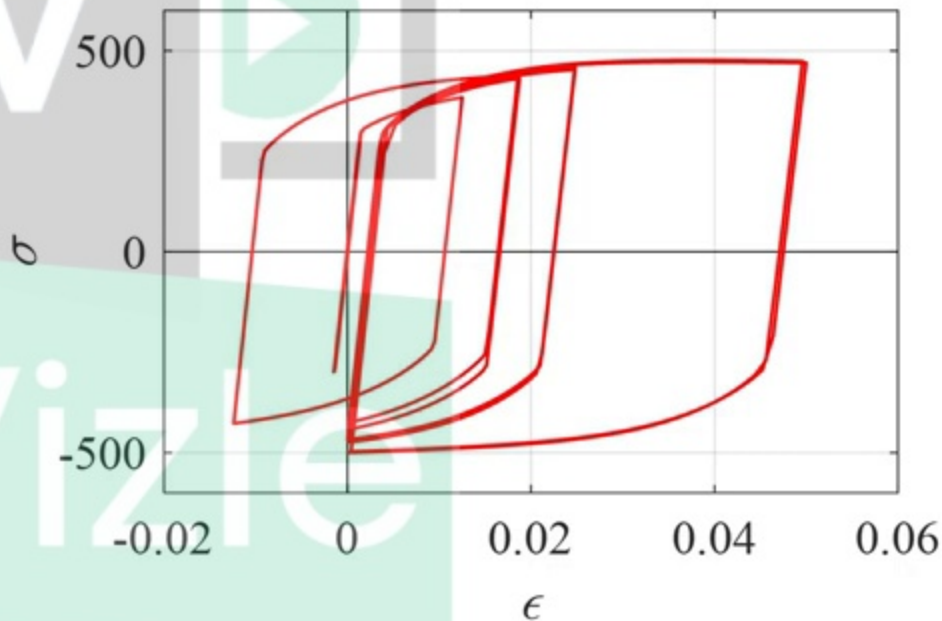
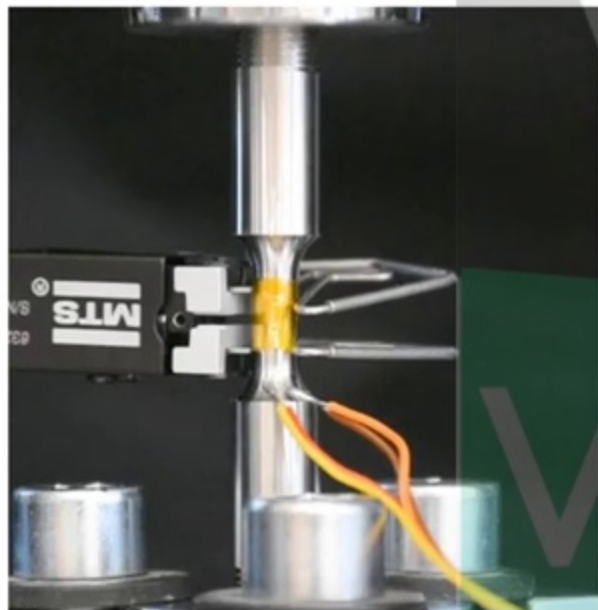


# ABAQUS: Ductile Metal Material Definition

## Hardening Rule for Cyclic Loading





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## Vizle Material Plasticity: *Hardening rule under cyclic loading*

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### 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*

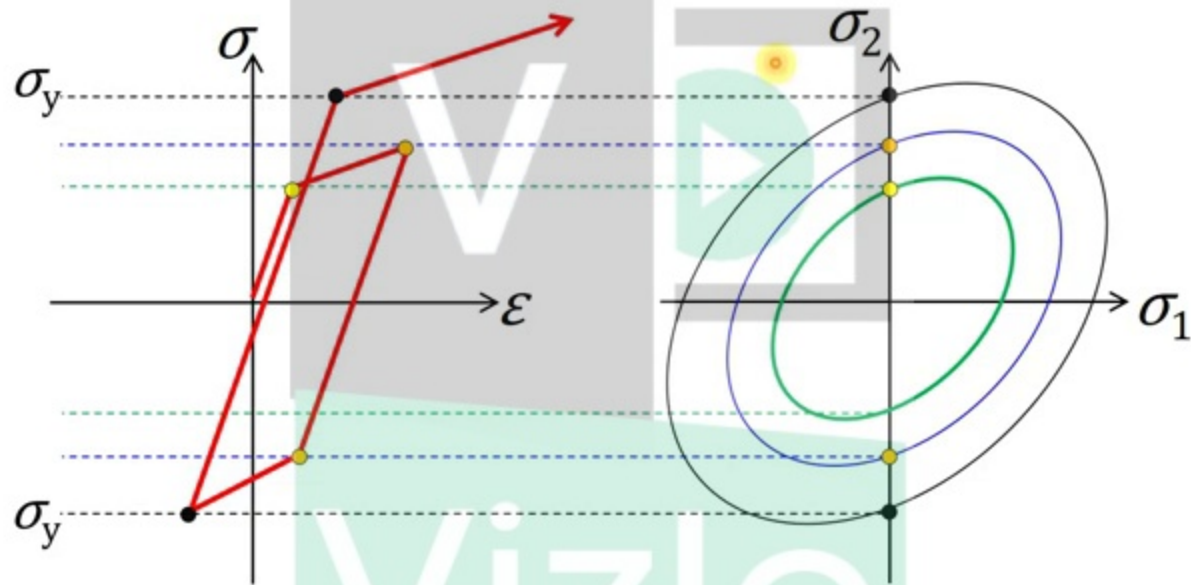
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## Von Mises Equivalent Stress $\sigma_v$

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

# Vizle tal Plasticity: *Plastic flow rule - Isotropic hardening*

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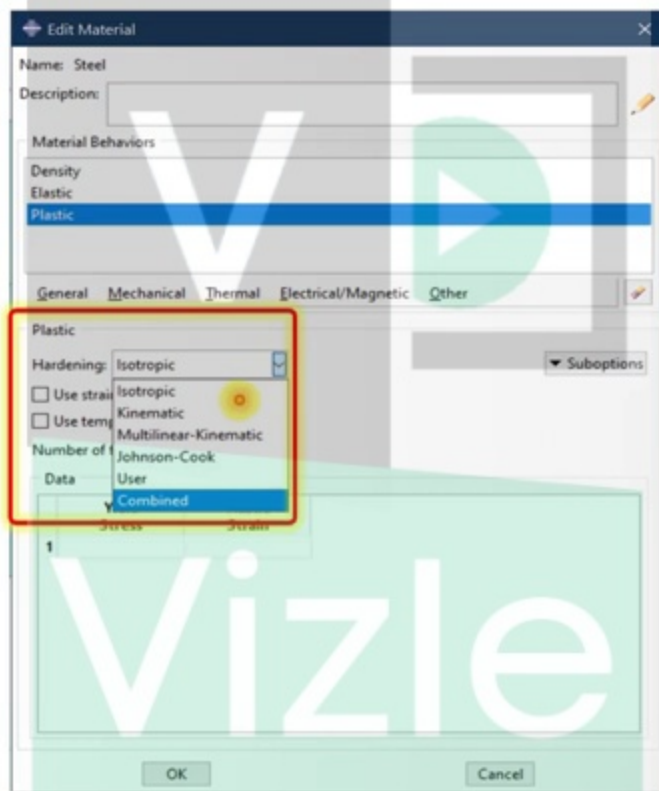


The yield surface size expands uniformly. In other words, the yield point  $\sigma_y$  keeps getting larger while the accumulated plastic strains are pushed further



# Material Plasticity: *Combined hardening*

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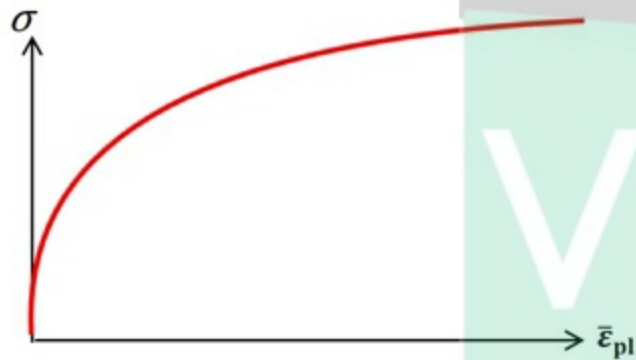


# Plasticity: *Combined hardening – Kinematic – Parameters*

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$$\sigma = \frac{C}{\gamma} (1 - e^{-\gamma \bar{\epsilon}_{pl}})$$

$C$  kinematic hardening modulus  
 $\gamma$  rate at which  $C$  decreases with increasing equivalent plastic strain

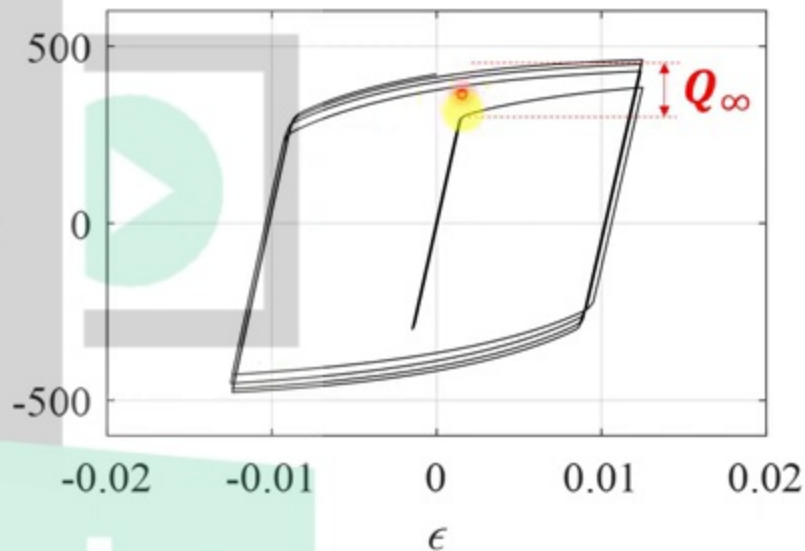
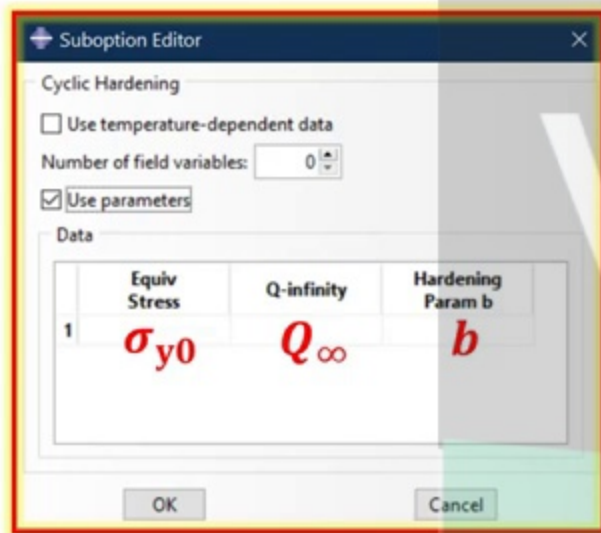


The image shows the 'Edit Material' dialog box in ABAQUS for a material named 'Steel'. The 'Plastic' behavior is selected. The 'Hardening' type is set to 'Combined'. The 'Data type' is 'Parameters'. The 'Number of Half Cycle' is set to 1. The 'Use temperature dependent data' checkbox is unchecked. The 'Number of field variables' is 0. The 'Data' table is as follows:

	Yield Stress At Zero Plastic Strain	Kinematic Hard Parameter C1	Gamma 1
1	$\sigma_y$	$C$	$\gamma$

Buttons for 'OK' and 'Cancel' are visible at the bottom.

# Vizle Metal Plasticity: *Combined hardening rule – Cyclic hardening*



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

$Q_{\infty}$   
 $b$  maximum change in yield surface size rate at which  $Q_{\infty}$  changes with increasing equivalent plastic strain





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