The VE2 method: the Virtual Element Method for Multiscale Computational Analyses with Polycrystalline Microstructures

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Abstract

The efficient integration of micromechanical relationships into macroscopic modeling is crucial for accurately capturing micromechanical effects under macroscopic load conditions. However, achieving the desired level of accuracy often requires increased discretization, which in turn raises computational costs in real-world material analyses. This talk investigates the performance of the Virtual Element Method (VEM) in multiscale computational analyses of structures characterized by crystalline microstructures. VEM's inherent flexibility in accommodating arbitrary element shapes allows for direct discretization of existing (crystalline or composite) microstructures using element-to-grain approaches.
The discussion begins with an exploration of some advantages of employing VEM-based formulations in staggered schemes based on numerical homogenization schemes. These advantages are demonstrated by addressing a broad range of material responses, from nonlinear elasticity and dissipative processes to complex multi-physics phenomena. It then shifts focus to monolithic formulations, which integrate microscopic response calculations based on VEM directly into macroscopic boundary value problems solved either through FEM or VEM. Analogously to FE2, these are denoted as VE2 or FE-VE schemes. The multiscale integration is achieved through a consistent sensitivity analysis approach tailored to virtual elements and developed for various stabilization schemes.
Results demonstrate that VEM-based monolithic schemes enable fully multiscale simulations at just 10% of the computational cost of corresponding FE2 simulations. This significant cost reduction arises from enhanced flexibility in mesh generation, improved solution space properties, and the inherent low order integration of the method. These advantages firmly establish VEM as a highly promising tool for multiscale computational analyses in real engineering contexts.

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