Three dimensional quasi-static multi-scale analysis of metals by using the marker integration Eulerian FEM

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ABSTRACT

In this paper, the multi-scale simulation method has been applied to the simulations for severe plastic deformations of metals, such as ECAP (Equal Channel Angular pressing). To achieve the high strength metals with finer grains in their microstructures, the severe plastic deformations are now under development in metalworkings. The ECAP technique is one of the most famous severe plastic deformation processes, in which, the change in the geometries of test pieces is very small, and very large shearing strains (over 1.0) are achieved. From the view point of numerical simulation for these SPD processes, the implicit Lagrangian finite element methods with elasto-plasticy fail because of mesh crashing or over distortion of meshes. So the rigid-plastic models and Euler type finite element method are employed for these problems[1]. Eulerian approach, the computational meshes define the entire domain of interest and remain fixed in space and the transportation of the solution variables should be evaluated by solving the advection equation, which may have a tendency to diffuse in numerical methods. To overcome such a difficulty, the material point method (MPM)[2] has been developed and applied successfully to the elastoplasticity[2]. The MPM combines the Lagrangian description, using material points, with an Eulerian mesh and then advection equations and numerical diffusion of material variables can be avoided.

The authors have firstly developed the marker integration Eulerian finite element method for large deformation problems of solid. In this approach, the characteristic Galerkin approximation in time is employed and the marker particles are utilized not only for tracking the interface but also the numerical integration as sampling points in a similar way of the material point method (MPM). In this approach, the Lagrangian particle has no mass in contrast to MPM. This methodology is then applied three dimensional quasi-static analysis of incompressible hyperelasticity, which is a representative character of rubber-like materials or metals. Incompressibility is handled by a mixed variational formulation in which displacement and pressure fields are taken as unknown variables. In its finite element approximation, linear tetrahedral element is employed for the displacement field and piecewise constant pressure is assumed for each element. This combination of displacement and pressure violates the inf-sup condition that ensures the existence of a unique solution and hence a stabilization procedure penalizing the jumps over the element edges of the piecewise constant pressures is introduced.

Then, the methodology is applied to the multi-scale simulations[3] for severe plastic deformation processes, in which, the microscopic computations for RVE are defined at every integration points in macroscopic FE models. The advantage of the method, that is all of the deformation histories are stored at Lagrangian particle, makes our implementation easy. That is there is no computation on the transportations of "Unit cells". Some benchmark problems and examples of ECAP simulations with more than 100% shearing strains would be presented to show the advantage.

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