Chapter 1
Introduction and previous research

When material behaviour (e.g. a mechanical property) is studied, the scale of observation must be taken into account as an important parameter. This means that one property can have different values depending on the scale of the study and place of the measurement. Moreover the deviation of the results strongly depends on this scale of study for materials that are clearly not homogeneous. This is the case of the concrete which is represented, in this study, as a three phase material: consisting of aggregates (most stiff), matrix (less stiff than aggregates) and a Interfacial Transition Zone (ITZ) (with the smallest values of the stiffness).

One of the main challenges in solid mechanics is the transition from a heterogeneous micro-structure to an approximating continuum model. For this reason a representative volume of the sample is needed.

Many definitions for the Representative Volume Element (RVE) can be found in the scientific literature. Just to mention some of them the following definitions are given.

- Drugan and Willis [1]: The RVE is the smallest material volume element of the composite for which the usual spatially constant "overall modulus" macroscopic constitutive representation is a sufficiently accurate model to represent mean constitutive response.

- Hashin [2]: The RVE is a model of the material to be used to determine the corresponding effective properties for the homogenized macroscopic model. The RVE should be large enough to contain sufficient information about the micro-structure in order to be representative, however it should be much smaller than the macroscopic body.

- Ostoja-Starzewski [3]: The RVE is very clearly defined in two situations only:
  i) Unit cell in a periodic micro-structure.
  ii) Volume containing a very large (mathematically infinite) set of micro-scale elements (e.g. grains), possessing statistically homogeneous and ergodic properties.
It is important to remark from the results of the above-mentioned references that the RVE is not unique for a material but that it depends on the property under investigation.

The objective of this study is to verify the existence of RVEs in different regimes of loading and possibly to quantify the size of a RVE for brittle materials. For this purpose a set of material samples is envisaged to be generated. This set is composed by samples with different size and aggregate density distribution. Afterwards, a mechanical test is imposed via a Finite Element (FE) program in order to study the mechanical response of the material. Next, certain properties of the material are chosen in order to study their statistics in different parts of the global behaviour. Finally, conclusions are made about the existence of an RVE in any part of the global behaviour according to the statistical results.

The first two chapters introduce the present research and explain its objectives and methodology. Chapter three contains information about the mesh generation, the software used for the generation and the final results and parameters of the meshes. Chapter four explains the code and the FE program used for the numerical simulations. For that, some preliminaries of damage mechanics are introduced. Results of the mechanical behaviour are summarized in chapter five and chapter six contains the statistical analysis of the previous results. Finally, conclusions about the results of this research are presented in chapter seven.

1.1 Related Studies

Previous studies have been elaborated in order to determine the RVE for a certain property of the material. Here we explain some of them. Specially the first one has the closest content to the present text.

In reference [4] a numerical approach is proposed to quantify the size of RVEs for materials that consist of particles in a matrix. Various particle distributions of different densities are generated and used as input for nonlinear finite element simulations. Also a statistical procedure is used to determine averages and standard deviations for each test series. It is found in the study that the size of the RVE depends on the mechanical property used in the statistical procedure (e.g. peak load, dissipated energy or strain intensity factor). Furthermore, the sensitivity to these three properties is assessed. The study concludes that the output quantity from the FE computations strongly determines the size of the RVE. Furthermore the size of the RVE depends on the particle density [4]. The study also shows that there is a sensitivity of the criteria to particle size distribution. It is found that for the peak load criterion and dissipated energy, a replacement of smaller particles by larger is allowed. On the other hand the strain concentration factor appears to be sensitive to the particle size distribution [4].

In reference [5] a methodology is developed to arrive at a sufficiently small micro-structural window that can be regarded as a RVE of a non-uniform micro-structure of a ceramic matrix composite containing a range of fiber sizes and fiber-rich and poor regions. The methodology involves a quantitative characterization of the geometry and spatial arrangement of the micro-structural features using stereological and image analysis techniques, development of micro-structure simulated model and finite elements
based simulations of the mechanical response. Such an RVE is useful for realistic simulations of damage initiation.

Reference [6] investigates the dependence of the strength transverse to the distribution of fibers in the cross-section of a unidirectional composite. The results provide some useful insight into the importance of non-uniform spatial distribution with regard to the transverse failure of composites [6].

We could also cite more studies but their common aim is already clear: the transition from a heterogeneous micro-structure to a homogeneous continuum model because of the latter's obvious advantages in simulating large scale engineering structures.