DEFINITION OF RATCHETTING: INCREMENT OF STRAIN PER CYCLE DUE NONCLOSURE OF THE HYSTERESIS LOOP
EXPERIMENTAL RATCHETTING FOR A NOPROPORTIONAL AXIAL-TORSIONAL LOADING PATH

EXPERIMENTAL RATCHETTING FOR A TWO-STEP NONPROPORTIONAL LOADING HISTORY

Step 1
- \( \Delta\sigma = 0 \)
- \( \sigma_m = 300 \text{MPa} \)
- \( \Delta\tau/2 = 230 \text{MPa}, \tau_m = 0 \)

Step 2
- \( \Delta\sigma = 0 \)
- \( \sigma_m = 60 \text{MPa} \)
- \( \Delta\tau/2 = 230 \text{MPa}, \tau_m = 0 \)
EXPERIMENTAL OBSERVATIONS

• The ratchetting direction is coincident with the mean stress direction under single-step proportional loading.

• For 1070 Steel, the ratchetting rate decreases with increasing number of loading cycles for both proportional and nonproportional loadings.

• Under multiple-step loadings, the material exhibits a memory of the previous loading history.
PREDICTION OF THE “ELLIPSE” PATH

Number of Cycles

Axial Ratchetting Strain

Shear Ratchetting Strain

Mroz/Garud
Chaboche
A-F
Bower
Experiment
Plasticity Fundamentals

\[ f = (S - \alpha):(S - \alpha) - 2k^2 = 0 \]

\[ d\varepsilon^p = \frac{1}{h} \langle dS:n \rangle \ n \quad n = \frac{S - \alpha}{\| S - \alpha \|} \]

\[ df = 0 \]

\[ dS:n - d\alpha:n - 2k \ dk = 0 \]
EVOLUTION OF BACK STRESS

\[ d\alpha^{(i)} = f_1^{(i)} \left( n - f_2^{(i)} L^{(i)} \right) dp \quad (\text{i}=1, 2, ..., M) \]

\[ M=1 \quad f_1^{(1)} = a_a \quad f_2^{(1)} = \frac{c_a}{a_a} \| \alpha \| \]

\[ f_1^{(i)} = c^{(i)} r^{(i)} \quad f_2^{(i)} = \frac{\| \alpha^{(i)} \|}{r^{(i)}} \quad (\text{i}=1, 2, ..., M) \]

\[ f_1^{(i)} = c^{(i)} r^{(i)} \quad f_2^{(i)} = \left( \frac{\| \alpha^{(i)} \|}{r^{(i)}} \right)^{\chi^{(i)+1}} \left( n : L^{(i)} \right) \quad (\text{i}=1, 2, ..., M) \]
NEW PLASTICITY MODEL


\[ \alpha = \sum_{i=1}^{M} \alpha^{(i)} \quad \text{d} \alpha^{(i)} = c^{(i)} r^{(i)} \left( n - \left( \frac{\|\alpha^{(i)}\|}{r^{(i)}} \right) \chi^{(i)} + 1 \right) L^{(i)} \right) \text{d} p \]

\[ (i=1, 2, ..., M) \]
EXPERIMENTAL “ELLIPSE PATH”

1070 Steel

Axial Stress, MPa

Shear Stress, MPa

Axial Strain

Shear Strain

1070 Steel Experiment

-0.010 -0.005 0.000 0.005 0.010

-0.010 -0.005 0.000 0.005 0.010

1070 Steel

$\Delta \sigma / 2 = 222 \text{MPa} \quad \sigma_m = 222 \text{MPa}$

$\Delta \tau / 2 = 224 \text{MPa} \quad \tau_m = 0$
PREDICTION OF THE "ELLIPSE" PATH

[Graph showing Axial and Shear Ratchetting Strain vs. Number of Cycles for various models: Chaboche, Mroz/Garud, Armstrong-Frederick, Bower, and Experiment.]
CAPABILITY OF PROPOSED MODEL IN UNIAXIAL LOADING

\[ \chi^{(i)} = 0 \quad (i=1, 2, ..., 10) \]

1070 Steel

\[ \Delta \sigma / 2 = 205 \text{MPa} \]
\[ \sigma_m = 205 \text{MPa} \]

Ratchetting Rate, 1/cycle

Number of Cycles

\[ \chi = +\infty \]

Experiment

10/6/21
CAPABILITY OF PROPOSED MODEL IN NONPROPORTIONAL LOADING

Axial Ratchetting Rate, 1/cycle

Number of Cycles

1070 Steel

Δσ/2=0  σ_m=300MPa
Δτ/2=230MPa  τ_m=0

χ_0^{(i)} = 0  (i=1,2,...,10)

χ^{(i)} = ∞  (i=1,2,...,10)
CAPABILITY OF PROPOSED MODEL IN NONPROPORTIONAL LOADING

Axial Ratchetting Rate, 1/cycle

1070 Steel

- $\Delta \sigma / 2 = 225 \text{MPa}$, $\sigma_m = -225 \text{MPa}$
- $\Delta \tau / 2 = 215 \text{MPa}$, $\tau_m = 0$

Shear Ratchetting Strain

- $\Delta \sigma / 2 = 225 \text{MPa}$, $\sigma_m = -225 \text{MPa}$
- $\Delta \tau / 2 = 215 \text{MPa}$, $\tau_m = 0$
PREDICTION OF RATCHETTING RATES IN TWO STEP PROPORTIONAL LOADING

Step 1
65 cycles

Step 2
16400 cycles

Step 1
1070 Steel

Step 2

Experiment
New Model

\begin{align*}
\Delta \sigma &= 396 \text{MPa} \\
\sigma_m &= 204 \text{MPa} \\
\Delta \sigma &= 396 \text{MPa} \\
\sigma_m &= 78 \text{MPa}
\end{align*}

Axial Ratchetting Strain

Number of Cycle

Number of Cycles

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Jiang-Sehitoglu (JS) Plasticity Model

• Only model that can predict ratcheting under complex loading scenarios
• Backstress is divided into multiple components
• Translation of the backstress is not constricted to the direction of the normal
• Elastic stress state is computed first, and a relaxation procedure is implemented to determine the final stress state
JS Plasticity Model


\[ \alpha = \sum_{i=1}^{M} \alpha^{(i)} \]

\[ d\alpha^{(i)} = c^{(i)} r^{(i)} \left| n - \left( \frac{\alpha^{(i)}}{r^{(i)}} \right) \right| \chi^{(i)} + 1 L^{(i)} dp \]

\[ (i = 1, 2, ..., M) \]
Material Constant Sets

• $r^{(i)}$ and $c^{(i)}$
  – Define the stress-strain behavior of the material in a linear piece-wise manner
  – Determined from fully reversed stress-plastic strain data

• $\chi^{(i)}$
  – Defines the ratcheting rate decay of the material
  – Determined from uniaxial ratcheting experiments
Eliminate the Elastic Strain

$2\sigma_y^*$
Select Piece-Wise Linear Segments

- Stress-Plastic Strain Coordinates of the Selected Points Specify $r^{(i)}$ and $c^{(i)}$
Determining X

• Plot uniaxial ratcheting rate from experimental data

• Simulate ratcheting rate from JS model
  – Use $r^{(i)}$ and $c^{(i)}$ determined above
  – Guess a value for X

• Trial and Error until the simulated curve equals the experimental curve