Strain Localization Finite Elements and Their Application to Shear Banding, Fracture and Fragmentation

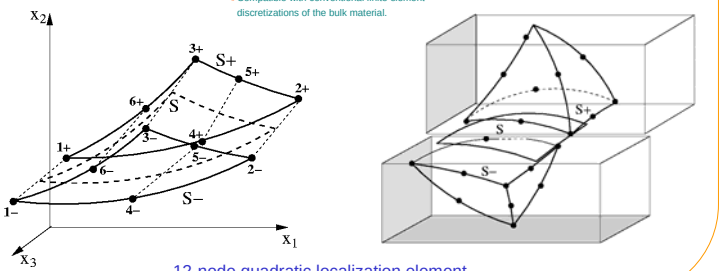
Qiang Yang, Alejandro Mota, Kerstin Weinberg, Jaroslaw Knap, Michael Ortiz

Localization Element Model

- **Multiplicative Decomposition of Deformation Gradient**

$$\boldsymbol{F} = \boldsymbol{F}^{\parallel}\boldsymbol{F}^{\perp} \quad \text{with} \quad \boldsymbol{F}^{\perp} = \boldsymbol{I} + \frac{\boldsymbol{\delta}}{h} \otimes \boldsymbol{N}$$

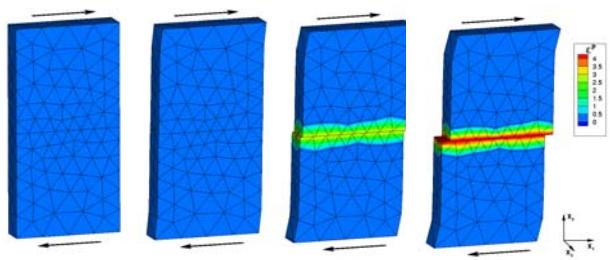
- Finite-deformation kinematics.
- Accurate and efficient.
- Simulation of strain localization.
- No additional constitutive assumptions required.
- Compatible with conventional finite element discretizations of the bulk material.



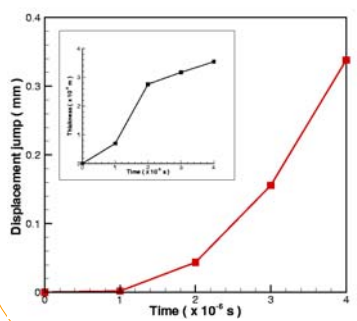
12-node quadratic localization element

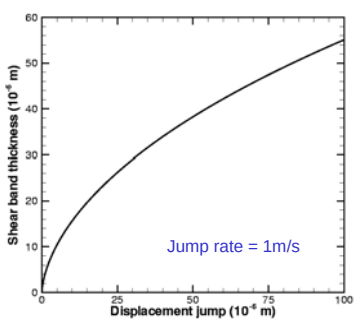
Variational Update of Localization Element Thickness

- Simple shear test.
- Localization elements are pre-inserted in the middle of the sample.
- A velocity field is applied with shear strain rate of 80.
- The sample is modeled as C300 steel with J2 plasticity and thermal updates.
- The evolution of the shear band thickness is obtained by minimizing a potential functional under a variational framework.



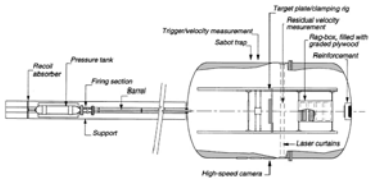
Time = 0 μs Time = 1 μs Time = 2 μs Time = 3 μs



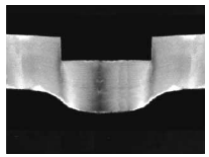


Ballistic Penetration of Mild-Steel Plate – Plugging

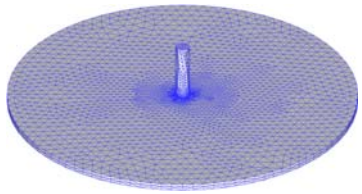
- Shear plug formation in circular steel plate impacted by blunt-nosed cylindrical projectile.
- Shear bands play an important role in the penetration of the target by the projectile.
- If no shear bands are formed, there is well-distributed plastic deformation.
- The formation of shear bands establishes the shear failure path and is responsible for the clean "plugging" of the target.
- The target has a diameter of 500mm with a thickness of 10mm.
- The length of the projectile is 80mm and its diameter is 20mm.
- The target material is mild-steel modeled with J2-plasticity with thermal updates.
- The projectile material is steel modeled with J2-plasticity with thermal updates.



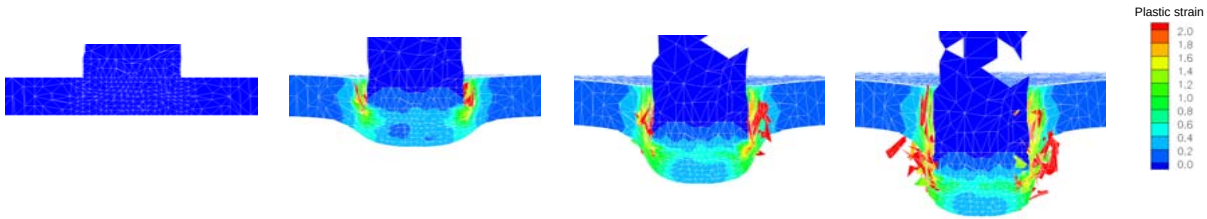
Experimental setup (Børvik et al., 2003)



Deformed sample (Børvik et al., 2001)



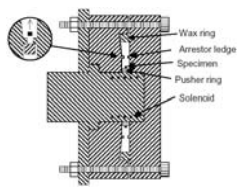
3D Mesh for simulation
6430 elements, 4 processors



Time = 0 μs Time = 33 μs Time = 66 μs Time = 99 μs

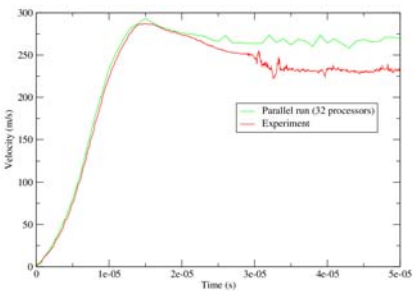
Fracture and Fragmentation of U-6%Nb Ring

- Forced expansion and ductile fracture and fragmentation.
- Outward radial force applied on the rings by a driver ring, which in turn interacts with a solenoid.
- When current is applied to the solenoid, a magnetic force is induced in the driver ring creating a uniform radial body force.
- The U-6%Nb rings are thus forced to expand and eventually fracture dynamically.
- The U-6%Nb rings have an inner diameter of 34.37mm, an outer diameter of 35.89mm, and thickness of 0.76mm.
- An arrestor ledge in the experimental device prevents the driver ring to expand beyond a diameter of 40.0mm.
- The U-6%Nb rings are allowed to expand driven by their kinetic energy, until they eventually fracture and fragment.
- The initial velocity applied to the U-6%Nb ring varies according to an accelerating voltages of 7.5kV



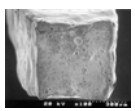
Experiment setup (Olsen et al., 2001)

Experimental result (Olsen et al., 2001)

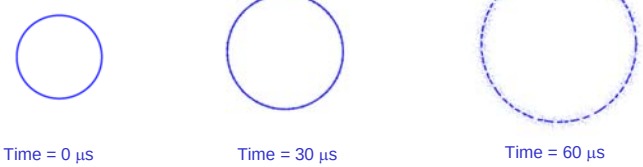


Velocity history for U-6%Nb ring

3D Mesh for simulation
32727 elements, 32 processors



Necking and ductile fracture (Olsen et al., 2001)



Time = 0 μs Time = 30 μs Time = 60 μs Time = 90 μs