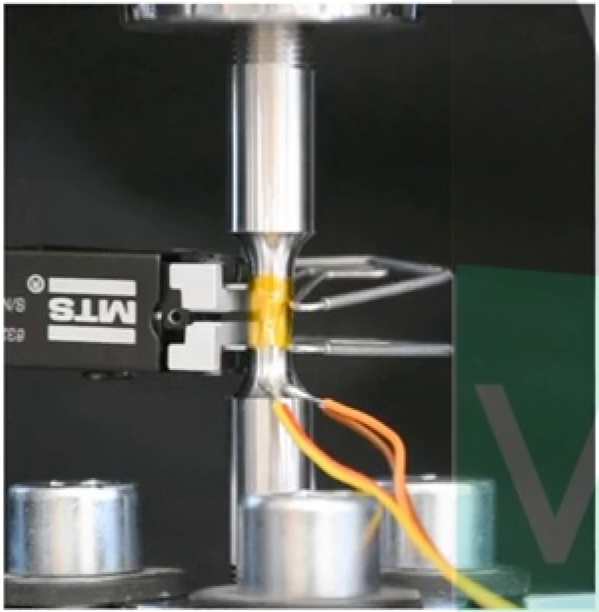
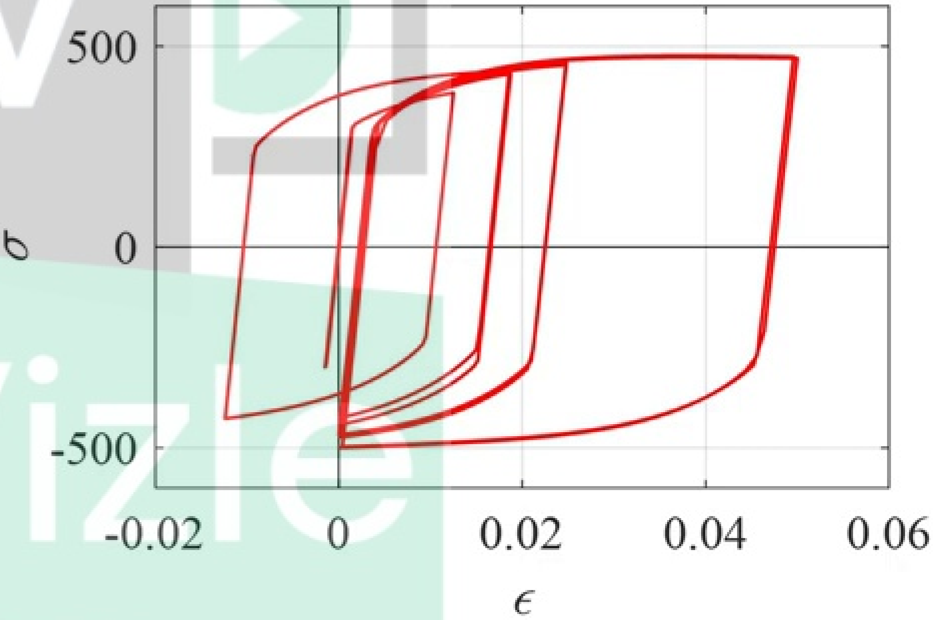
ABAQUS: Ductile Metal Material Definition

Hardening Rule for Cyclic Loading





Metal Plasticity: *Hardening rule under cyclic loading*

Material definitions:

- Yield criterion (also known as the yield surface)

  The criterion that indicates that yielding (the transition from the elastic to plastic branch) have occurred

- Plastic flow rule

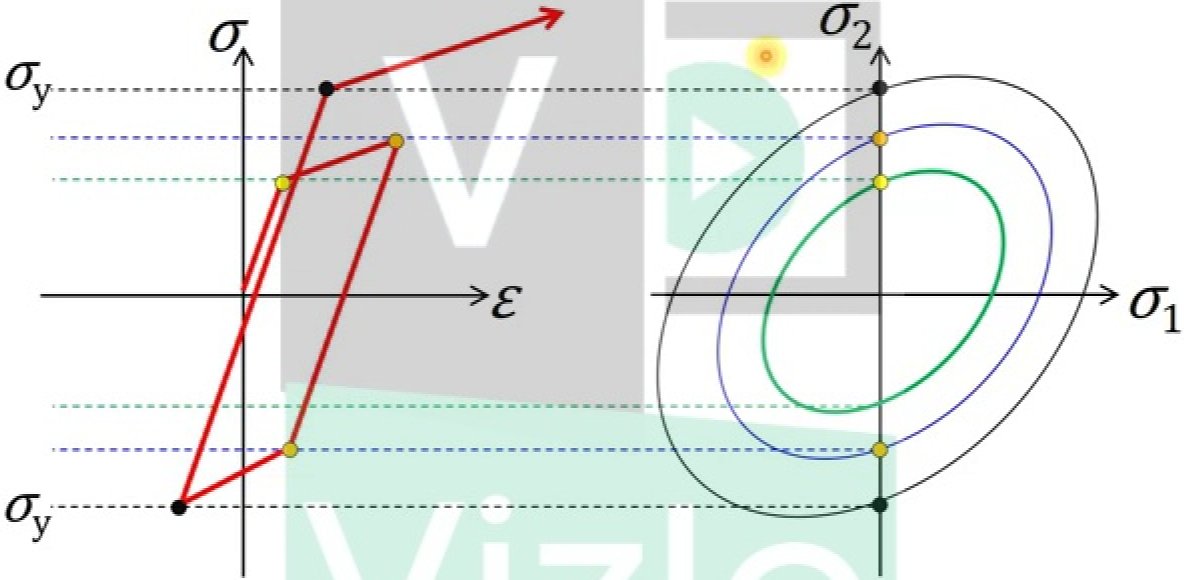
  The rule that dictates how the yield surface shifts and changes in size with plastic deformation

Metal Plasticity: *Yield surface criterion*

Von Mises Equivalent Stress σ_v

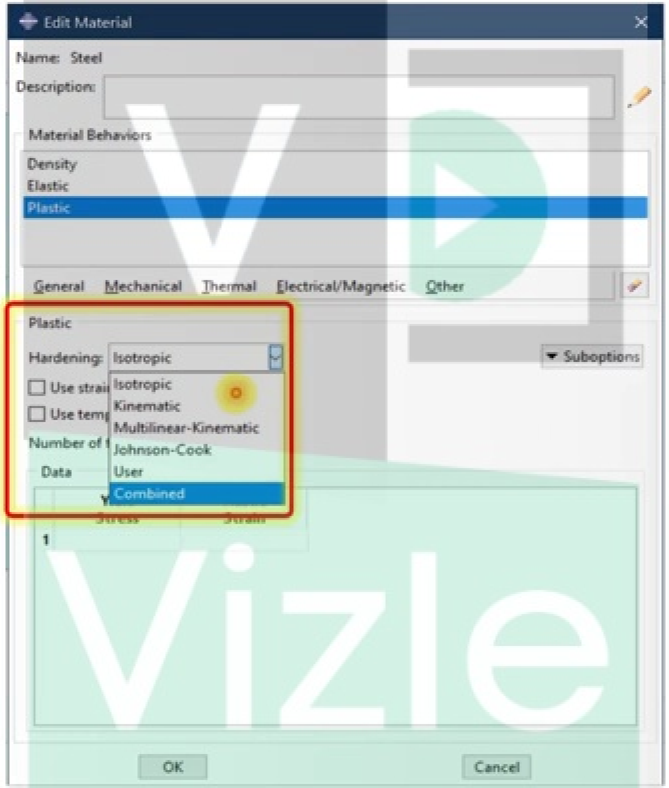
State of stress	Boundary conditions	von Mises equations
General	No restrictions	$\sigma_v = \sqrt{\frac{1}{2}\left[(\sigma_{11}-\sigma_{22})^2 + (\sigma_{22}-\sigma_{33})^2 + (\sigma_{33}-\sigma_{11})^2\right] + 3\left(\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2\right)}$
Principal stresses	$\sigma_{12} = \sigma_{31} = \sigma_{23} = 0$	$\sigma_v = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2\right]}$
General plane stress	$\sigma_3 = 0$ $\sigma_{31} = \sigma_{23} = 0$	$\sigma_v = \sqrt{\sigma_{11}^2 - \sigma_{11}\sigma_{22} + \sigma_{22}^2 + 3\sigma_{12}^2}$
Principal plane stress	$\sigma_3 = 0$ $\sigma_{12} = \sigma_{31} = \sigma_{23} = 0$	$\sigma_v = \sqrt{\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2}$
Pure shear	$\sigma_1 = \sigma_2 = \sigma_3 = 0$ $\sigma_{31} = \sigma_{23} = 0$	$\sigma_v = \sqrt{3}\lvert\sigma_{12}\rvert$
Uniaxial	$\sigma_2 = \sigma_3 = 0$ $\sigma_{12} = \sigma_{31} = \sigma_{23} = 0$	$\sigma_v = \sigma_1$

Metal Plasticity: *Plastic flow rule - Isotropic hardening*



The yield surface size expands uniformly. In other words, the yield point σ_y keeps getting larger while the accumulated plastic strains are pushed further

Metal Plasticity: *Combined hardening*

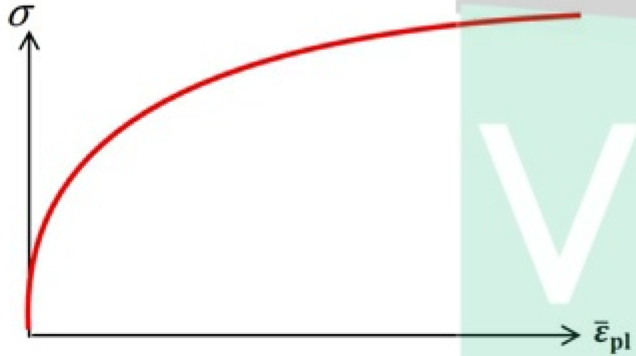


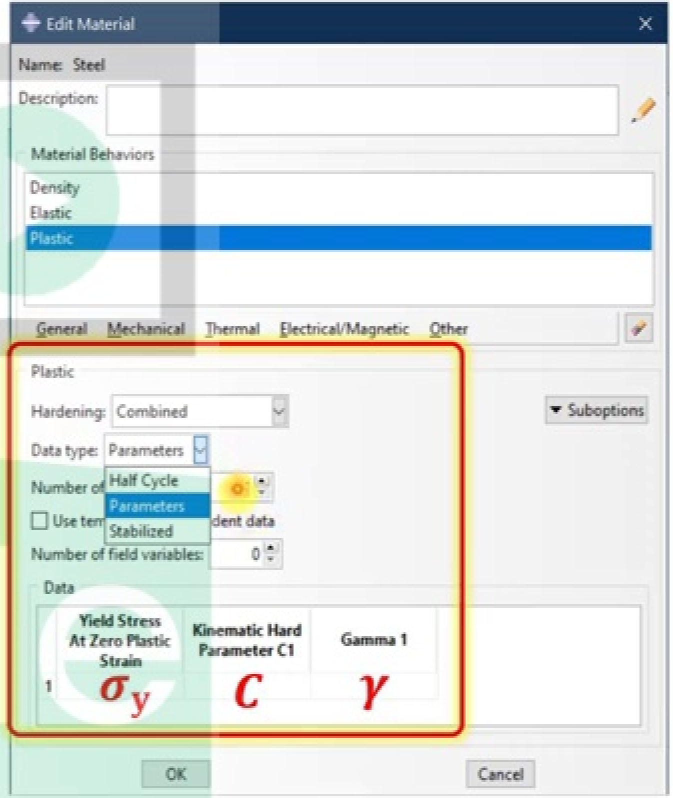
Metal Plasticity: *Combined hardening – Kinematic – Parameters*

$$\sigma = \frac{C}{\gamma}\left(1 - e^{-\gamma \bar{\varepsilon}_{\text{pl}}}\right)$$

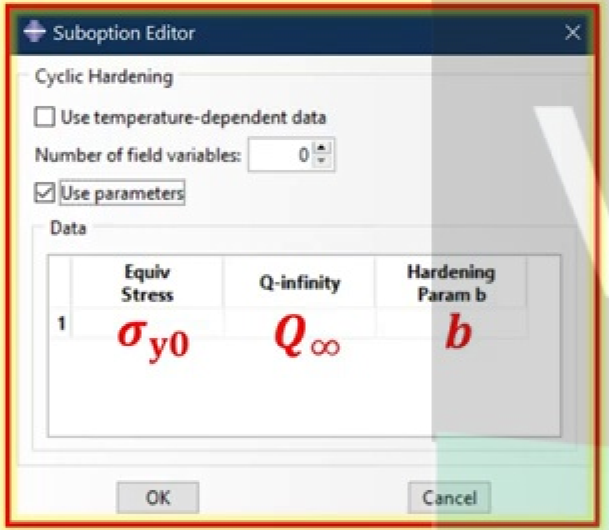
C kinematic hardening modulus

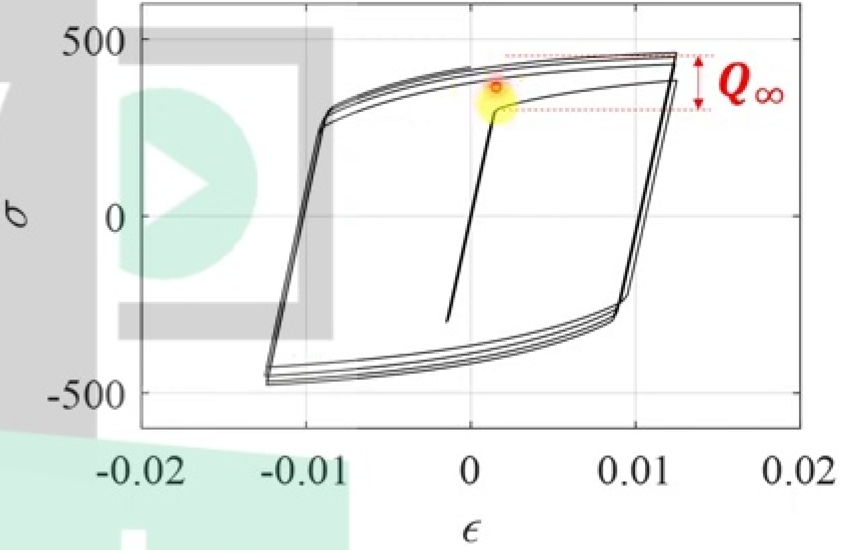
γ rate at which C decreases with increasing equivalent plastic strain





Metal Plasticity: *Combined hardening rule – Cyclic hardening*





$$\sigma_y = \sigma_{y0} + Q_\infty \left(1 - e^{-b\bar{\varepsilon}_{pl}}\right)$$

Q_∞ maximum change in yield surface size

b rate at which Q_∞ changes with increasing equivalent plastic strain