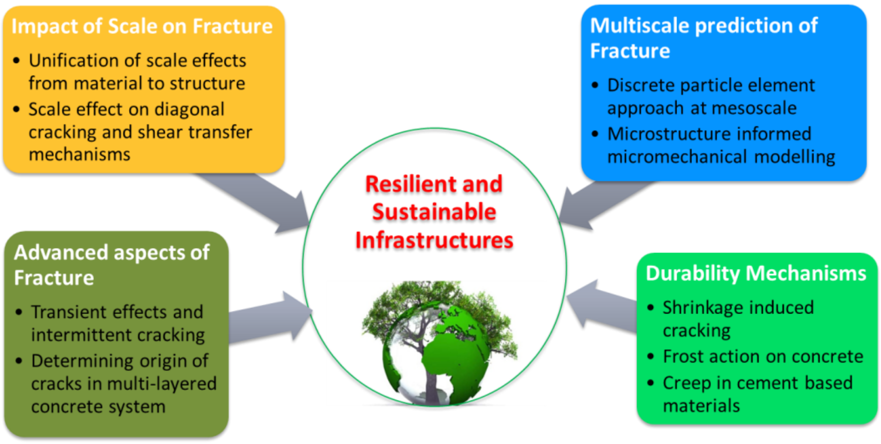
Unified approach for fracture in cementitious materials considering microstructure, scale effects and durability mechanisms

Fracture being the most critical aspect of concrete material degradation, should be investigated by gathering knowledge of several mechanisms and processes related to the scale, the application portfolio and the governing chemo-physio-mechanical rules. This reflection has laid down the foundation of my research goals which I carried through the supervision of several Doctoral and Master thesis since my own PhD. Within this context, my research can be divided into four folds as shown in the figure below. For each fold, scientific challenges and achievements have been briefly introduced in the following.



Summarized portrait of research

Experimental determination of fracture parameters like crack initiation, opening and propagation is important to ensure structural stability and durability but also to validate numerical models. Within this context and my involvement in National Projects ANR ECOREB and ANR ECOBA, my research work (*Part I*) was mainly focused at the intermittent cracking phase and transient effects during the transition from continuum and discontinuum and to identify the origin of cracks in the complex microstructure. The results have shown that during this fracturing phase, the quantities so called energy dissipation and displacement discontinuities evolve differently. An underlying process involving interaction between macrocrack and surroundings microcracks has been experimentally identified and theoretically developed.

During the fracture in concrete and reinforced structures, size effect has been an important physical problem as it affects significantly the engineering design, fracture and durability properties. Although size effect is considered as a structural problem, however, the underlying physical property namely "fracture process zone" is dependent on the size of heterogeneities present in the material. Within this context, the main focus of my research (*Part II*) was to develop a material based size effect theory. Through experimental investigation we have shown that size effect is the scaling of the size of structure relative to the size of material heterogeneity. We experimentally demonstrated that similar size effect can be obtained by scaling the heterogeneity size and by scaling the specimen size. This result has been further extended to the development of a new material based size effect model. Further, we also investigated the role of aggregates (interlock) on the size effect in shear failure which leads to the understanding that the curvature of the shear crack significantly affects the aggregate interlock phenomenon.

Cementitious materials are complex on one hand due to the presence of heterogeneities and on the other hand due to complex composition of the cement paste matrix. The hydrated cement paste consists of several phases which make the fracture mechanisms relatively less understood. In the current context of sustainable infrastructures, one must include the effects of cement paste composition and heterogeneities in the estimation of fracture. In this regard, efforts are performed in *Part III* of this research where multi-scale numerical approaches: discrete element method and micromechanics are used to precisely model the fracture in cementitious materials at several scales. Since the approach is based on the fracture characteristics of hydration products, it takes into account any change in the concrete mix-design and the underlying mechanisms are modelled without any experimental calibration or adjustments in the numerical approach.

Material design is a key aspect in cementitious materials. Research has been significantly advanced during the recent years in order to develop more sustainable and resilient materials since the degradation of these materials is a serious concern which may arise due to mechanical and/or physio-chemical actions. The principal physio-chemical mechanisms occur either due to the time dependant interactions and evolution in material microstructure and/or due to the exposure to severe environmental conditions. *Part IV* of my research was mainly focused on the experimental and numerical characterisation of durability mechanisms at the material scale. Within the framework of Edycem Chair, the first scientific challenge of this study was to better understand the shrinkage and curling mechanisms in cementitious materials and identify the most influential parameters in order to limit its final amplitude. The experimental campaign involves numerous characterizations and the development of new measurement devices. The second scientific challenge of this study was to investigate the degradation process due to freeze-thaw cycles. A numerical modelling approach is adopted in this research in which each freeze-thaw mechanism is studied individually. A micromechanics-based model considering an explicit representation of pore size distribution is considered, in order to realistically model the freeze-thaw behaviour and to investigate the influence of each mechanism such as hydrostatic pressure, hydraulic pressure and osmotic pressure.