Numerical strategies for prediction of drying cracks in heterogeneous materials: Comparison upon experimental results

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Both experimental and numerical studies are presented dealing with the separation, identification and quantification of drying shrinkage incompatibilities effects between cement paste and aggregate on mechanical behaviour of cementitious materials. The experimental protocol allows us to separate these effects due to the material heterogeneity from the structural ones (drying shrinkage gradient). In order to limit the parametric study to size and volume fraction effects, a “model” (controlled) material, composed of cement paste and cylindrical sandstone aggregates, is considered. Cracking observation is undertaken using digital image correlation. These experimental investigations have been completed by a numerical study to evaluate the ability of two different models (using either smeared or discrete cracks description) to describe the experimental behaviour observed at the mesoscopic scale.

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1. Introduction
Exposing a concrete structure to low relative humidity conditions (for example after formwork removal) leads to a hygrometrical imbalance. Water transport is so induced inside the material from the core toward the outside so as to retrieve equilibrium (in terms of relative humidity RH). During this drying, concrete undergoes an apparent shrinkage called drying shrinkage [1]. The latter leads to self-stresses induced at different scales. At macro scale, drying at the surface of the structure generates moisture gradients inside the structure which will induce drying shrinkage gradients and thus stress gradients [2,3]: compression in the core and tension near the surface. This structural effect is associated with the apparition of microcracks (openings less than 50 µm) near the drying surface and perpendicular to this surface [2,4]. At meso-scale, we have to consider the two main components of concrete: cement paste and aggregates. Cement paste shrinkage is restrained by the aggregates leading to debonding at the cement paste/aggregate interfaces (circumferential cracks) and to the growth of intergranular cracks (radial cracks) [5,6]. These mechanical effects can be prejudicial for the durability of these concrete structures (e.g. superficial cracks inducing an increase of diffusion and permeability). To accurately predict the durability of these structures requires the development of a powerful numerical tool to account for the influence of drying loadings on the mechanical response.

The aim of the following subsection (Section 1.1) is to present the motivation of the realized works: drying effects prediction for cement paste composites (in terms of cracking and mechanical properties evolution). To that aim, the next parts (Sections 1.2 and 1.3) describe the experimental and numerical approaches.

1.1. Motivation
An accurate prediction of concrete’s behaviour during drying implies a good understanding of these two types of cracking (structural drying shrinkage gradients and strain incompatibilities effects) and the ability of predicting their respective parts in the global mechanical response. Many papers deals with the structural effects of drying, reporting qualitative and quantitative experimental (e.g. [4,6–8]) and numerical studies (e.g. [3,8–12]). Few works [6,13–16] have been devoted to cement paste and aggregates strain incompatibilities. These lack of numerical and experimental knowledge of this heterogeneity effect can be explained, first by the difficulty to separate the two scales effects on concrete’s cracking. Moreover, a lot of parameters are involved on aggregates effects on a drying concrete specimen (e.g. size, aggregate content, shape, distribution, aggregates type, rugosity, and interfacial transition zone) which increases these difficulties. Consequently, separating and quantifying aggregates effects with classical experiments is an important challenge. However, without