leipzig University and MFPA Leipzig in Germany The background in industry and the state of national infrastructures continues to be highly challenging and demanding The facts remain that much of our concrete infrastructure deteriorates at unacceptable rates that we need appropriate tools and techniques to undertake the vast task of sound repair maintenance and rehabilitation of such infrastructure and that all this must be undertaken with due cognisance of the limited budgets available for such work New ways need to be found to extend the useful life of concrete structures cost effectively Confidence in concrete as a viable construction material into the 21st century needs to be retained and sustained particularly considering the environmental challenges that the industry and society now face The conference proceedings contain papers presented at the conference and classified into a total of 12 sub themes which can be grouped under the three main themes of i Concrete durability aspects ii Condition assessment of concrete structures and iii Concrete repair rehabilitation and retrofitting The major interests in terms of submissions exists in the fields of innovative materials for durable concrete construction integrated service life modelling of reinforced concrete structures NDE NDT and measurement techniques repair methods and materials and structural strengthening and retrofitting techniques The large number of high quality papers presented and the wide range of relevant topics covered confirm that these proceedings will

be a valued reference for many working in the important fields of concrete durability and repair and that they will form a suitable base for discussion and provide suggestions for future development and research

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

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

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

Computational Mechanics, Materials and Engineering Applications Jian Rong Yang, Min Yu, 2011-12-22 Selected peer reviewed papers from the 2011 International Workshop on Computational Mechanics Materials and Engineering Applications CMMEA 2011 July 23 24 2011 in Kunming P R China

Bond Behaviour of FRP in Structures J. F. Chen, J. G. Teng, 2005

Nondestructive Evaluation and Health Monitoring of Aerospace Materials and Composites III Peter J. Shull, Andrew L. Gyekenyesi, 2004 Proceedings of SPIE present the original research papers presented at SPIE conferences and other high quality conferences in the broad ranging fields of optics and photonics These books provide prompt access to the latest innovations in research and technology in their respective fields Proceedings of SPIE are among the most cited references in patent literature

Mechanics of Masonry Structures Strengthened with Composite Materials IV Giovanni Castellazzi, Cristina Gentilini, Angelo Di Tommaso, 2022-04-07 Selected peer reviewed full text papers from the 7th International Conference on Mechanics of Masonry Structures Strengthened With Composite Materials MuRiCo 7

Mechatronics and Computational Mechanics II Abdel-Hamid I. Mourad, József Kázmér Tar, 2014-02-06 Selected peer reviewed papers from the 2013 2nd International Conference on Mechatronics and Computational Mechanics ICMCM 2013 December 30 31 2013 Frankfurt Germany

Durability of Carbon Fiber Reinforced Polymer (CFRP) Repair/strengthening Concrete Beams Jiangang Deng, 2008 Carbon fiber reinforced polymers CFRP have been widely used as externally epoxy bonded reinforcement for repair and retrofit of existing concrete structures As the use of CFRP in construction increases it is essential to consider the long term behavior In this study concrete specimens with externally bonded CFRP composite systems were exposed to various accelerated ageing environments different elevated temperature water immersion varying relative humidity exposure real time solar exposure pressurized hygrothermal exposure and fatigue loading Three point loading test and direct tension test were used to evaluate the flexural and tensile strength of CFRP specimens This research recommends that the durability strength reduction factor be defined as the ratio of the flexural strength of a test specimen after exposure for 60 days at 60C to the strength of a control specimen at the initiation of exposure Test specimens exposure environments testing procedures and field application environments are selected to assure uniform reporting testing and application of durability strength reduction factors Two exposure environments are recommended for design wet and air Water can diffuse through concrete and accumulate on the epoxy concrete interface in a wet environment and is the default condition for design An air environment precludes water accumulation but requires engineering design and validation to guarantee compliance The resulting durability strength

reduction factor may be used to calculate the reduced strength for environmental exposure b qualify a specific CFRP system c compare durability reduction factors to those provided by system suppliers and d confirm compliance with project specifications

Durability of CFRP Strengthened RC Elements in Severe Environments Amal AlFar,2014-10-27 Externally bonded CFRP composite plates showed a great potential in the area of structural rehabilitation and impressive applications have been reported However there are heightened concerns related to the overall durability under harsh environmental conditions In aggressive environments CFRP retrofitted systems are subjected to moisture salts ultraviolet radiations and high temperatures which not only causing steel to corrode and concrete to deteriorate but it may degraded the adhesive bond hence limiting the strength of the retrofitted system This is evident since at best an insufficient bond renders the external reinforcement as ineffective as it is the mean to transfer stresses between the adherents This study intends to examine the durability of the adhesive bond under accelerated laboratory conditions that mimic harsh environmental conditions and under severe real life environments that are prevalent at the Middle East countries particularly at the Dead Sea and Aqaba regions of Jordan

Frontiers of Composite Materials Ramesh K. Agarwal,2017-03-28 Selected peer reviewed papers from the the First International Conference on Frontiers of Composite Materials ICFCM 2016 November 19 21 2016 Auckland New Zealand

Innovation & Sustainability of Structures ,2005

Structural Integrity of RC Columns Wrapped with FRP Sheet Subjected to Various Environmental Conditions Including Corrosion ,2004 Although the short term performance of reinforced concrete RC columns wrapped with fiber reinforced polymer FRP composite materials has been widely studied research studies on the long term performance are limited The objective of this study was to evaluate the effects of various environmental conditions on the long term behavior of RC columns wrapped with FRP sheets The experimental program comprised two parts ambient environmental effect tests and corrosion tests The environmental conditions considered in the ambient environmental tests included 1 freeze thaw cycles 2 high temperature cycles 3 high humidity cycles 4 ultraviolet UV radiation and 5 saline solution while the corrosion tests dealt with the corrosion of steel reinforcement embedded in RC columns wrapped with FRP sheets RC columns were wrapped with carbon fiber reinforced polymer CFRP sheets and glass fiber reinforced polymer GFRP sheets and conditioned under the environmental conditions listed After the environmental conditioning uni axial compression tests were conducted in order to evaluate the effects on the mechanical properties such as column capacity stiffness and ductility

Experimental and Numerical Investigations on Bond Durability of CFRP Strengthened Concrete Members Subjected to Environmental Exposure Haider Al-Jelawy,2013 Results of tensile tests on FRP coupons indicate that both epoxy and polyurethane FRP systems do not degrade significantly under environmental exposure However flexural tests on the FRP strengthened concrete beams indicate that bond between FRP and concrete shows significant degradation especially for aqueous exposure Moreover a protective coating suppresses the measured degradation Also experimental load displacement curves for control beams show

excellent agreement with numerical load displacement curves obtained using the proposed bond model Finally a bond slip model is predicted for concrete leachate conditioned beams by matching load displacement curves for those beams with numerical load displacement curves

Fiber-reinforced-plastic (FRP) Reinforcement for Concrete Structures Antonio Nanni,1993 The 20 papers in this volume contribute to the advancing knowledge and acceptance of fibre reinforced plastic FRP composites for concrete reinforcement The book is divided into three parts reinforcement for concrete structures an international perspective and FRP reinforcement products

Extending Performance of Concrete Structures Ravindra K Dhir,Paul A J Tittle,1999-10 Topics discussed in these papers include developments in materials and methods for repair of existing structures and use in new construction The themes of the seminar are Materials Development and Practical Applications

Fiber-reinforced Polymer (FRP) Reinforcement for Concrete Structures ,2005 **Canadian Journal of Civil Engineering** ,2007

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