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Advances in Computational Efficiency and Material Models

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MSC Software

Outline

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- Review of Solver Technology
- New Parallel Processing Capability
- Other Computational Improvements
- Granular (Powder – Soil) Material Model
- Particle Tracking

Review of Solver Technology

- Direct Solvers
  - Multifrontal
- Iterative
  - Internally Developed
  - CASI
- Mixed Direct / Iterative
- Domain Decomposition

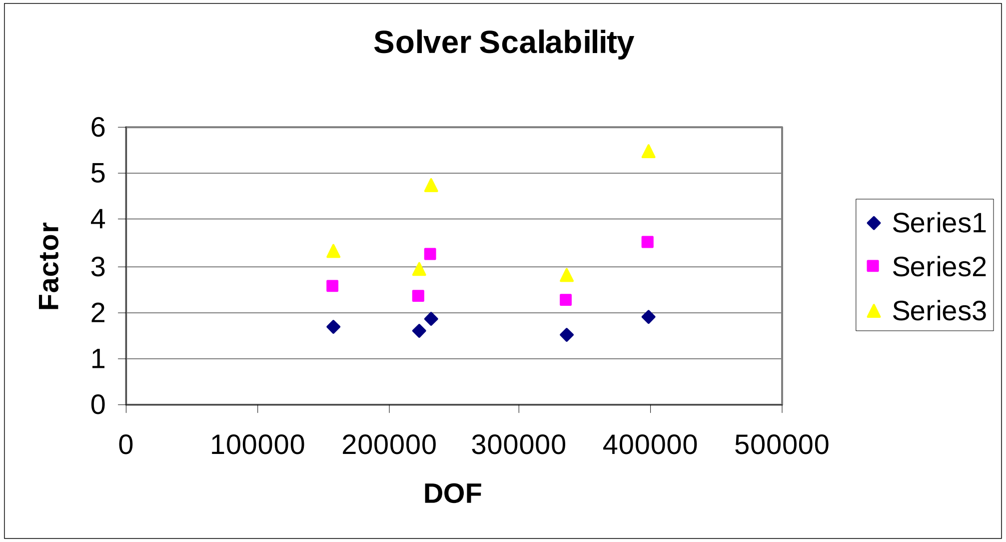
New Parallel Solvers

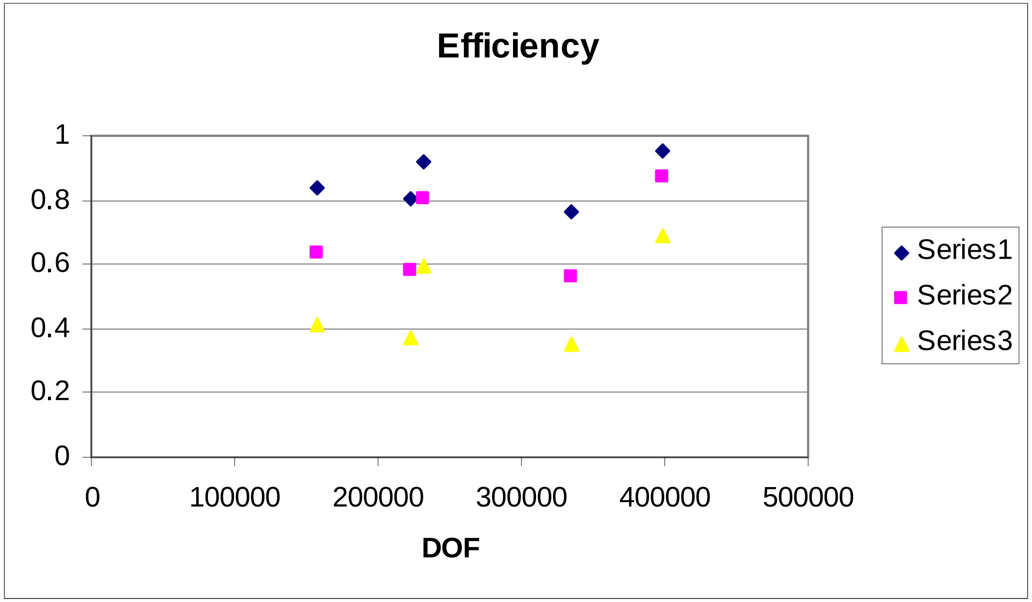
- Requirements to do Larger Problems Faster
- Multi-Core Chips Architecture
- Reduced Latency
- More Memory on the Chip

New Parallel Solvers

- Pardiso – Direct Shared Memory – Win 32, Win 64, Linux 32, Linux 64
- MUMPS – Direct Distributed Memory - Win 32, Win 64, Linux 32, Linux 64, IBM, possibly others
- DDM / Parallel Iterative – utilizing CASI - All

Pardiso

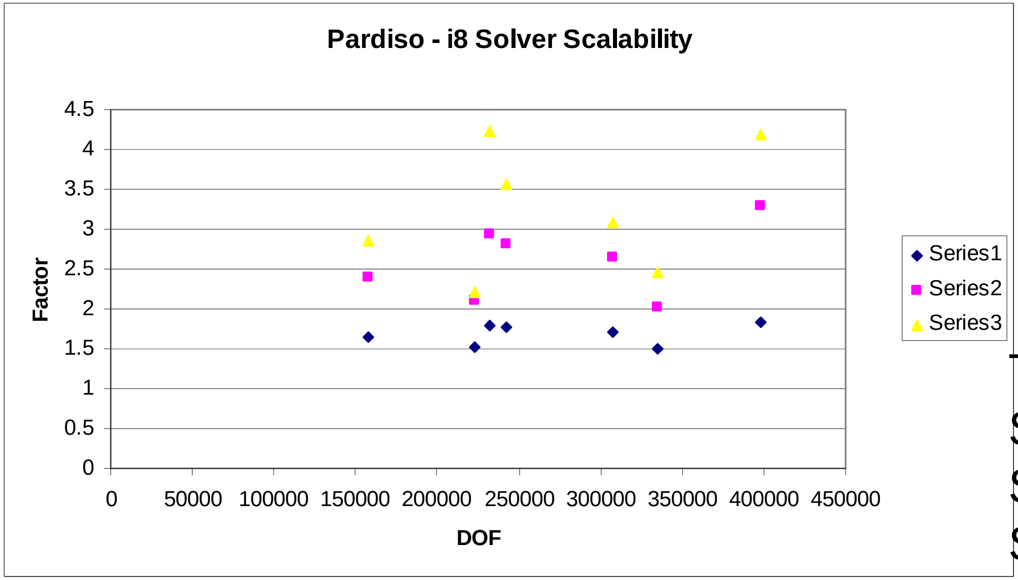




The legend indicates
Series 1 - 2 CPU
Series 2 - 4 CPU
Series 3 - 8 CPU

AMD –i4

Pardiso



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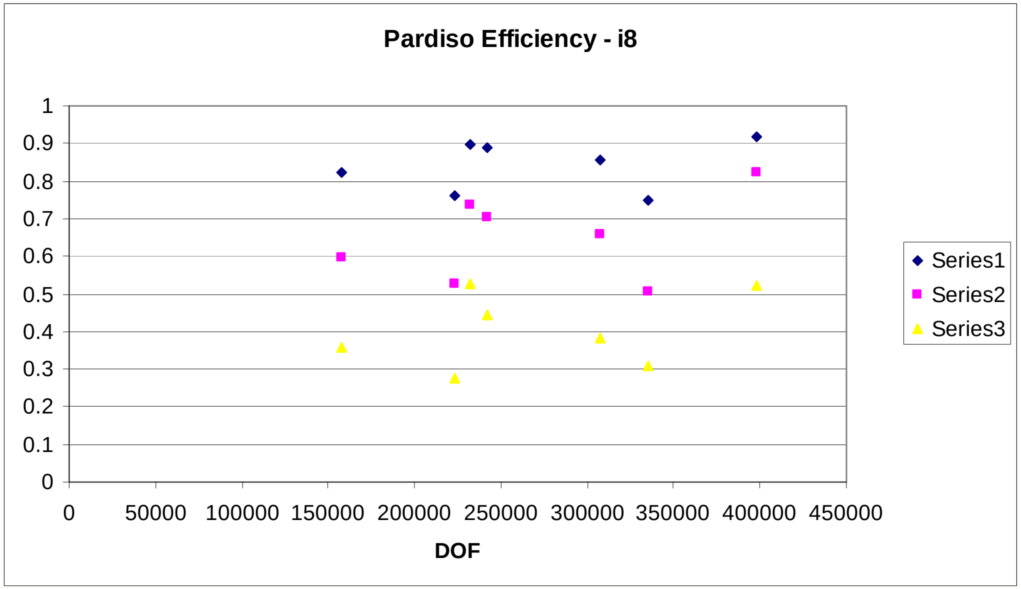
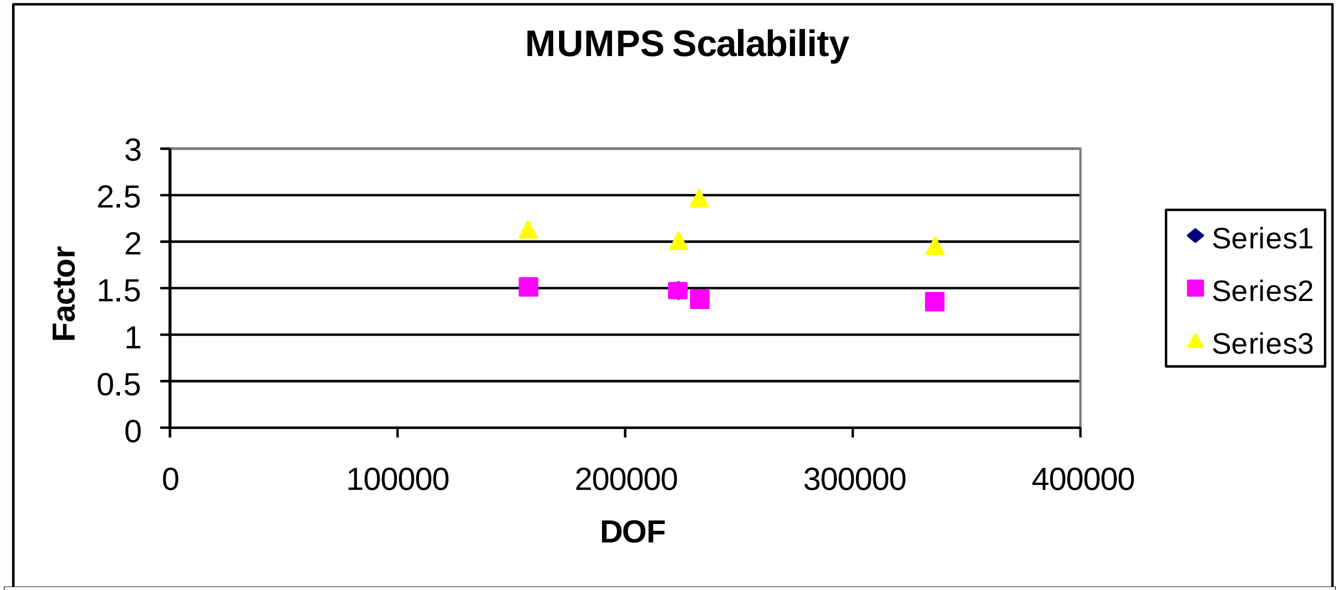
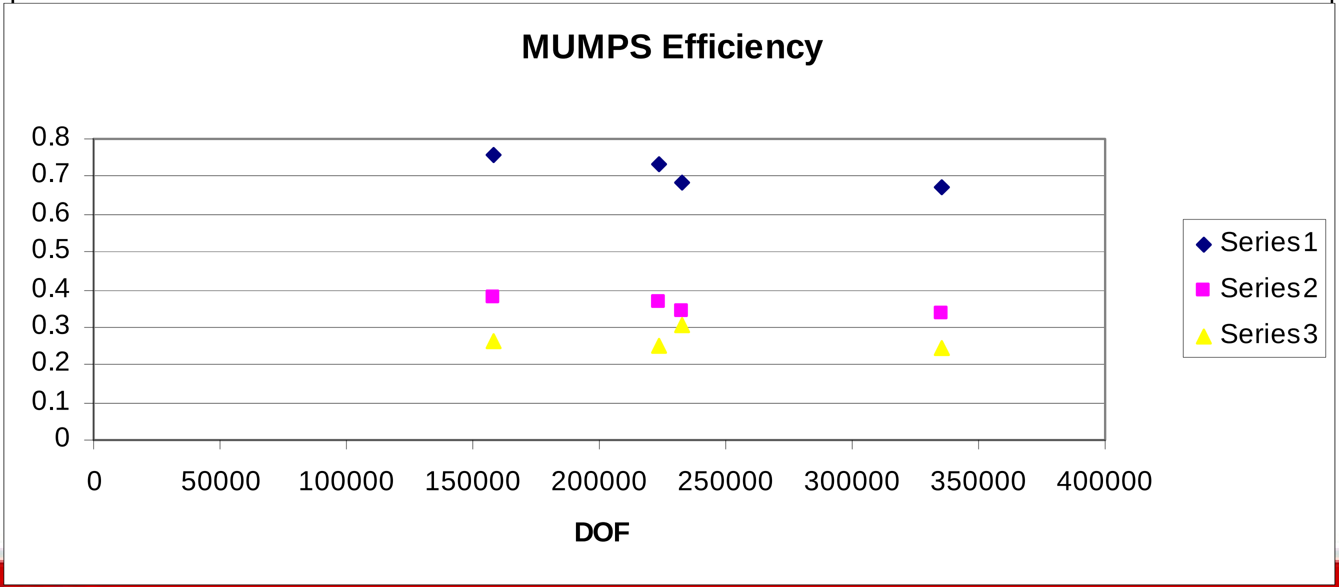


AMD –i8

MUMPS


MUMPS Scalability
Factor
3
2.5
2
1.5
1
0.5
0
0
100000
200000
300000
400000
DOF
Series1
Series2
Series3

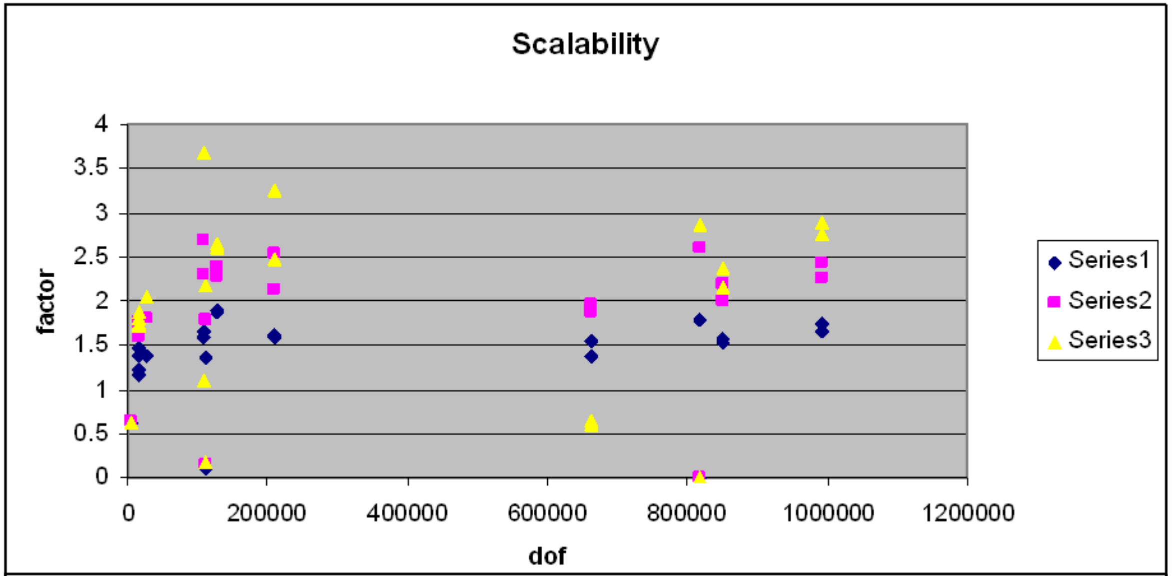

MUMPS Efficiency
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50000
100000
150000
200000
250000
300000
350000
400000
DOF
Series1
Series2
Series3

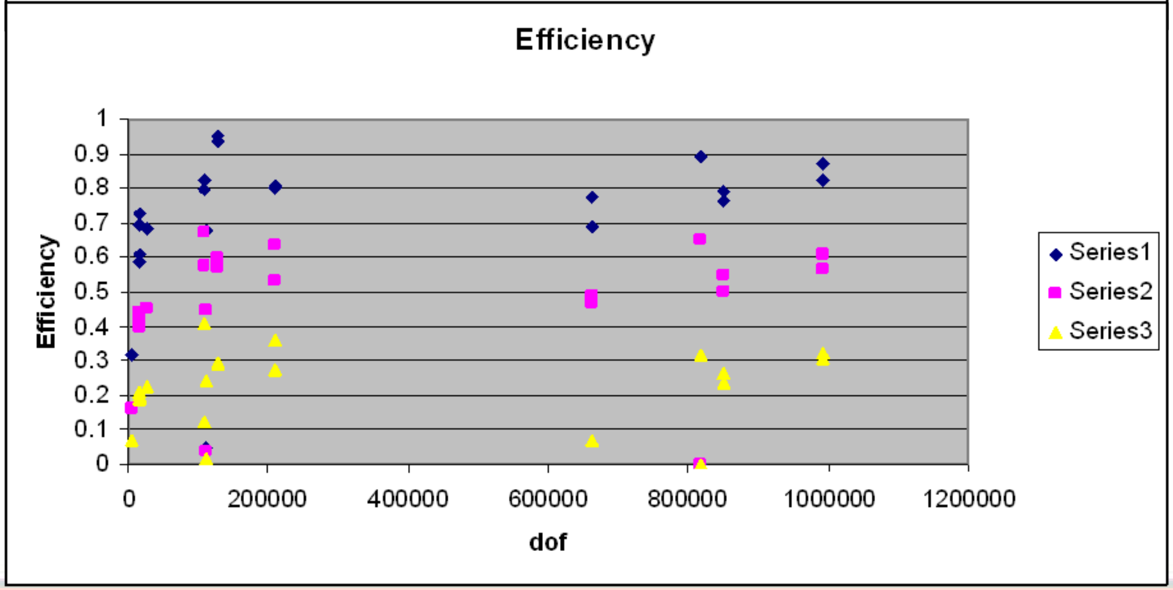
MUMPS

- 8 Distributed CPU – 1 GB Ethernet
- 2 Quad Core CPU

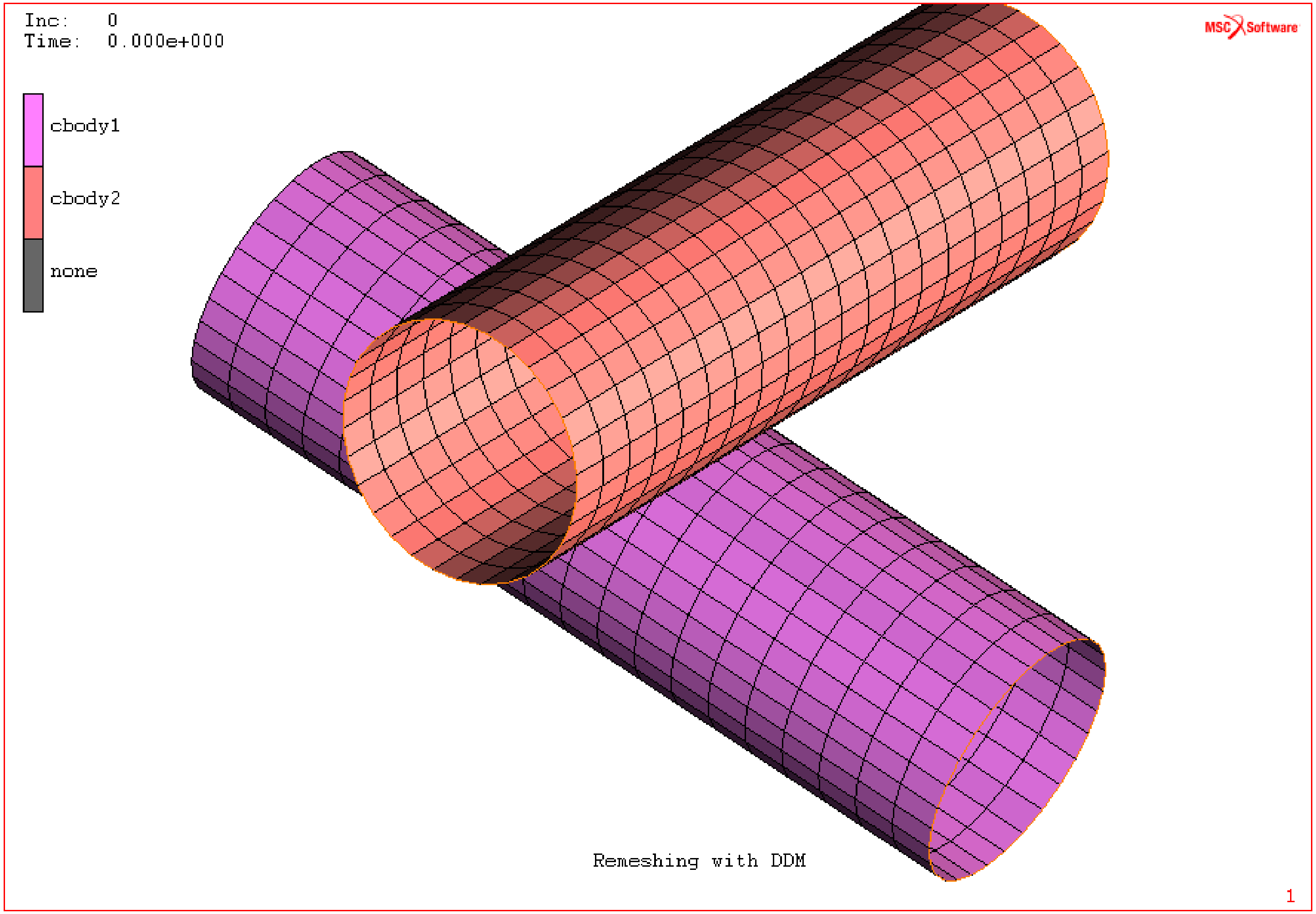
- 3.8 Scalability
- 4.5 Scalability

CASI


Scalability
factor
4
3.5
3
2.5
2
1.5
1
0.5
0
0
200000
400000
600000
800000
1000000
1200000
dof
Series1
Series2
Series3

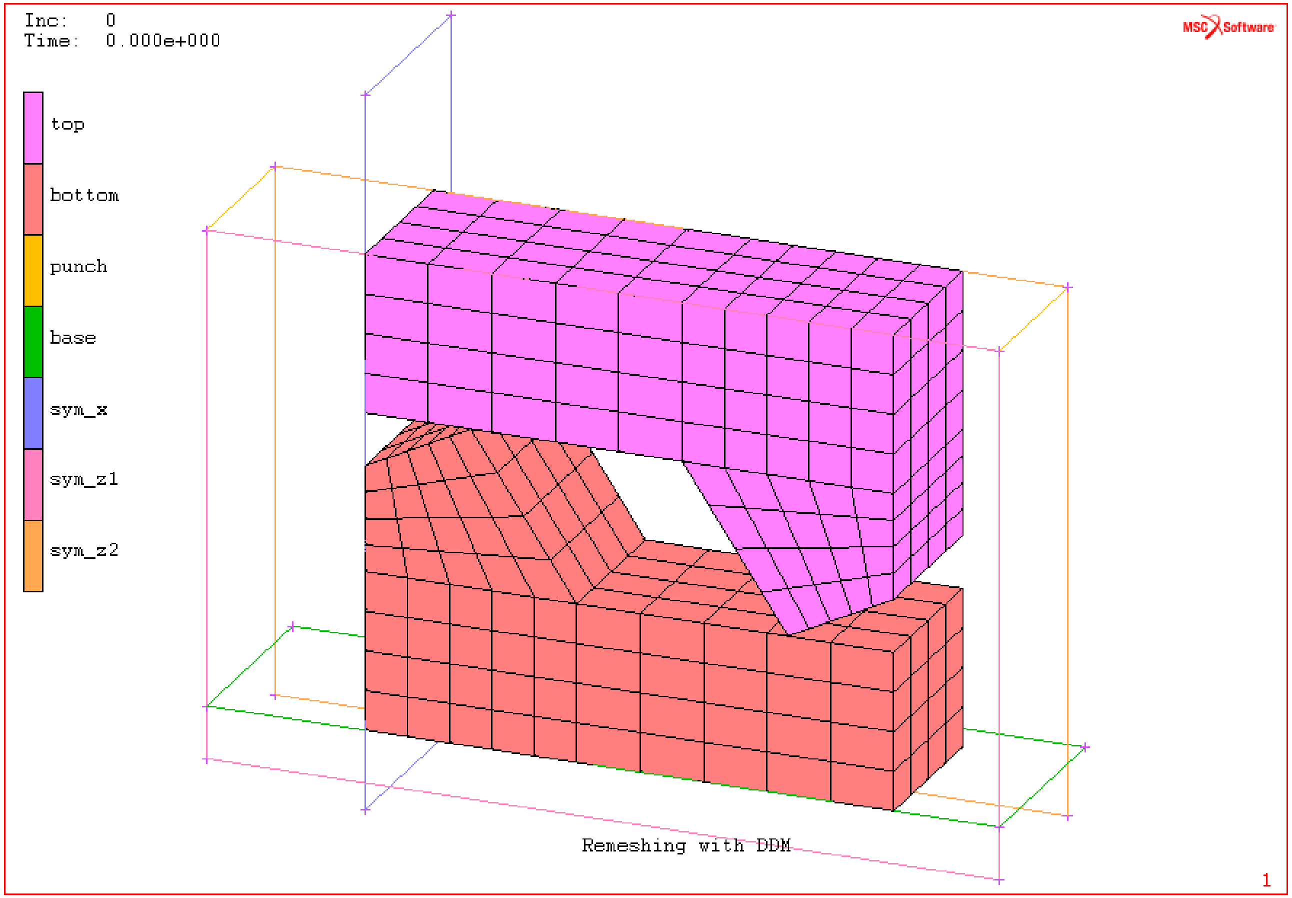

Efficiency
Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200000
400000
600000
800000
1000000
1200000
dof
Series1
Series2
Series3

Remeshing with DDM



25% reduction

Remeshing with DDM



32% reduction

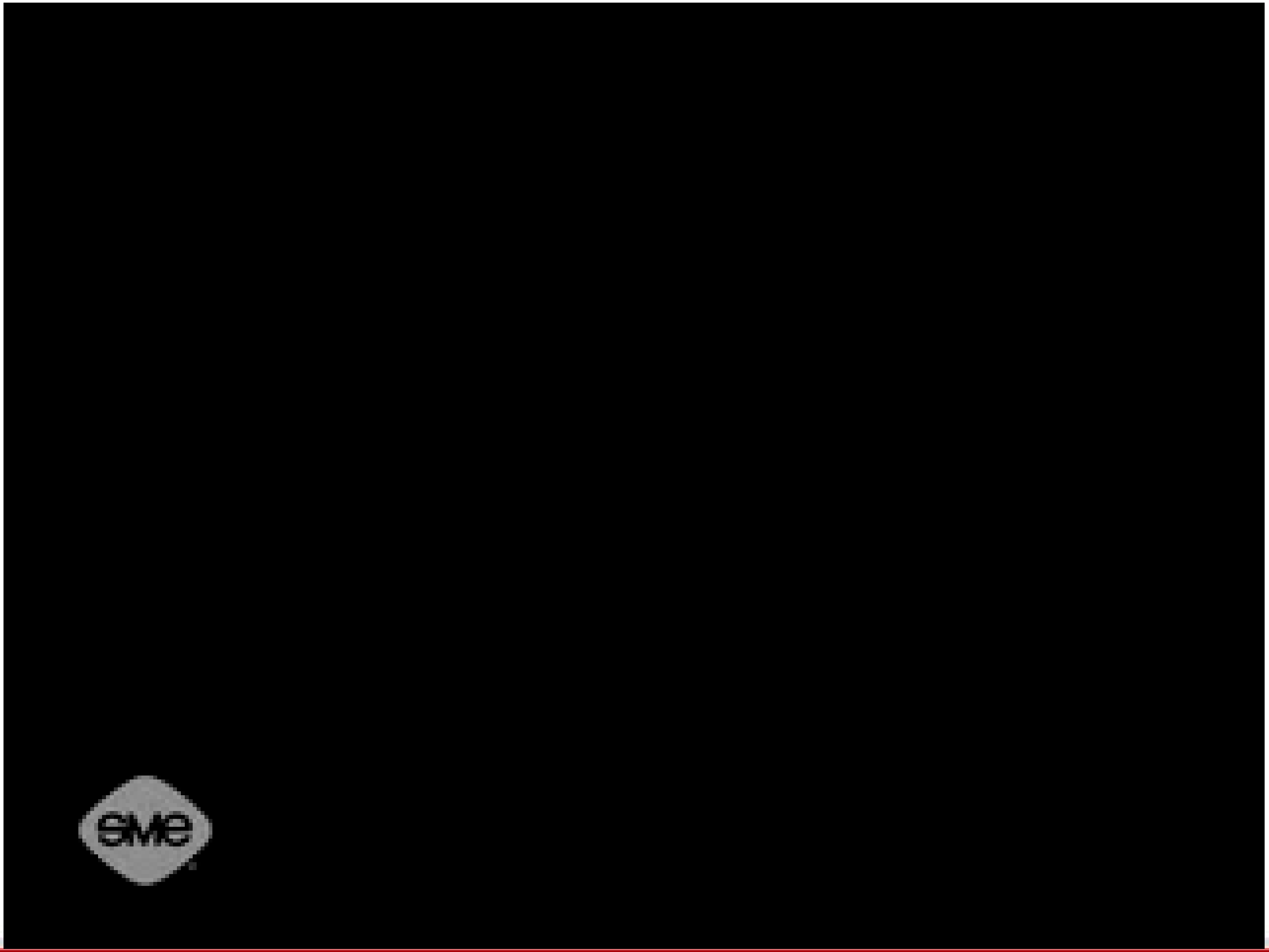
Powder Metallurgy

- High Quality Parts
- Manufacture Parts of Materials that are difficult to Machine.
-

Granular Material Modeling

- Soil / Powder is a compressible material and the yielding is dependent on hydrostatic stress.
- At low mean stress failure is by shear localization.
- At higher mean stress strain hardening behavior is observed, hence a moving failure surface is required.

Powder Metallurgy

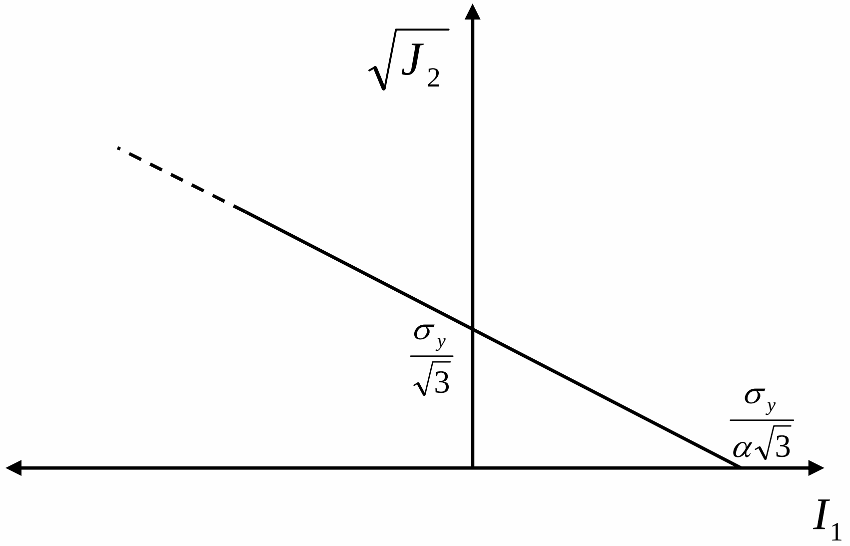


Linear Drucker-Prager

- Two parameter yield surface
- Takes hydrostatic stress dependence into account

$$f(I_1, J_2) = \alpha I_1 + \sqrt{J_2} - \frac{\sigma_y}{\sqrt{3}}$$

α, σ_y are material parameters.



Limitations:

- Densification is not taken into account

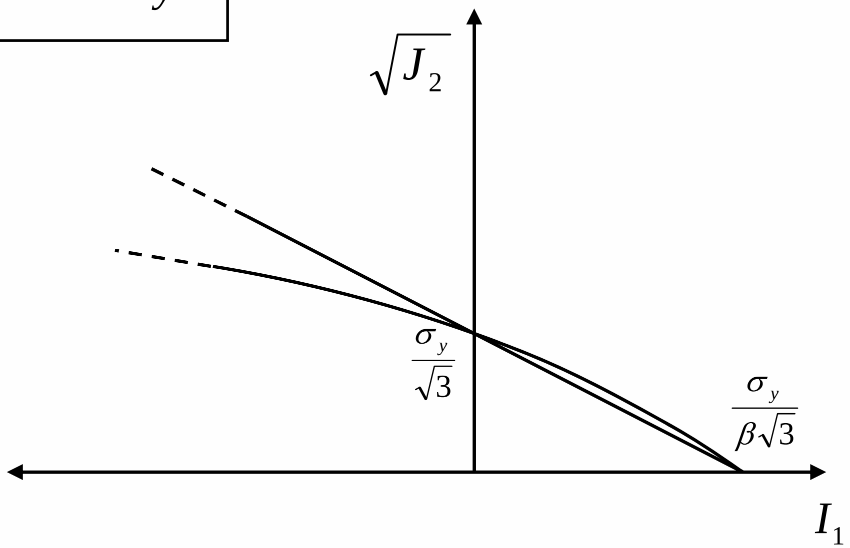
Note: Referred to as Linear Mohr-Coulomb in Marc

Parabolic Drucker-Prager

- Two parameter yield surface
- Takes hydrostatic stress dependence into account

$$f(I_1, J_2) = (3J_2 + \sqrt{3}\beta\sigma_y I_1)^{1/2} - \sigma_y$$

β, σ_y are material parameters.



Limitations:

- Densification is not taken into account

Note: Referred to as Parabolic Mohr-Coulomb in Marc

Shima-Oyane

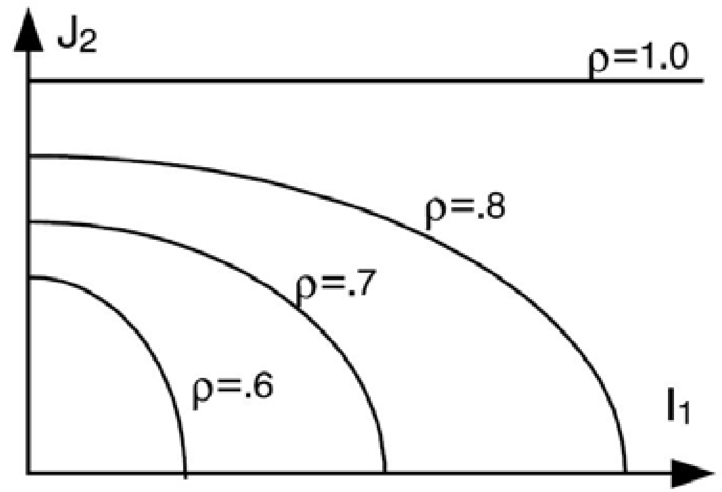
- Takes hydrostatic stress dependence into account
- Material parameters are functions of the relative density

$$f(p, J_2) = \frac{1}{\gamma}\left(J_2 + \frac{p^2}{\beta^2}\right)^{1/2} - \sigma_y$$

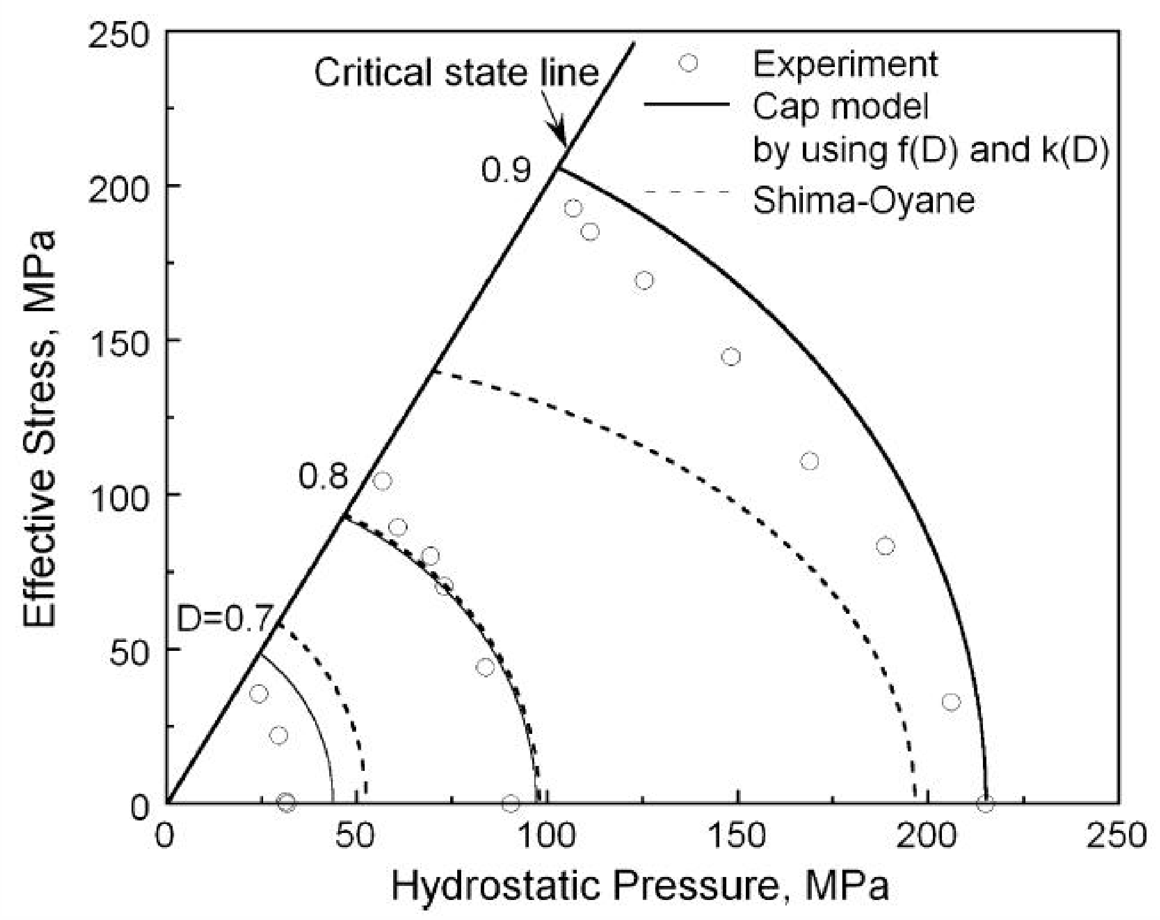
$\gamma(\rho)$ $\beta(\rho)$ are material parameters.

Limitations:

- In low and high density regions Shima-Oyane does not agree well with experimental data.



Comparison with experiments



[3] S.C. Lee et.al. 2007

Drucker-Prager Cap Plasticity

- Cap plasticity model captures shear localization failure at low mean stress and strain-hardening behavior at high mean stress
- Good agreement with experiments, better than Shima-Oyane

$$f_1(p, \sqrt{J_2}, \kappa) = \alpha p + \sqrt{J_2} - k$$

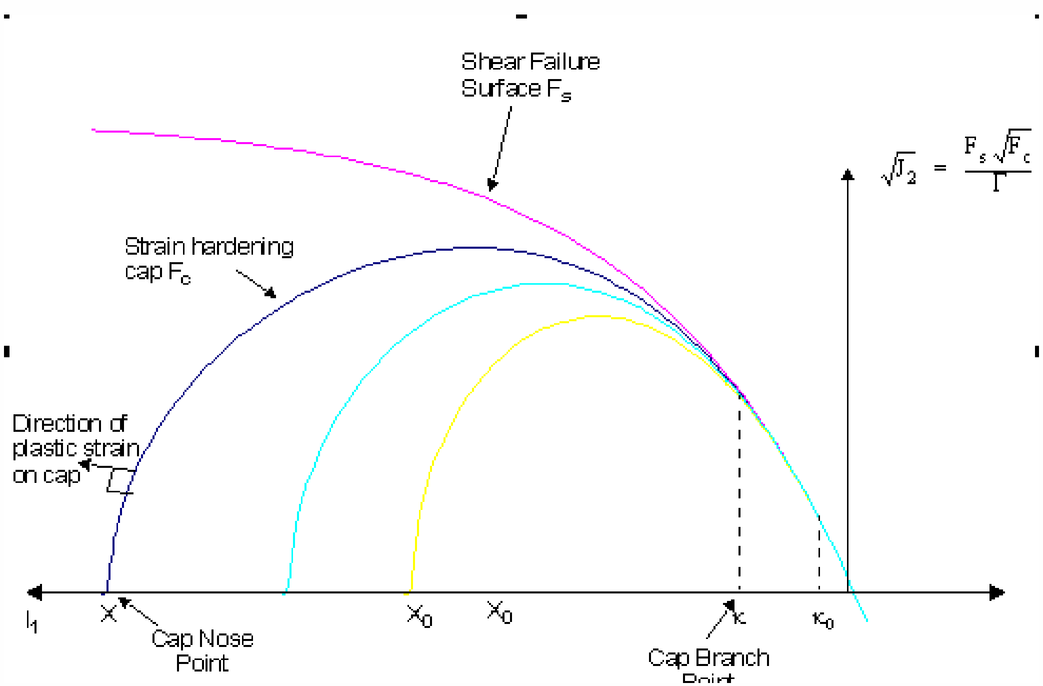
α, k are constants related to the angle of friction and cohesion of the material.

$$f_2(p, \sqrt{J_2}, \kappa) = -(p - \kappa) + R^2 J_2$$

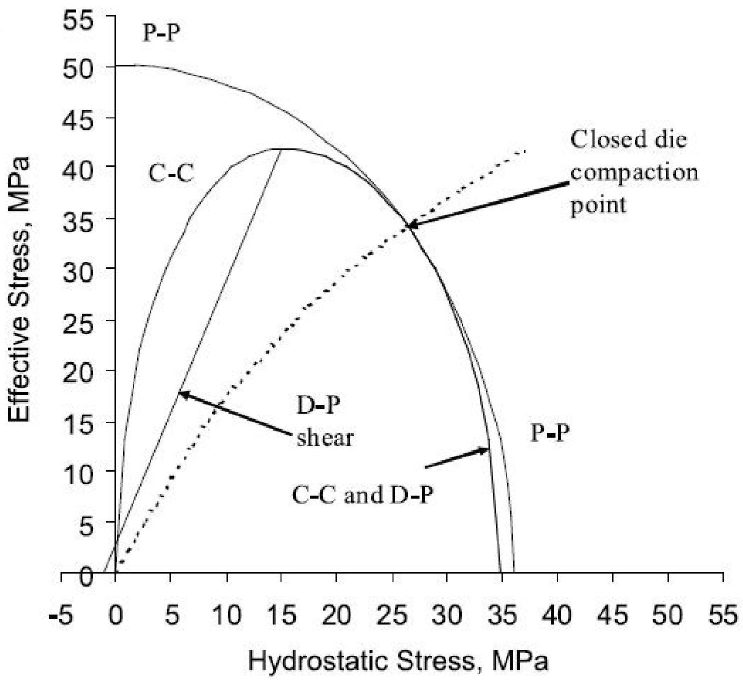
R is the shape factor

κ is the hardening parameter which is a function of the relative density

Yield Surface of the Cap model



Sandia Geomodel



P-P : Porous Plasticity
C-C : Cam-Clay
D-P : Drucker-Prager with Cap

[8] I.C. Sinka et.al.(2007)

Drucker-Prager Cap Plasticity

Limitations:

- Indeterminacy of flow direction at the intersection of the shear failure surface and cap hardening surface.
- Numerically excessive time is spent iterating to find the intersection of the shear failure surface and the cap hardening surface.
- Physically, a limitation is imposed on pre-failure dilatant deformation, contradictory to experiments.

Sandia Geomodel

Highlights:

- Geomodel has one continuous yield surface
- Allows cracks and voids to interact phenomenologically in a way which reproduces observed data better.
- Flexibility to reduce the model to other more classical models

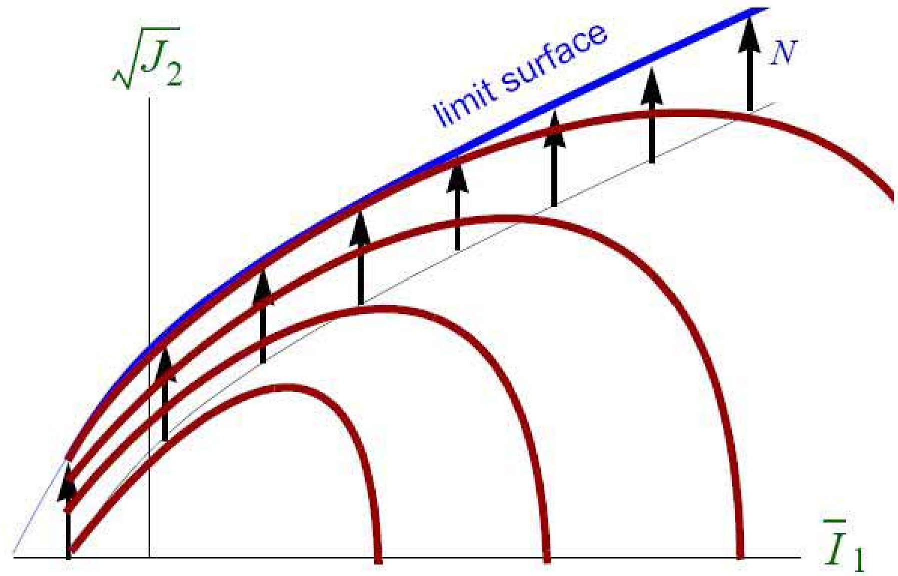
$$f(I_1, J_2, J_3; \kappa) = \Gamma^2(\bar{\theta}) J_2 - f_f^{\,2}(I_1) f_c^{\,2}(I_1, \kappa)$$

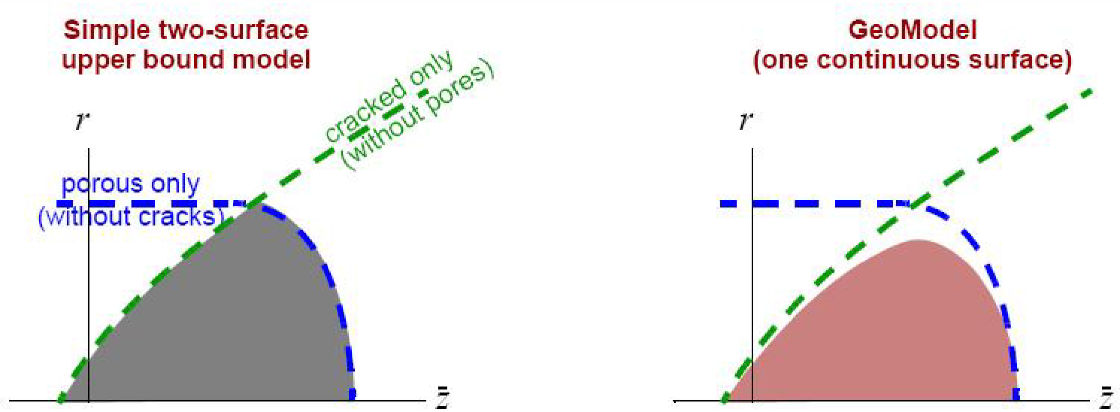
$$f_f = a_1 - a_3 e^{-a_2 I} + a_4 I_1$$

Shear Failure surface

$$f_c^{\,2}(I_1, \kappa) = \begin{cases} 1 & \text{if} \quad I_1 < \kappa \\ 1 - \left(\dfrac{I_1 - \kappa}{X - \kappa} \right)^2 & \text{otherwise} \end{cases}$$

Sandia Geomodel





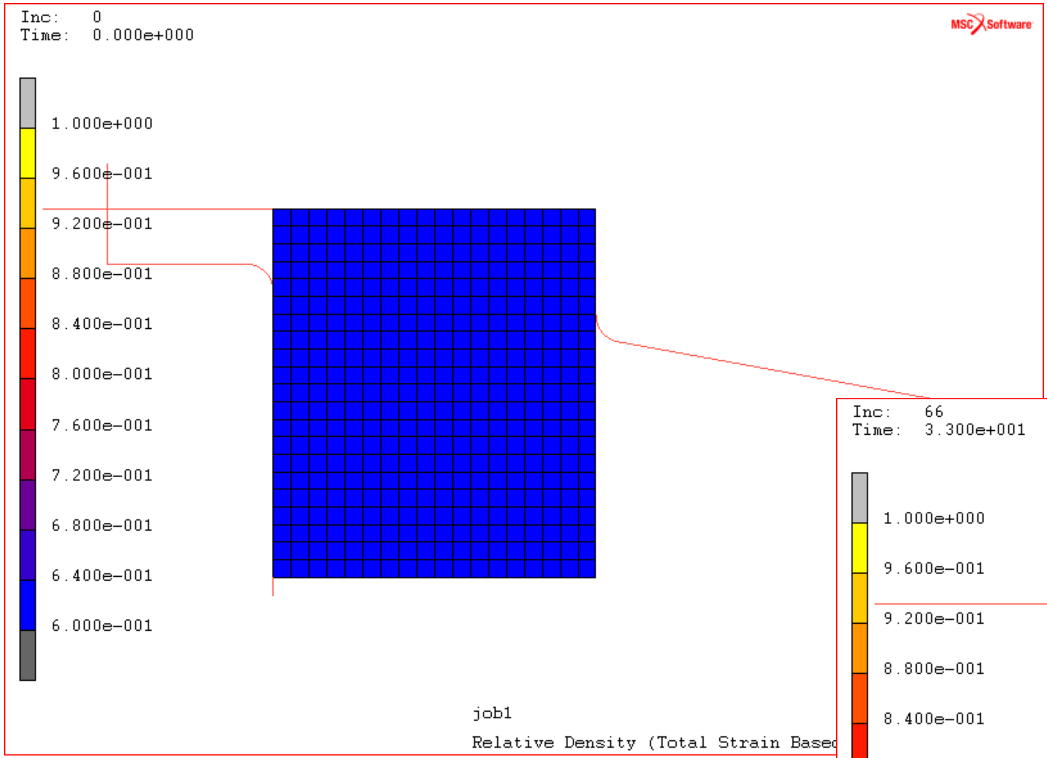
[6] A.F. Fossum et. al. (2004)

Sandia Geomodel

Limitations:

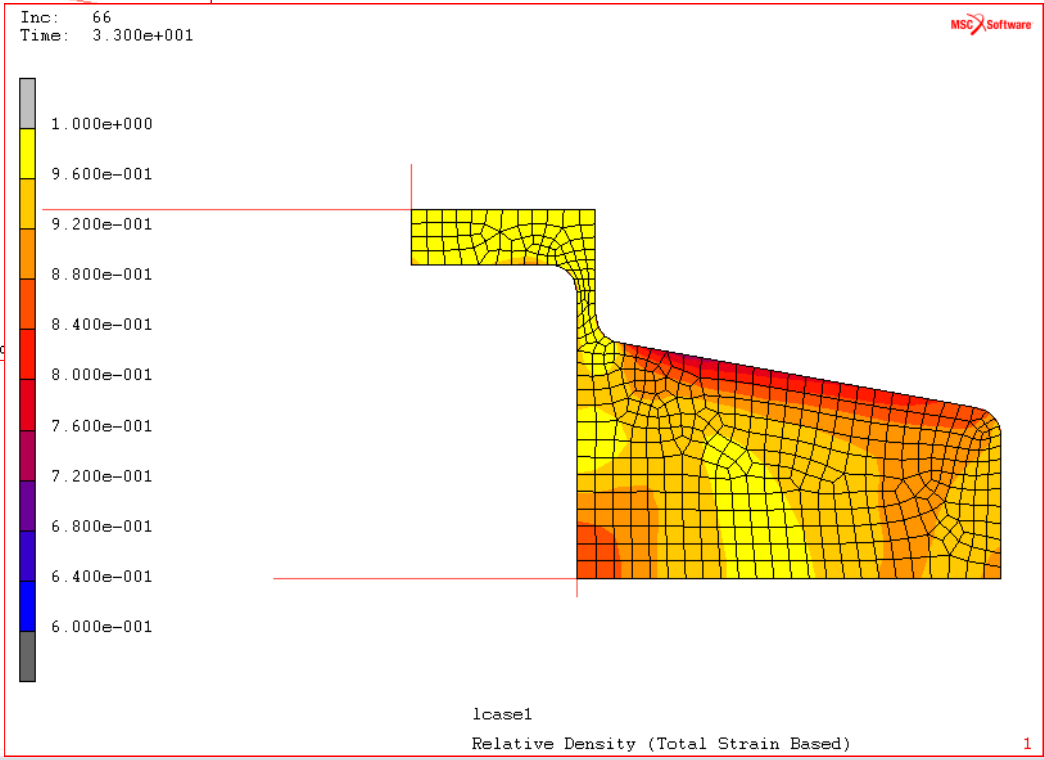
- Is initially isotropic, kinematic hardening is the only mechanism for deformation induced anisotropy.
- Geomodel is limited to relatively small distortional (shear) strains, large volume changes are permitted.
- Generation of the coefficients used in the model

Backward Extrusion with Powder material

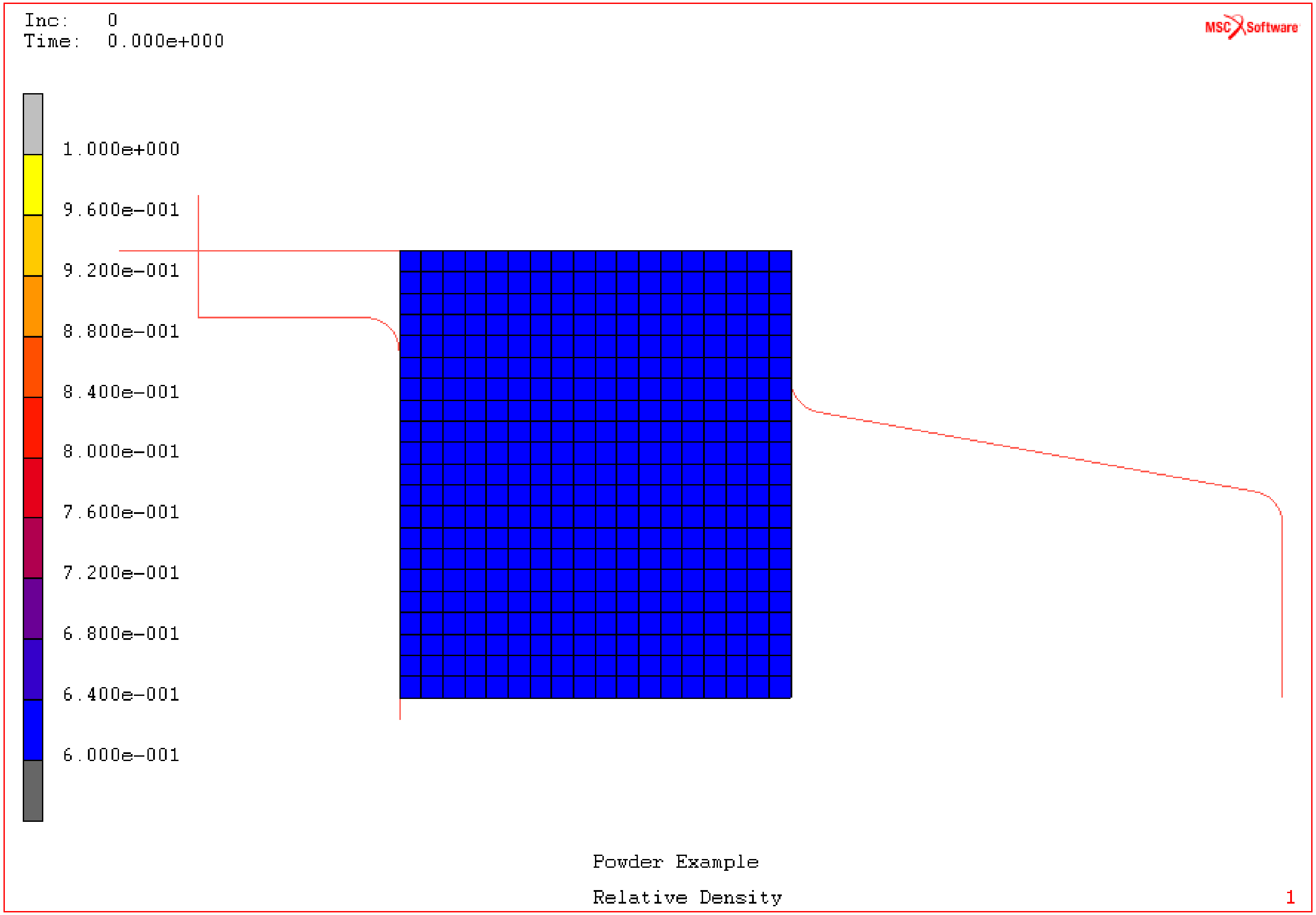


Extrusion setup with initial relative density=0.6

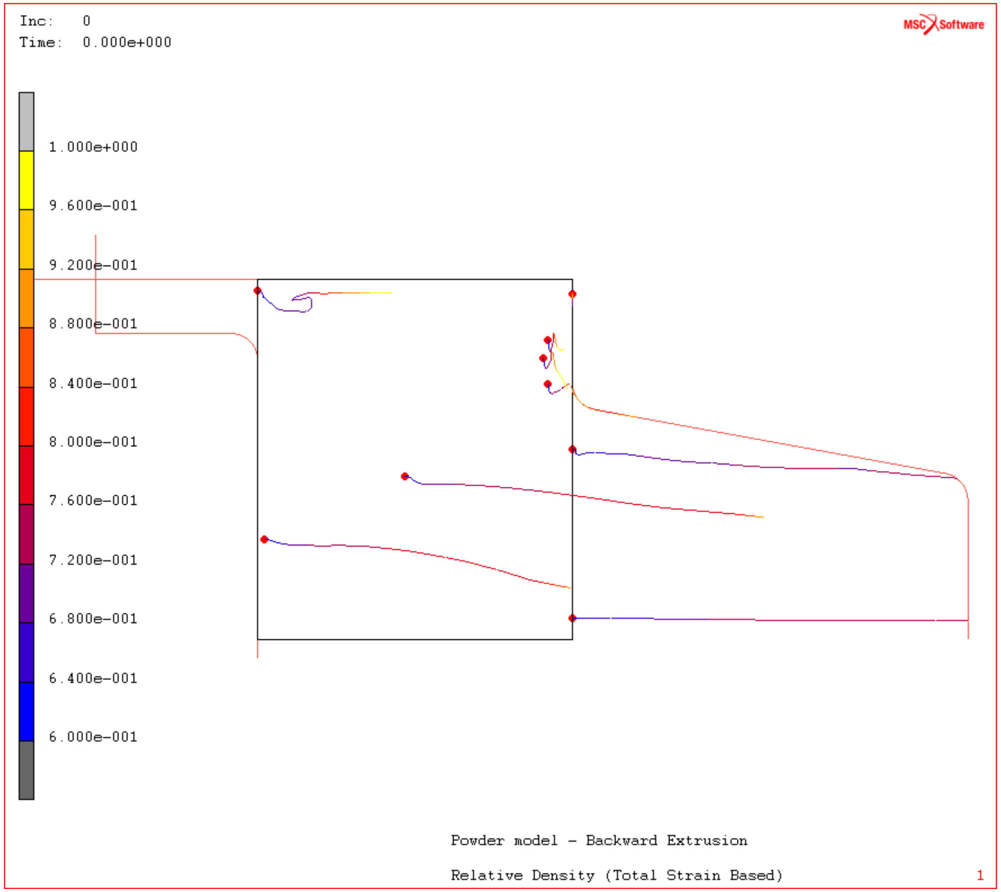
Powder compact showing densification contours



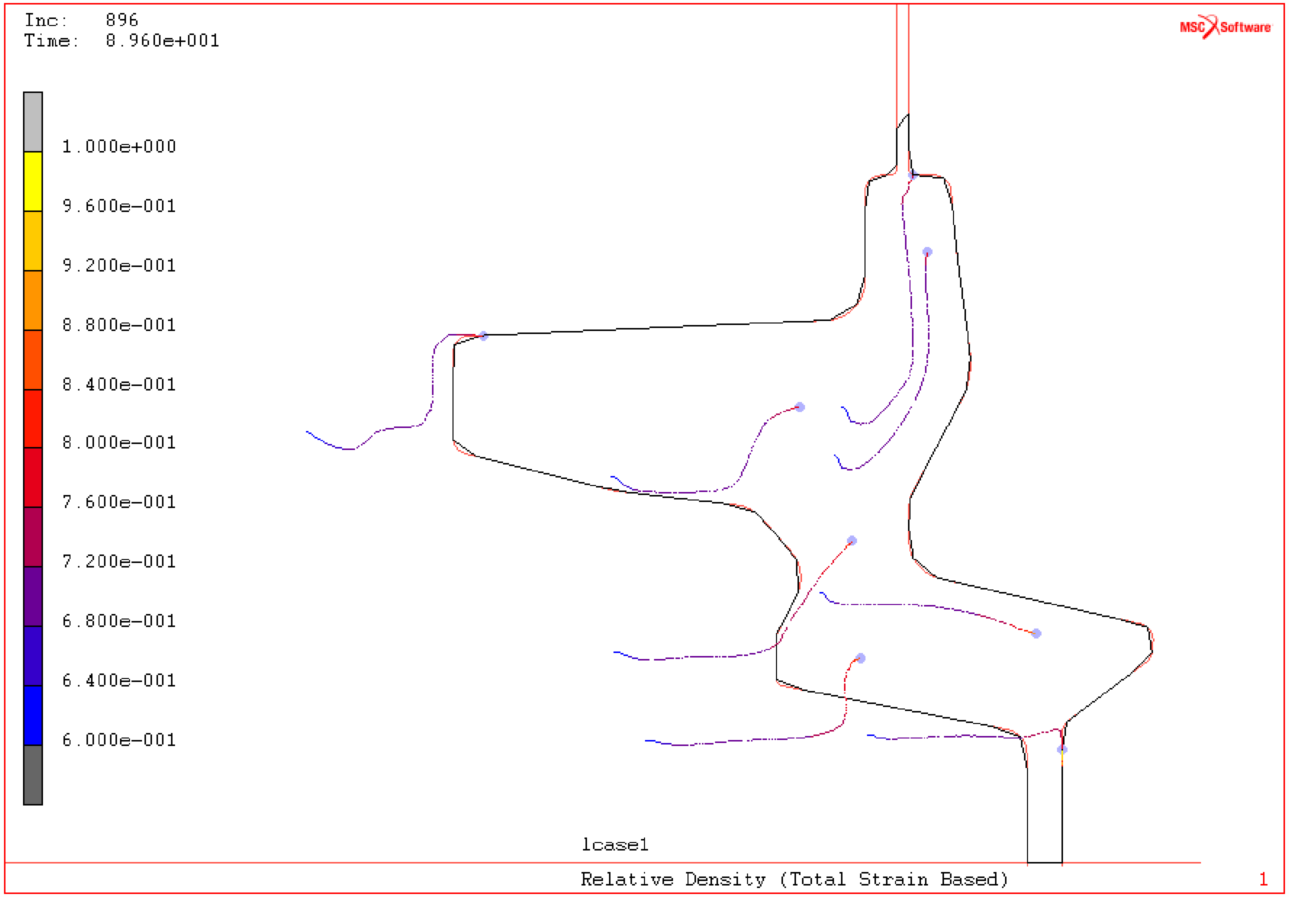
Powder - Global Adaptive Meshing



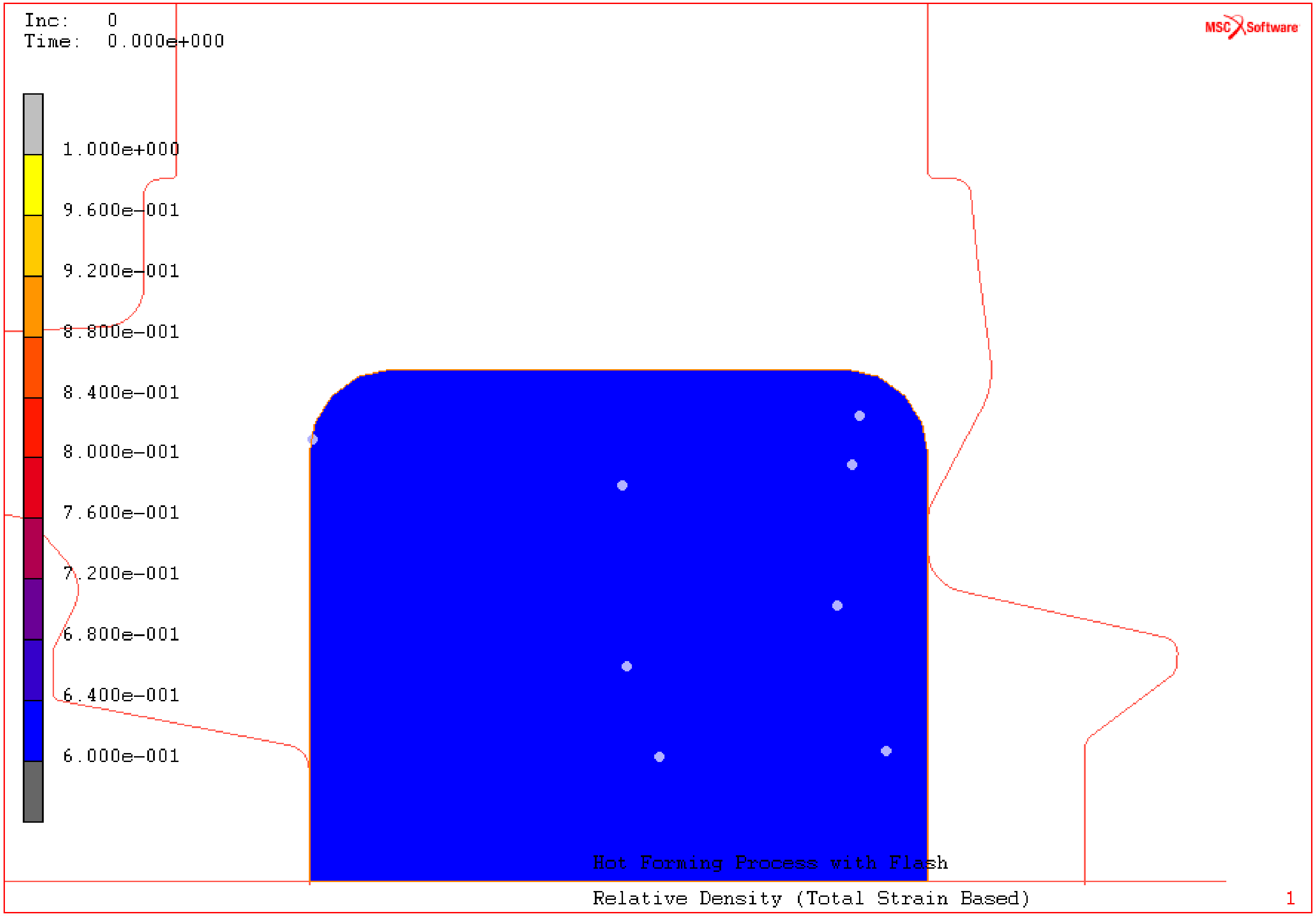
Particle Tracking - Forward – Backward Extrusion



Particle Tracking



Particle Tracking



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