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Computational Homogenization of Thin Walled Structures: On the Influence of the Global vs Local Applied Plane Stress Condition

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Abstract : The increased application of novel structural materials, such as high grade asphalt, concrete and laminated composites, has sparked the need for a better understanding of the often complex, non-linear mechanical behavior of such materials. The effective macroscopic mechanical response is generally dependent on the applied load path. Moreover, it is also significantly influenced by the microstructure of the material, e.g. embedded fibers, voids and/or grain morphology. At present, multiscale techniques are widely adopted to assess micro-macro interactions in a numerically efficient way. Computational homogenization techniques have been successfully applied over a wide range of engineering cases, e.g. cases involving first order and second order continua, thin shells and cohesive zone models. Most of these homogenization methods rely on Representative Volume Elements (RVE), which model the relevant microstructural details in a confined volume. Imposed through kinematical constraints or boundary conditions, a RVE can be subjected to a microscopic load sequence. This provides the RVE's effective stress-strain response, which can serve as constitutive input for macroscale analyses. Simultaneously, such a study of a RVE gives insight into fine scale phenomena such as microstructural damage and its evolution. It has been reported by several authors that the type of boundary conditions applied to the RVE affect the resulting homogenized stress-strain response. As a consequence, dedicated boundary conditions have been proposed to appropriately deal with this concern. For the specific case of a planar assumption for the analyzed structure, e.g. plane strain, axisymmetric or plane stress, this assumption needs to be addressed consistently in all considered scales. Although in many multiscale studies a planar condition has been employed, the related impact on the multiscale solution has not been explicitly investigated. This work therefore focuses on the influence of the planar assumption for multiscale modeling. In particular the plane stress case is highlighted, by proposing three different implementation strategies which are compatible with a first-order computational homogenization framework. The first method consists of applying classical plane stress theory at the microscale, whereas with the second method a generalized plane stress condition is assumed at the RVE level. For the third method, the plane stress condition is applied at the macroscale by requiring that the resulting macroscopic out-of-plane forces are equal to zero. These strategies are assessed through a numerical study of a thin walled structure and the resulting effective macroscale stress-strain response is compared. It is shown that there is a clear influence of the length scale at which the planar condition is applied.

Keywords : first-order computational homogenization, planar analysis, multiscale, microstrucutures
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