Incremental Transformation Field Analysis for Heterogenous Composite Materials using Numerically Determined Interaction Tensors

Kevin Spilker, Ludovic Noels, Ling Wu

Two-scale simulations for multiscale modeling purposes require the solution of boundary value problems for each macroscopic material point. Each macroscopic point contains a representative volume element (RVE) that exhibits the micro-structure of the material, constituted by microscopic points. When dealing with complex heterogeneous micro-structures, the computational effort to solve the boundary problems for all macroscopic points is immense. In order to make multiscale simulations utilizable for a wider range of purposes, a reduction of the computational complexity is indispensable. A reduction of the systems internal variables can be achieved by a decomposition of the full RVE into several subdomains, constituted by clusters of microscopic material points. Constitutive equations need to be solved for all subdomains instead of for all microscopic points in the so-called “online” stage, using quantitites pre-computed in the “offline” stage. In this work, the Transformation Field Analysis (TFA) strategy is implemented, assuming uniform stress and strain fields within the subdomains (Dvorak, 1992). The division of all microscopic points into the clusters depends on their mechanical behavior, represented by the strain concentration tensors at all microscopic locations. The subdivision based on the mechanical behavior is expected to improve results in the elasto-plastic range due to the enhanced ability to account for strain concentrations, a known shortcoming of the original TFA method. The constitutive equations for the TFA model are coupling relations between the macroscopic internal variables and the internal variables in the single subdomains. The coupling equations rely on the “offline” and once for all computed strain concentration tensors of the subdomains, representing the distribution of the applied macroscopic strain in the single subdomains. After the onset of plasticity in one or more subdomains, interactions between the occurring plastic strain, treated as present eigenstrains in the corresponding subdomains, and the strain in the other clusters need to be taken into account to compute the overall RVE response. These influences rely on eigenstrain – strain interaction tensors, which are also determined once for all and numerically. The numerical instead of analytical determination of the interaction tensors allows to account for eigenstrain influences in highly heterogeneous and anisotropic geometries. For the solution of the TFA equations in the “online” stage, an increasing number of clusters provides more accurate results due to a better capability to represent plastic strain effects. The incremental tangent stiffness is commonly utilized to account for the inelastic deformation in the single subdomains. However, this approach can lead to over-stiff results according to various numerical findings. In order to recuperate this shortcoming, a different approach was tested: the use of the incremental secant stiffness instead of the incremental tangent stiffness for the subdomains. The incremental secant stiffness is determined by a virtual elastic unloading step to a vanishing stress of the homogenized material and computation of the new internal variables of the subdomains from the total unloaded state. The use of the incremental secant stiffness instead of the incremental tangent stiffness is expected to provide more accurate results and an improved way for the modeling of the material behavior under non-proportional loading conditions.

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