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MODELING OF METAL FORMING PROCESSES VIA THE ENRICHED X–ALE–FEM TECHNIQUE

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ABSTRACT

In large deformation analysis with large mass fluxes, the conventional finite element technique using the updated Lagrangian formulation may suffer from serious numerical difficulties when the deformation of material is significantly large. This difficulty can be particularly observed in higher order elements when severe distortion of elements may lead to singularities in the isoparametric mapping of the elements, aborting the calculations or causing numerical errors. In order to overcome this difficulty, the arbitrary Lagrangian– Eulerian (ALE) approach has been proposed in the literature [1, 2]. In ALE approach, the mesh motion is taken arbitrarily from material deformation to keep element shapes optimal.

In this paper, a new computational technique is presented based on the eXtended Finite Element Method for large deformation problems. An ALE technique is employed to capture the advantages of both Lagrangian and Eulerian methods and alleviate the drawbacks of the mesh distortion in Lagrangian formulation. The X-FEM procedure is implemented to capture the discontinuities independently of element boundaries. The process is accomplished by performing a splitting operator to separate the material (Lagrangian) phase from convective (Eulerian) phase, and partitioning the Lagrangian and relocated meshes with some triangular sub-elements whose Gauss points are used for integration of the domain of elements.

In ALE technique, the governing equations can be derived by substituting the relationship between the material time derivatives and referential time derivatives into the continuum mechanics governing equations. This substitution gives rise to convective terms in the ALE equations which account for the transport of material through the grid. Thus, the momentum equation in ALE formulation can be written similar to the updated Lagrangian description by consideration of the material time derivative terms. In addition, to describe the constitutive equation for nonlinear ALE formulation, the relationship between material time derivatives and referential time derivatives is specialized to the stress tensor.

In X-ALE-FEM analysis, the X-FEM method is performed together with an operator splitting technique, in which each time step consists of two stages; Lagrangian

(material) and Eulerian (smoothing) phases. In material phase, the X-FEM analysis is carried out based on an updated Lagrangian approach. It means that the convective terms are neglected and only material effects are considered. The time step is then followed by an Eulerian phase in which the convective terms are considered into account. In this step, the nodal points move arbitrarily in the space so that the computational mesh has regular shape and the mesh distortion can be prevented, however – the material interface is independent of the FE mesh.

The number of enriched nodes may be different during the X-ALE-FEM analysis, which results in different number of degrees-of-freedom in two successive steps. There are two main requirements, which need to be considered in the smoothing phase [3]. Firstly, due to movement of nodal points in the mesh motion process, a procedure must be applied to determine the new nodal values of level set enrichment function. Secondly, in the extended FE analysis, the number of Gauss quadrature points for numerical integration of elements cut by the interface can be determined using the sub-triangles obtained by partitioning procedure. However, in the case that the material interface leaves one element to another during the mesh update procedure, the number of Gauss quadrature points of an element may differ before and after mesh motion. Hence, an accurate and efficient technique must be applied into the Godunov scheme to update the stress values.

In order to present the capability of X-ALE-FEM model, the coining test by pressing a rigid component into the flexible elastic foam is analysed numericaly. In Figure 1, a good agreement can be observed between the deformed X-ALE-FEM and FEM configurations.

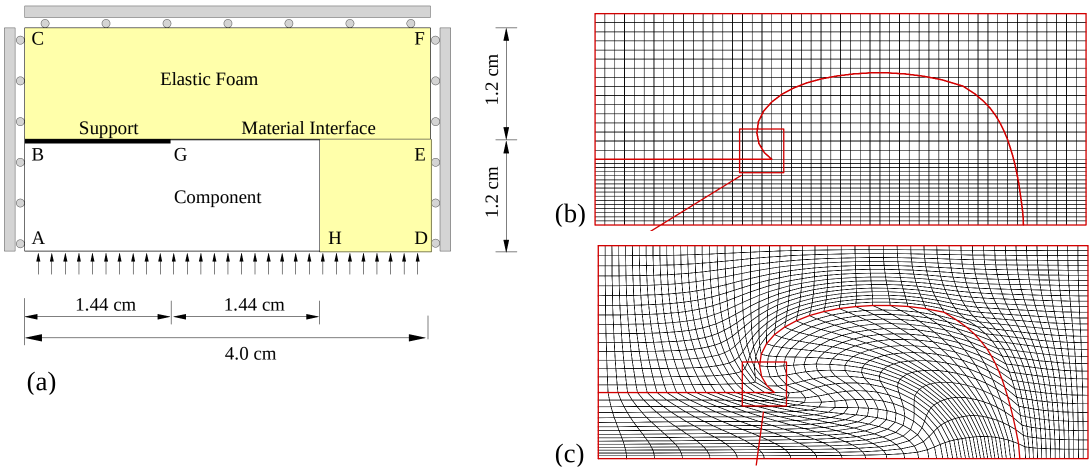

Figure 1. Coining test; a) Problem definition, b) Deformed X-ALE-FEM mesh, c) Deformed FEM mesh

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