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Modeling of Powder Forming Process using an Exponential-Cap Powder Model in Marc

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MSC Software

Considerations in Powder Modeling

- 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.

Sandia Geomodel

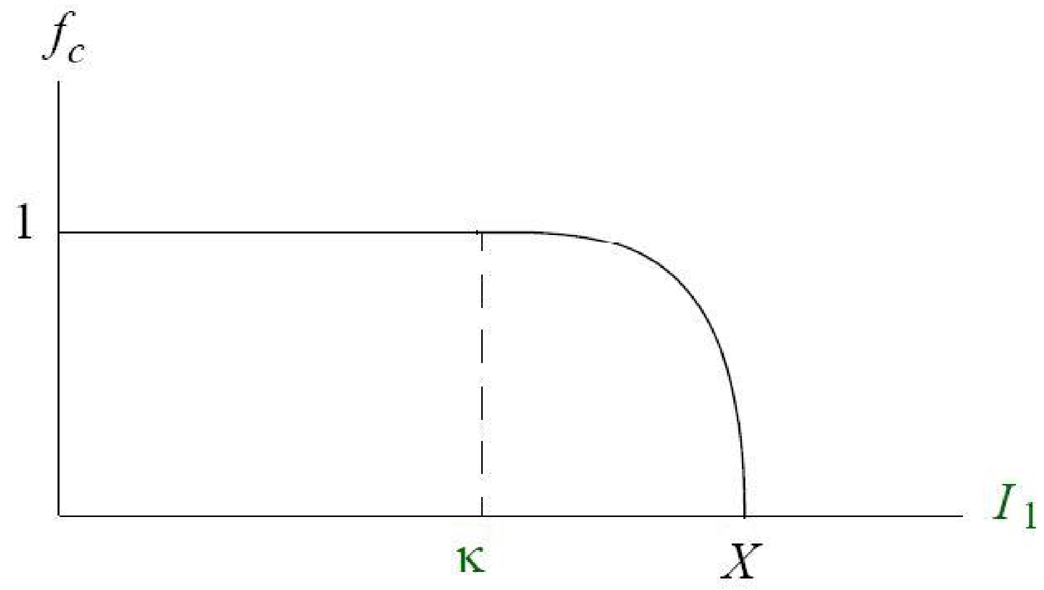
Highlights:

- Geomodel has one continuous yield surface.
- Cap feature accounts for the presence of pores in a material and allows for plastic volume changes even in pure hydrostatic loading .
- 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

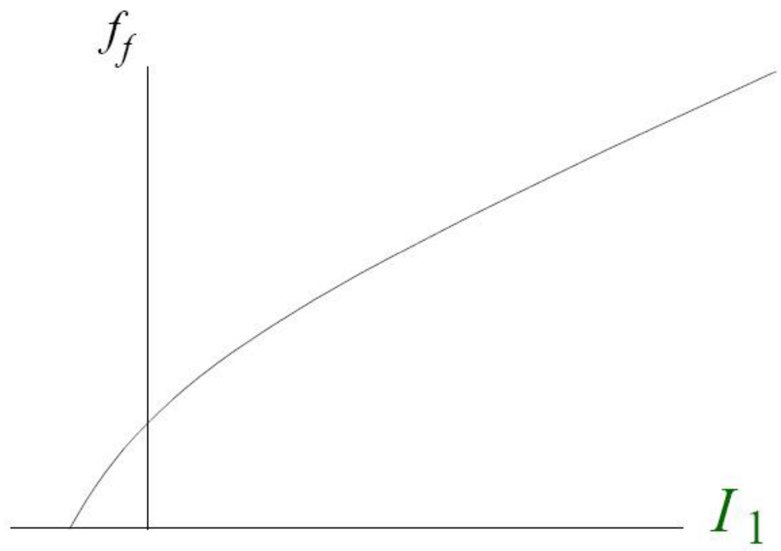
$$f(I_1, J_2, J_3; \kappa) = \Gamma^2(\bar{\theta}) J_2 - f_f^{\,2}(I_1) f_c^{\,2}(I_1, \kappa)$$

Sandia Geomodel

Cap Function f_c



Shear Limiter Function f_f



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

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

$$X = \kappa - R f_s$$

κ governs the evolution of the Cap surface

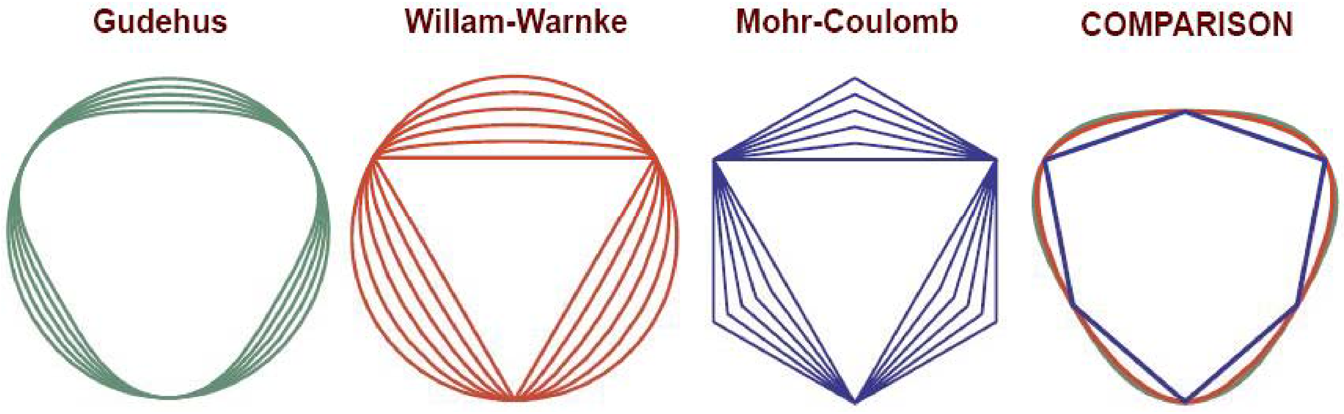
Lode Angle Function

1. Gudehus: $\Gamma(\bar{\theta}) = \frac{1}{2}\left[1 + \sin 3\bar{\theta} + \frac{1}{\psi}(1 - \sin 3\bar{\theta})\right]$

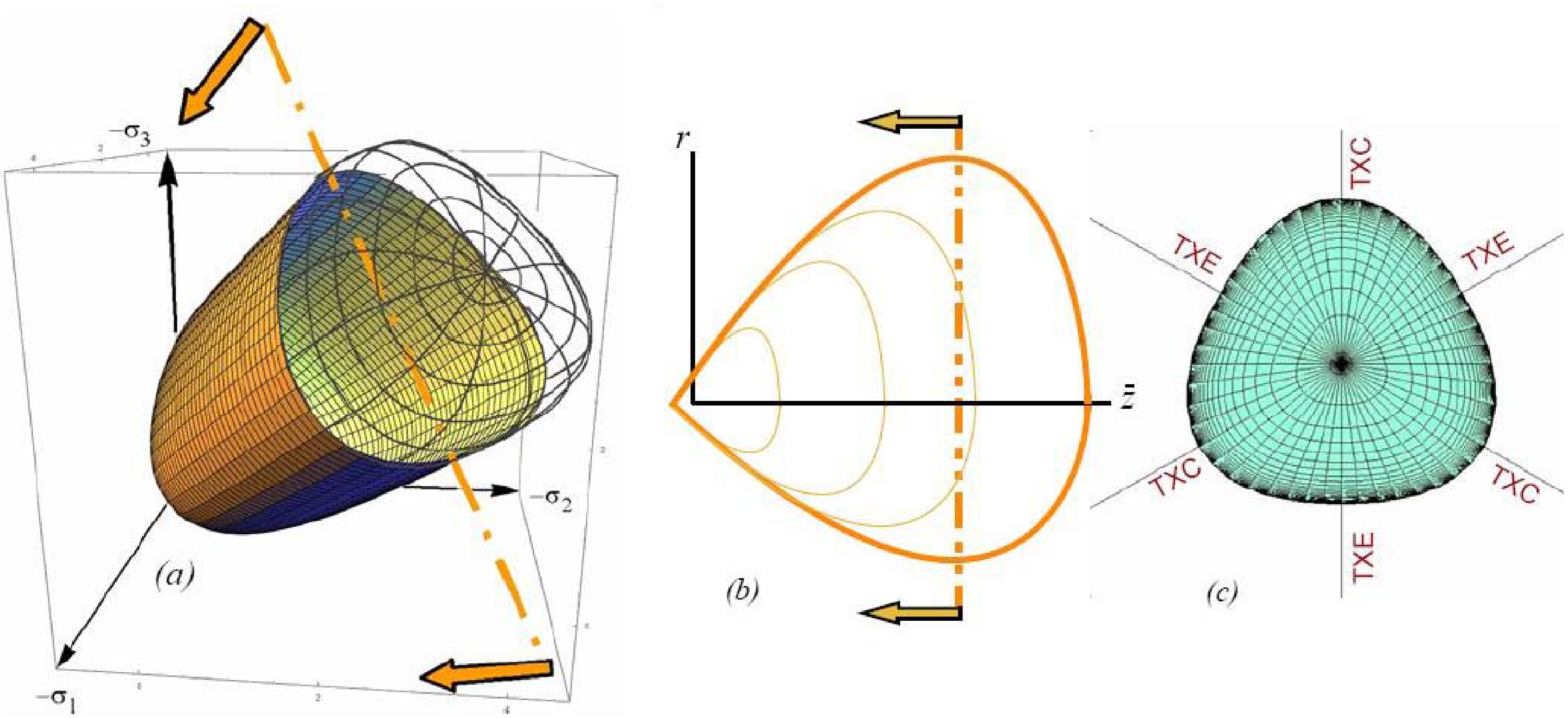
2. Willam-Warnke: $\Gamma(\bar{\theta}) = \dfrac{4(1-\psi^2)\cos^2\alpha^* + (2\psi - 1)^2}{2(1-\psi^2)\cos\alpha^* + (2\psi-1)\sqrt{4(1-\psi^2)\cos^2\alpha^* + 5\psi^2 - 4\psi}}$

   where $\alpha^* = \frac{\pi}{6} + \bar{\theta}$

3. Mohr-Coulomb: $\Gamma(\bar{\theta}) = \dfrac{2\sqrt{3}}{3 - \sin\phi}\left(\cos\bar{\theta} - \dfrac{\sin\phi \sin\bar{\theta}}{\sqrt{3}}\right)$

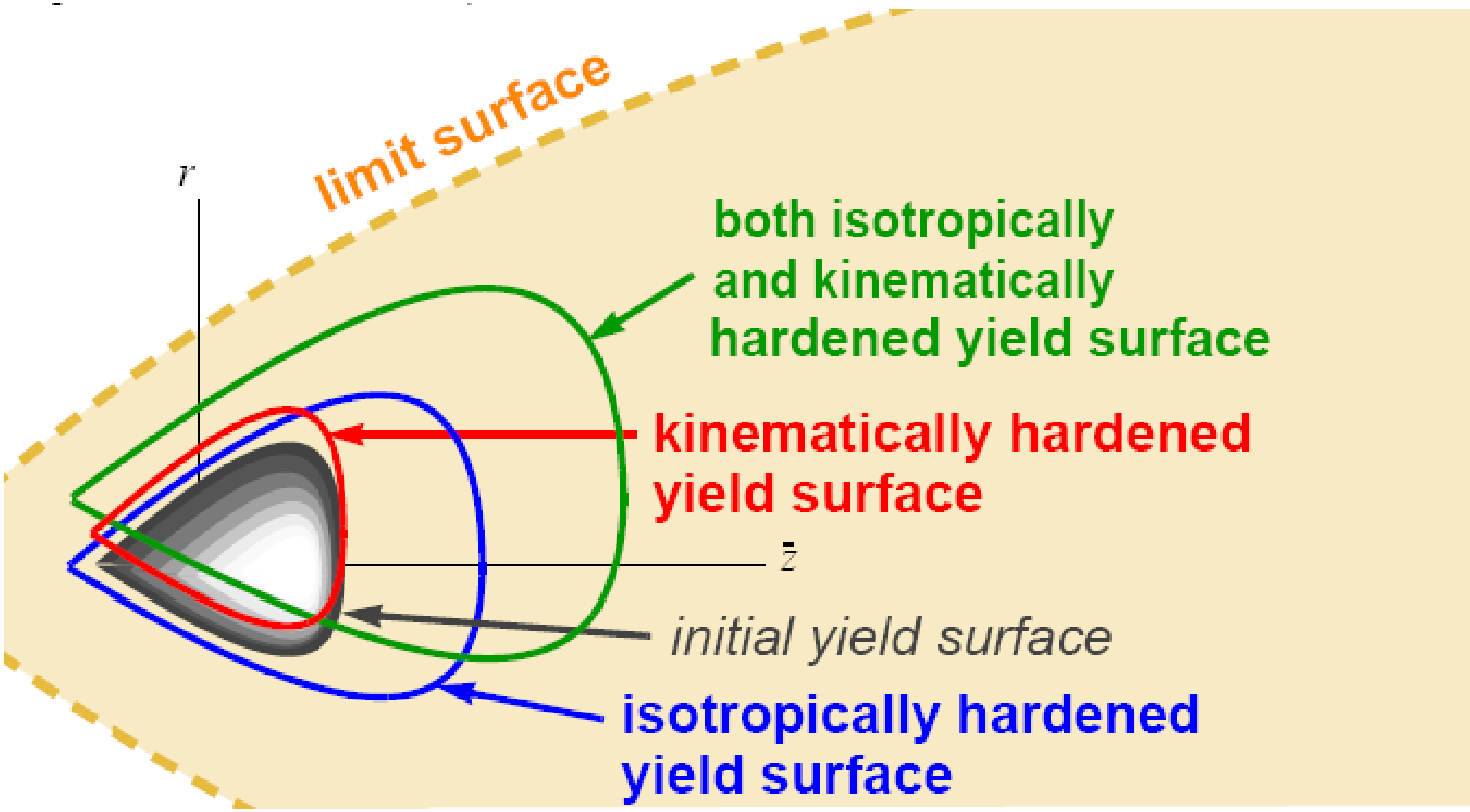


Yield Surface of Sandia Geomodel



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

Isotropic and Kinematic Hardening Mechanisms



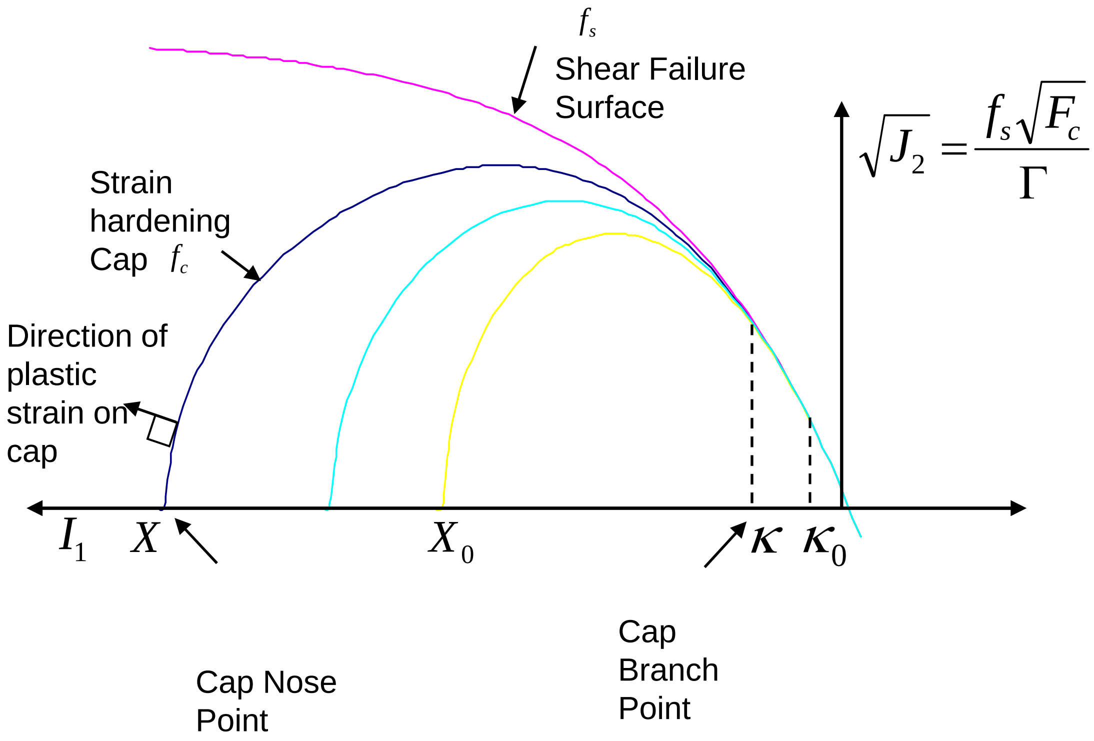
[4] A.F. Fossum et. al. (2004)

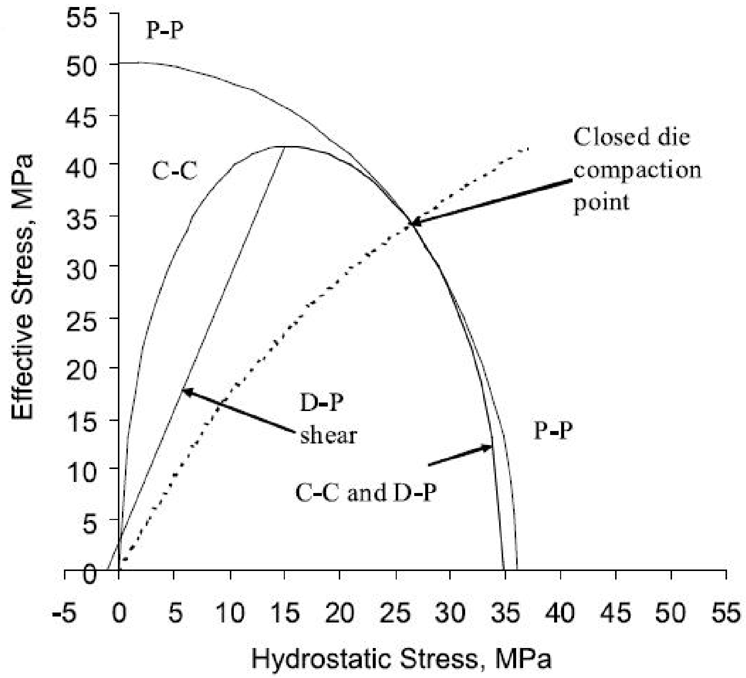
Sandia Geomodel

Limitations:

- Based on the infinitesimal strain theory, i.e., on the additive decomposition of the strain into elastic and plastic parts.
- Elastic model is hypoelastic rather than hyperelastic.
- Is initially isotropic, kinematic hardening is the only mechanism for deformation induced anisotropy.
- Geomodel is limited to relatively small distortional (shear) strains, though large volume changes are permitted.

Comparison with Other Models





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

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

Obtaining Shear Failure Parameters

Step1:

Conduct load-to-failure triaxial compression tests on the material and record all peak stress states. Each individual experiment has precisely one stress state at which the second stress variant achieves a peak value. Characterizing the shear failure surface requires numerous such experiments.

Step2:

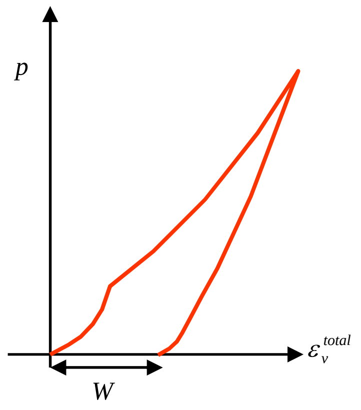
For every available load-to-failure experiment, find the stress state at which is larger than any of the other stress states in that experiment. Construct a table of data ($I_1^{peak}, \sqrt{J_2}$) where I_1^{peak} is the value of I_1 at the stress state at which J_2 is at its peak value.

Step3:

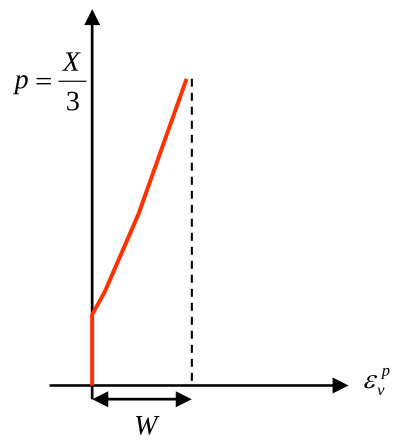
Fit the data to the exponential shear failure function using the curve fitting option provided in Mentat

$$f_s(I_1) = A_1 - A_3 e^{A_2 I_1} - A_4 I_1$$

Obtaining Crush Curve Parameters



Step1:
Obtain hydrostatic pressure vs total volumetric strain data by conducting experiments run to the point of total pore collapse.

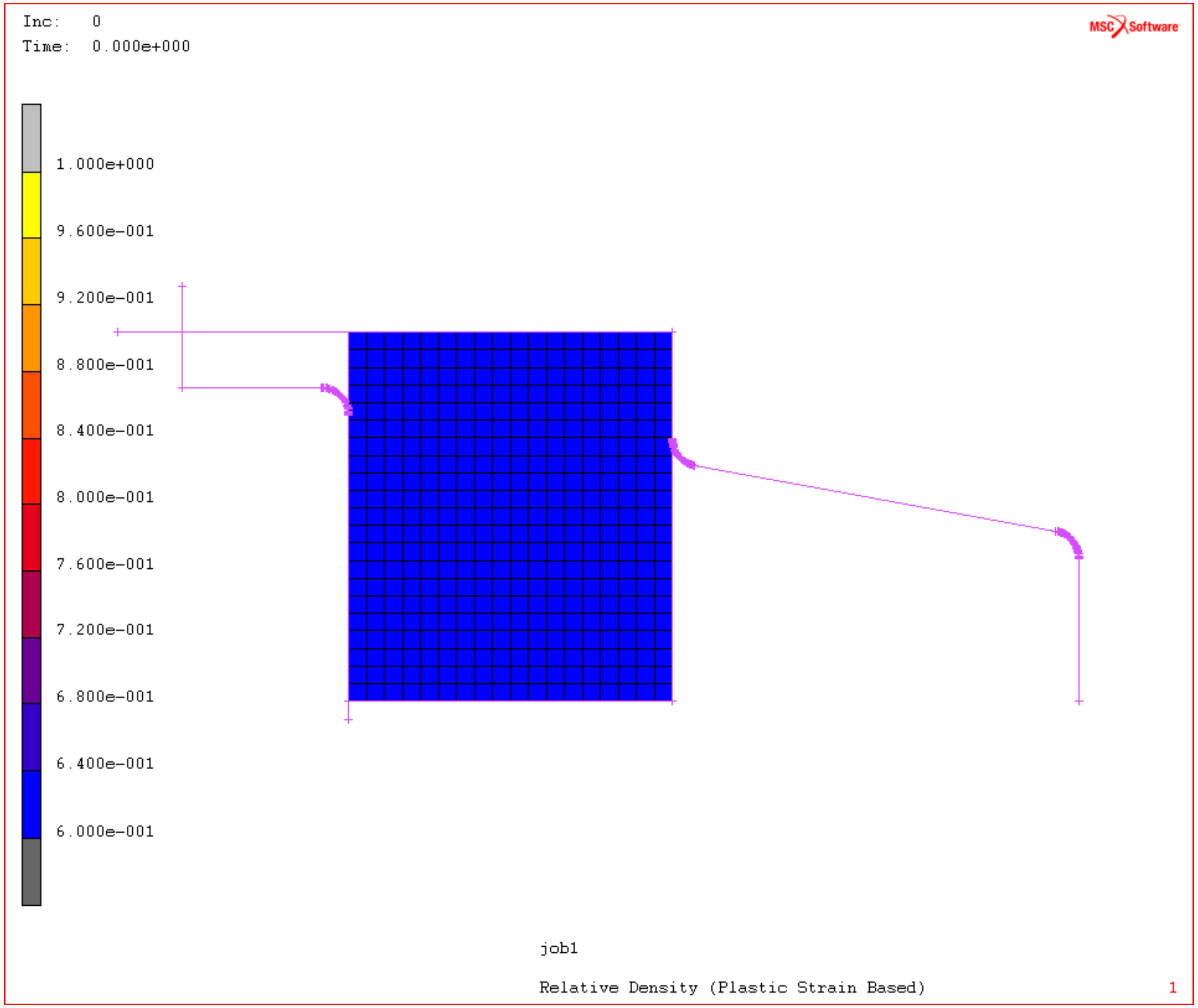


Step2:
Use the elastic unloading curve to determine a shift distance that must be applied at any pressure to remove the elastic part of the strain. This will give you a plot of pressure vs. plastic volumetric strain.

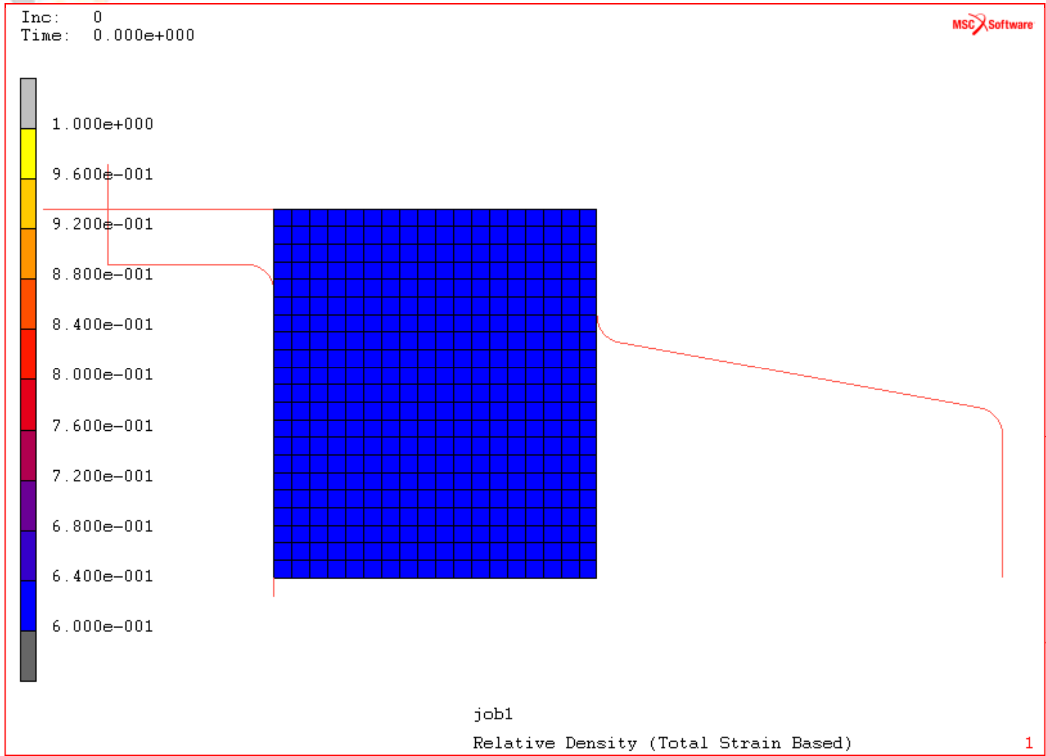
Step3:
Use curve fitting program provided in Mentat to fit the above data to the following curve

$$\varepsilon_v^p = W\left[e^{D_1(X-X_0)-D_2(X-X_0)^2} - 1\right]$$

Backward Extrusion with Powder material

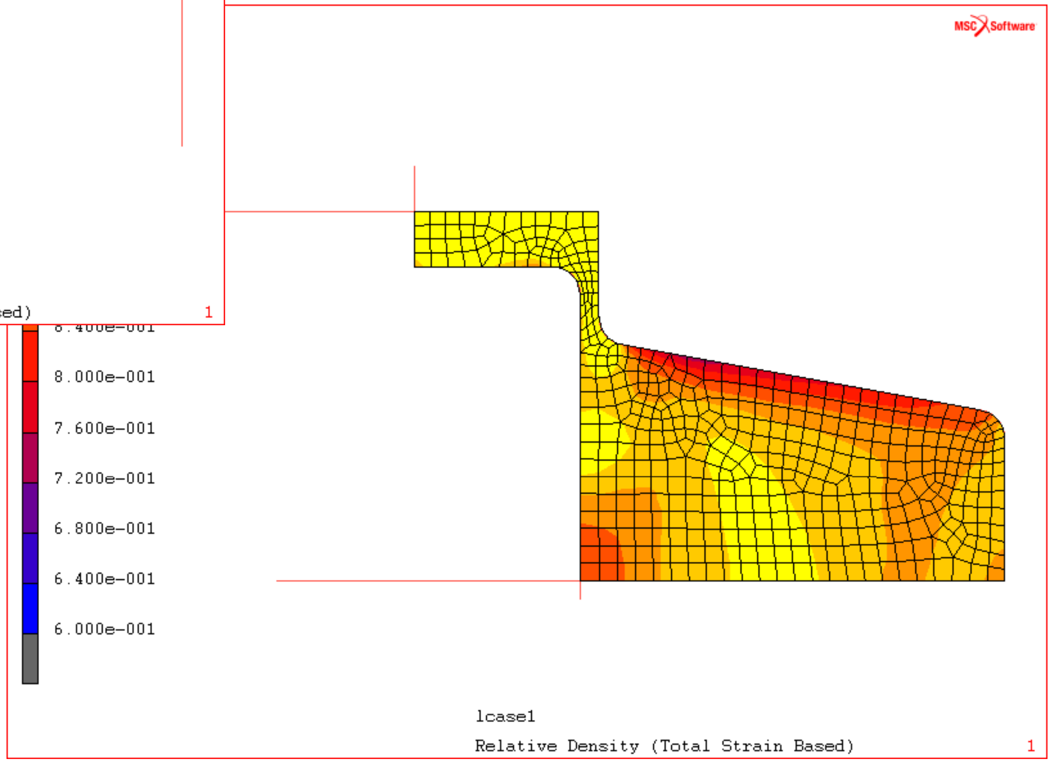


Backward Extrusion with Powder material

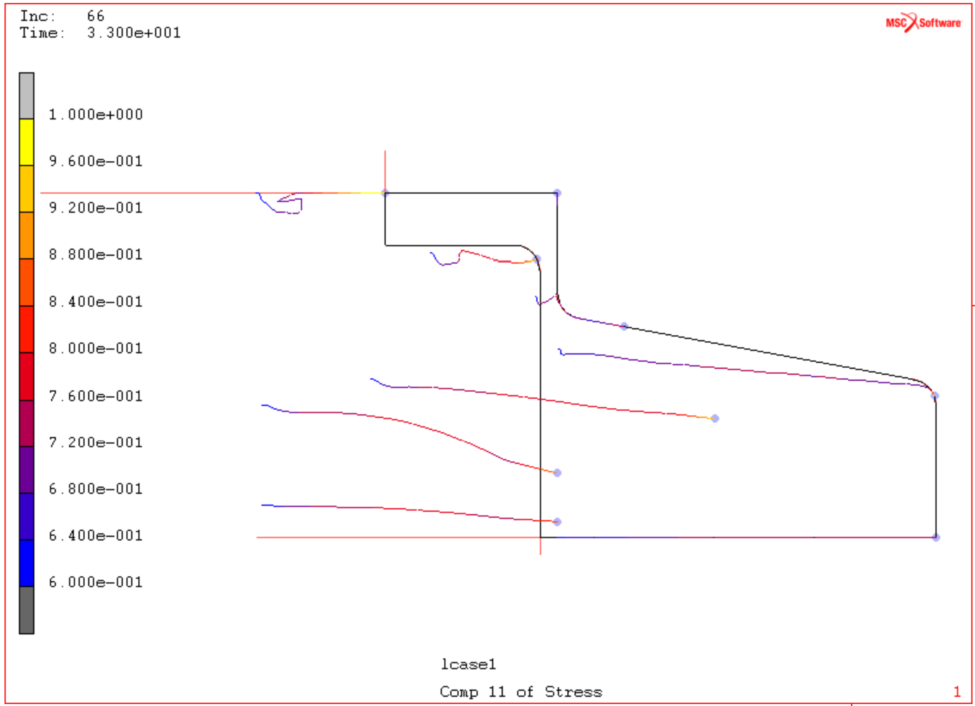


Extrusion setup with initial relative density=0.6

Powder compact showing densification contours

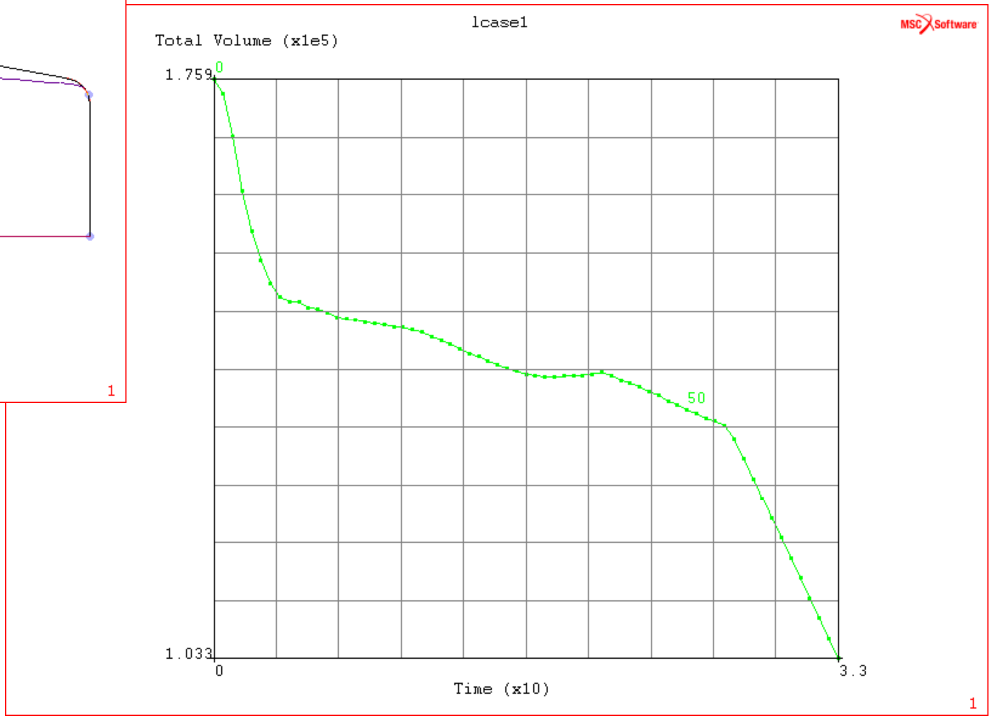


Backward Extrusion with Powder material



Flow lines plotted in Mentat

Volume change as powder is compressed



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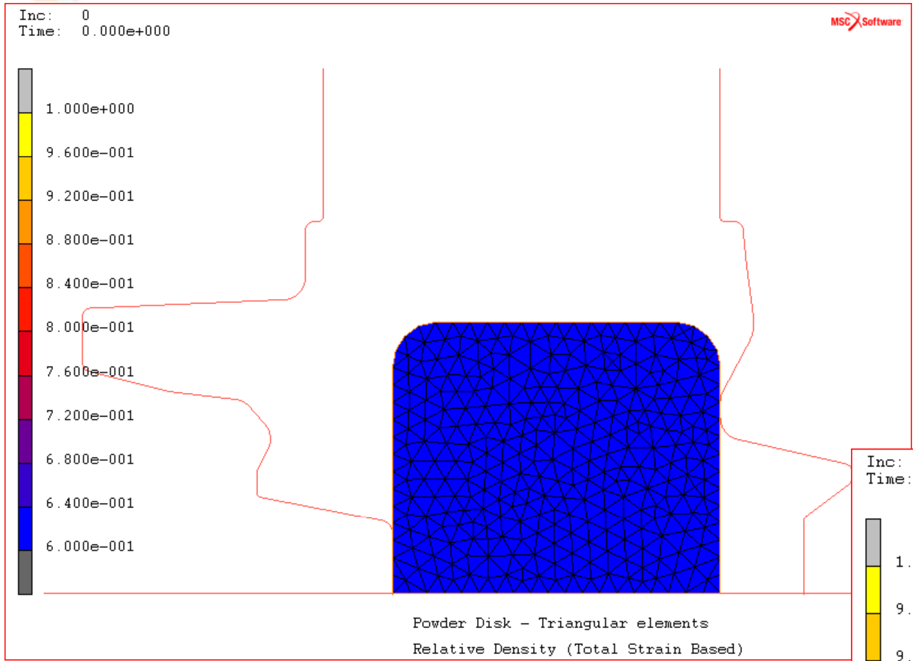
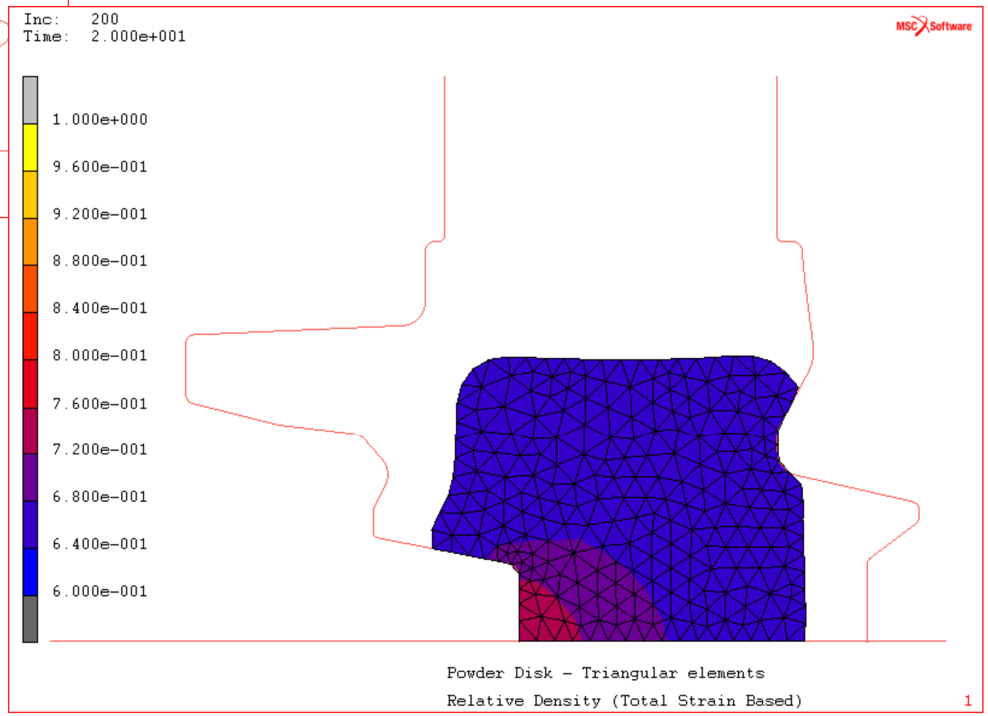
Axi-symmetric Disk with triangular Elements



Powder compact showing densification contours



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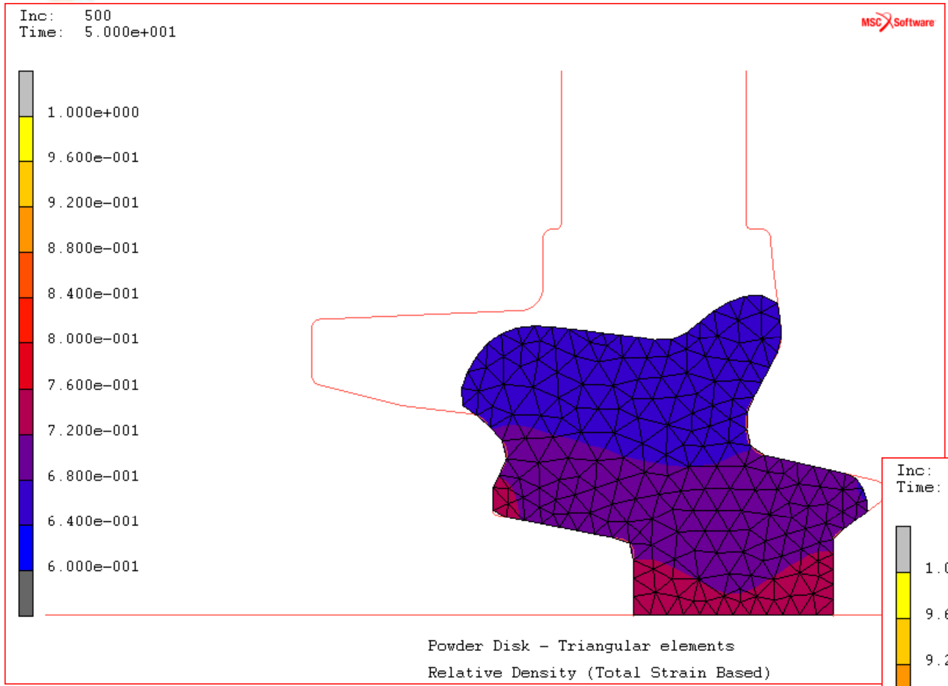
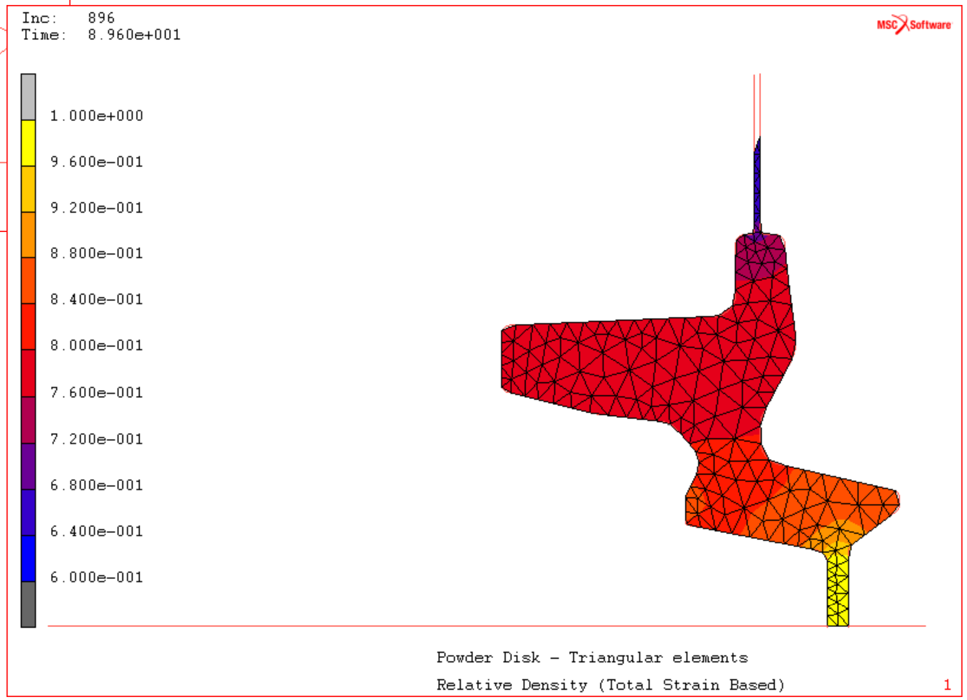


Powder compact showing densification contours



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