Summary

The purpose of this Thesis is to present a comprehensive interpretation of the flexural behaviour of fibre-reinforced and hybrid-reinforced cementitious composites in the framework of fracture mechanics. The Updated Bridged Crack Model (UBCM) is proposed as a numerical tool to point out the main variables affecting the flexural response of the composite, with a particular emphasis on the crucial role played by the amount of the reinforcing phases and by the structural size.

Chapter 1 deals with some basic issues regarding the use of *fibre-reinforced concrete* (FRC) in structural applications. Moreover, the reader is provided with a state of the art regarding the standard test methods and design guidelines for FRC members, which are included in the current version of international building codes.

Chapter 2 deals with the fundamental concepts of fracture mechanics. The Griffith energy criterion (1920) is presented, whereby for the first time the fracture resistance of a cracked plate was related to the size of the defect. An extensive discussion is provided regarding the concept of *stress singularities*, emphasizing the pioneering contributions of Westergaard (1939) and Williams (1952). Irwin's theorem is presented, thus providing a direct connection between global and local approaches. At the end of the chapter, some fundamental concepts related to nonlinear fracture mechanics models for quasi-brittle materials are presented, thus preparing the ground for the discussion of the subsequent chapters.

In Chapter 3, the fundamentals of UBCM are presented. The analytical model focuses on the fracturing process occurring in the critical cross-section of reinforced cementitous members. The cementitious matrix is assumed to be linear elastic-perfectly brittle, whereas nonlinear constitutive laws are used to describe the toughening action of the reinforcing phases. Equilibrium, constitutive, and displacement compatibility conditions permit to fully describe the behaviour of the cross-section in terms of fracturing moment vs local rotation diagrams. Within the model assumpions, the flexural response of the composite is found to be governed by three scale-dependent dimensionless numbers: (i) the *bar-reinforcement brittleness number*, $N_{\mathrm{P}}^{\mathrm{L}}$, which is proportional to the steel-bar area percentage, ρ_{s}; (ii) the *fibre-reinforcement brittleness number*, $N_{\mathrm{P,f}}$, which is proportional to the fibre volume fraction, V_{f}; (iii) the *pull-out brittleness number*, N_{w}, which is proportional to the critical embedded length of the fibre, $w_{\mathrm{f}}^{\mathrm{t}}$.

In Chapter 4 the applicability of UBCM is discussed in the case of FRC members

subjected to bending. In this framework, UBCM numerical simulations are presented to predict the different stages characterizing the FRC flexural response as a function of $N_{P,f}$ and N_w. The former, $N_{P,f}$, is found to define the load bearing capacity of the FRC specimen, thus defining also the minimum reinforcement condition, together with its scale dependence. On the other hand, N_w is found to govern the final softening tail of the response, with a direct influence on the inelastic rotation capacity of the cross-section. These numerical trends are compared to different experimental results of the literature, in which the influence of the amount of fibres and of the specimen size are taken into account. Eventually, the effectiveness of the model in the case of cyclic loading is also shown.

In Chapter 5 the applicability of UBCM is discussed in the case of *hybrid-reinforced concrete* (HRC), in which the reinforcing phase consists in a combination of continuous steel bars and short fibres. The key-point of the discussion relies in the minimum reinforcement condition for HRC members, which is predicted by a linear relationship between the critical values of N_P^L and $N_{P,f}$. All the parameters being the same, it can be translated into a relationship between the minimum steel-bar area percentage, $\rho_{s,min}$, and the minimum fibre volume fraction, $V_{f,min}$.