Chapter 1
Introduction

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Abstract This book analyses the current knowledge on structural behaviour of RC elements and structures strengthened with composite materials (experimental, analytical and numerical approaches for EBR and NSM), and the comparison of the predictions of the current available codes/recommendations/guidelines with selected experimental results. The book shows possible critical issues (discrepancies, lacunae, relevant parameters, test procedures, etc.) related to current code predictions or to evaluate their reliability, in order to develop more uniform methods and basic rules for design and control of FRP-strengthened RC structures. General problems/critical issues are clarified on the basis of the actual experiences, detect discrepancies in existing codes, lacunae in knowledge and, concerning these identified subjects, provide proposals for improvements. The book will help to contribute in promoting and consolidating a more qualified and conscious approach towards rehabilitation and strengthening existing RC structures with composites and their possible monitoring.

Keywords FRP · FRCM · Composites · Strengthening · Reinforced concrete

Introduction

Strengthening and retrofitting of existing structures have been widely discussed topics for the last few decades. A great number of existing structures need rehabilitation or strengthening because of improper design or construction, change of the design loads, damage caused by environmental and/or human factors, seismic events, etc. Several different systems have been developed and used to strengthen

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existing structures. They include replacing structural members, adding new material to improve their performance, modifying the restraint conditions, introducing post-tension, etc. These techniques have been proven to be effective, but in some cases they can be expensive and difficult to apply. The use of fibre reinforced composites applied to existing structural elements may represent a cost-effective alternative to such traditional strengthening techniques. Among fibre reinforced composites, strengthening by means of fibre reinforced polymers (FRP) has gained great popularity because of its high mechanical properties and relatively low cost. FRP composites are comprised of high strength fibres (e.g. carbon, glass, aramid) applied to the element surface through thermosetting organic matrices, usually epoxy resin. FRP composites can be externally bonded (ER) to the element surface or placed within groove carved into the element and filled with organic matrices (Near Surface Mounted technique, NSM). The fibres are meant to carry the tensile forces, whereas the matrix transfers the stress to the concrete support. They are easy to install, have a high strength-to-weight ratio, and have suitable mechanical properties. The structural behaviour of FRP composites applied to reinforced concrete (RC) elements and structures has been widely studied over the last decades and these studies have resulted in some design guidelines. American ACI 440.2R-08 (2008), European fib T.G. 9.3 (2001), and Italian CNR-DT 200 R1 (2013) are examples of such guidelines. Although a large number of experimental, analytical, and numerical studies regarding FRP composites are available in the literature, the predictions provided by guidelines and analytical models are sometimes contrasting and disagreeing with the experimental results. For this reason, the scientific community is still discussing about some important issues and new improved guidelines are under preparation all around the world. It has been observed that the use of organic resins, though effective, may represent an issue for the durability of the intervention. Indeed, organic matrices degrade when exposed to UV radiation and loose most of their mechanical properties when subjected to temperatures close (or higher) to their glass transition temperature. Promising newly-developed types of matrix that potentially represent a valid alternative to organic resins are the so-called inorganic matrices. Within the broad category of inorganic matrices, polymer-modified cement-based mortars have raised some interest in recent years. Composite materials that employ modified cement-based mortars are usually referred to as fiber-reinforced cementitious matrix (FRCM) composites. Although several works about FRP strengthening are available in the literature very few studies can be found regarding FRCM composites.

The international Rilem Technical Committee 234-DUC was created in 2009 with the aim of facing the issues connected with the use of fibre reinforced composites to strengthen RC elements and structures. This committee is composed by a team of experts representing most of the main international institutions working on the subject. Members become from international academic and research institutions, other Rilem technical committees working on reinforced concrete and composites, standardization groups, and national and international groups who have contributed to the development of the current codes/recommendations/guidelines. The committee includes members from Italy, Cyprus, United States, England, Portugal, China, Germany, Switzerland, Sweden, Spain, and other countries. Through the fruitful collaboration between members, promoted by the annual meetings, the committee could analyse many different aspects of the FRP strengthening technique and give insights for improvement and development of the existing analytical models. Furthermore, newly-developed promising fibre reinforced inorganic composites (FRCM) were analysed as well.

This book collect the results of 4 years of work by the Technical Committee 234-DUC. Chapter 2 provides the outcomes of a statistical analysis based on the indication of EN1990 and extended to the case of EBR FRP system. This chapter shows a procedure to evaluate the statistical parameters of the capacity models and to evaluate its characteristic values, which is the aim for application in design. Furthermore, some applications are reported to prove the feasibility of the proposed procedure. Chapter 3 provides a deep analysis of the bond behavior of FRP composites externally applied onto RC structures. The bond is described through a fracture mechanics approach and the theoretical models are compared with the experimental results available in the literature. An assessment of the most important analytical models for the estimation of the bond strength of FRP-concrete joints is provided as well. Finally, the chapter faces the critical issues of models and experimental procedures employed to investigate the FRP bond behavior. In Chap. 4 shear strengthening by means of EBR FRP is analyzed. The main analytical formulation for the evaluation of the shear strength of shear strengthened RC elements are recalled and new improved formulations are provided. The models analyzed are assessed through a wide experimental database to evaluate their accuracy with respect to the experimental evidences. Chapter 5 describes the use of FRP jackets for confining RC members mainly subjected to axial loading. The current formulations for the evaluation of the effective ultimate strain in the FRP are provided and discussed. The influence of the internal steel on the EBR FRP jackets and particularly the effects of possible bar buckling are discussed as well. Finally, experimental results available in the literature are compared with analytical provision to assess the accuracy of the proposed models. Chapter 6 gives an overview on the state-of-the-art about verifications of reinforced concrete structures using Externally Bonded (EB) Fibre Reinforced Polymers (FRP) under serviceability loading conditions (long term behaviour, durability under severe conditions), fatigue load, and fire and high temperature. Furthermore, the use of anchoring systems and mechanically fastened system is described. Chapter 7 describes the use of prestressed EBR FRP system. The chapter provides information regarding commercially available prestressing systems and their anchorage procedures. The newly-developed technique of "gradient anchorage" and various current prototypes at the laboratory-scale level are shown as well. Chapter 8 gives an overview on the state-of-the-art of the NSM technique for structural retrofitting of reinforced concrete structures using FRP composites. The chapter firstly describes the technique and addresses the existing knowledge on the bond behaviour. Furthermore, two formulations for predicting the NSM shear carrying capacity are provided. Finally, the needs for future research on this topic are identified. Chapter 9 describes the use of FRCM composites for strengthening existing RC and masonry structures. After introducing the commercially available composites, the chapter gives a state-of-the-art about the test methods under development for characterizing this materials and provides a fracture mechanics approach that allows for describing FRCM-concrete joints bond behaviour. Finally, the effectiveness of the FRCM technique for flexural strengthening and confinement of RC elements is shown and some experimental campaigns are described.