Metal Plasticity Seminar

Material Testing 2.0 for Thermomechanical Characterization of High Strength Steels

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Creep Modeling Framework for 30CrMoNiV11-5 Alloy
Application of Morch phenomenological Law and Mean-Field Creep Model

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Objective

Creep modeling framework for 30CrMoNiV11-5 alloy:

- Macro phenomenological Law within FE code
- Use of mean-field creep model (standalone).
- Validation and comparison with experimental data.

Target Material: 30CrMoNiV5-11 (Turbine manufacturers)

Different designations: DIN1.6946, SEW555

Family materials:

- **First developed:** 1CrMoV ;
- **After 1990:** 26CrMoNiV3-8 (in UK), 22Cr25NiWCoCu, GX12CrMoVNbN9-1, 9Cr-1Mo, X12CrMoWVNbN10-1-1, 2.25Cr steel, 9Cr steel, 12Cr steel, 28CrMoNiV4·9, 1Cr-steel, 10CrMoWV-steel

Larson and Miller Rupture time estimation:

$$\dot{\varepsilon} = Ae^{-\frac{\Delta H}{kT}} \rightarrow Const = T(\ln(t) + C)$$

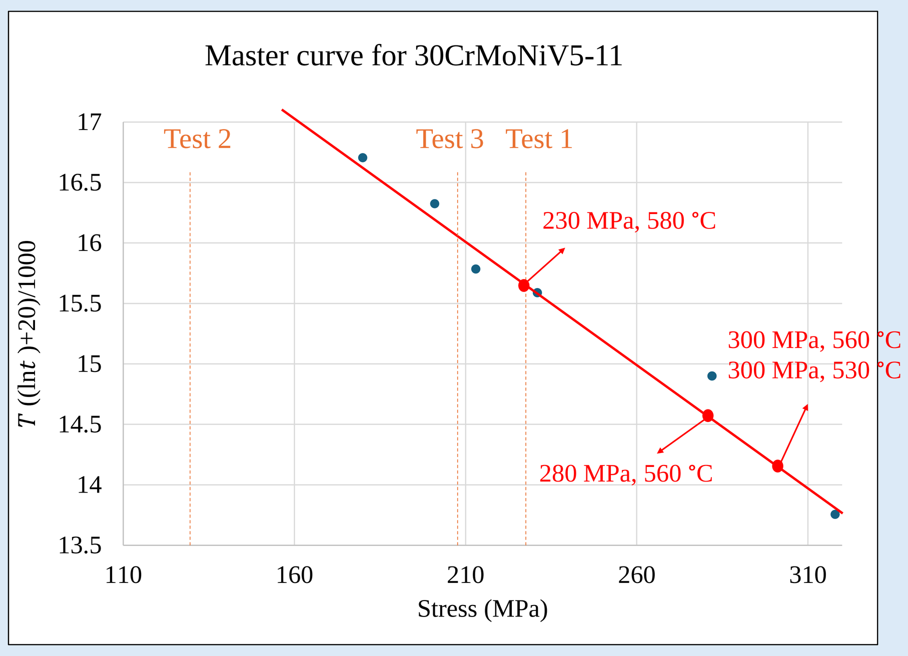
A is a constant

ΔH is activation energy

For most of the alloys, the constant C_1 is within range $35 < C_1 < 60$

Master curve

Rupture stress is plotted as a function of the parameter $T(\ln(t_R) + C_1)$



Line: project tests interesting RFC partner [6]

Estimate rupture time for project test:

1. 230 MPa, 560 °C: 2538 h (3.5 months)
2. 127 MPa, 560 °C: 136138 h (15.54 years)
3. 210 MPa, 530 °C: 17898 h (2.04 years)

Morch elasto-visco-plastic model

(PhD Uliege 2022 fatigue-creep model, just creep part used here):

- Primary stage: Isotropic hardening

$$R = Q(1 - e^{-b\dot{p}})$$

- Secondary stage: Norton-Hoff law

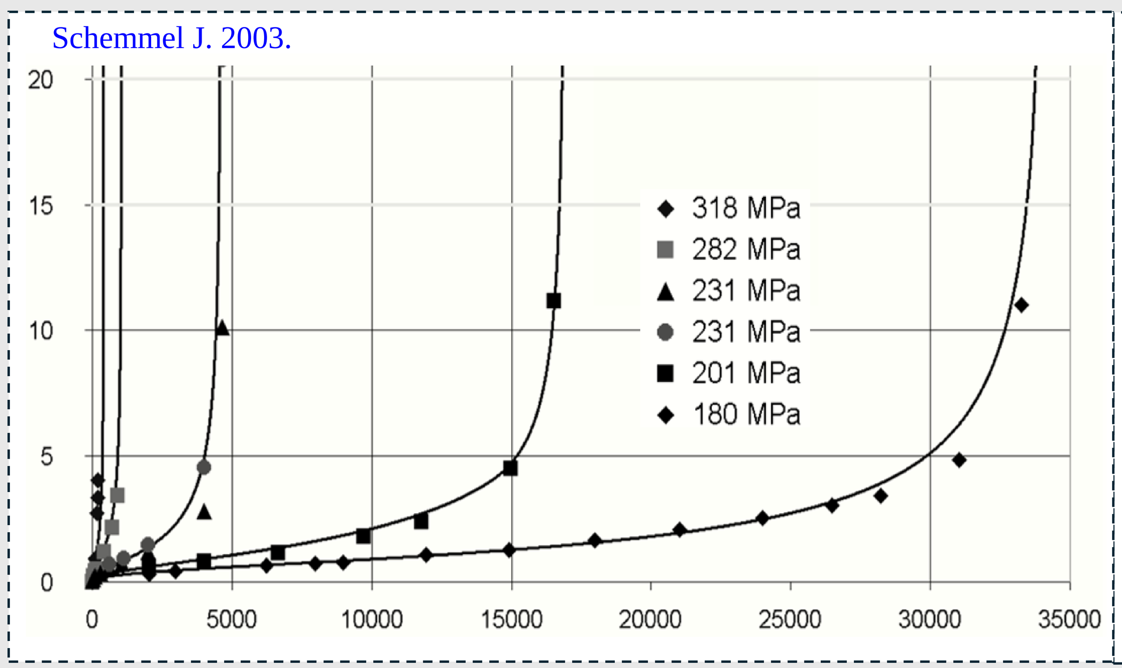
$$\sigma_v = \sigma - R - \sigma_y \qquad \dot{p} = \left\langle\frac{\sigma_v}{K}\right\rangle^n$$

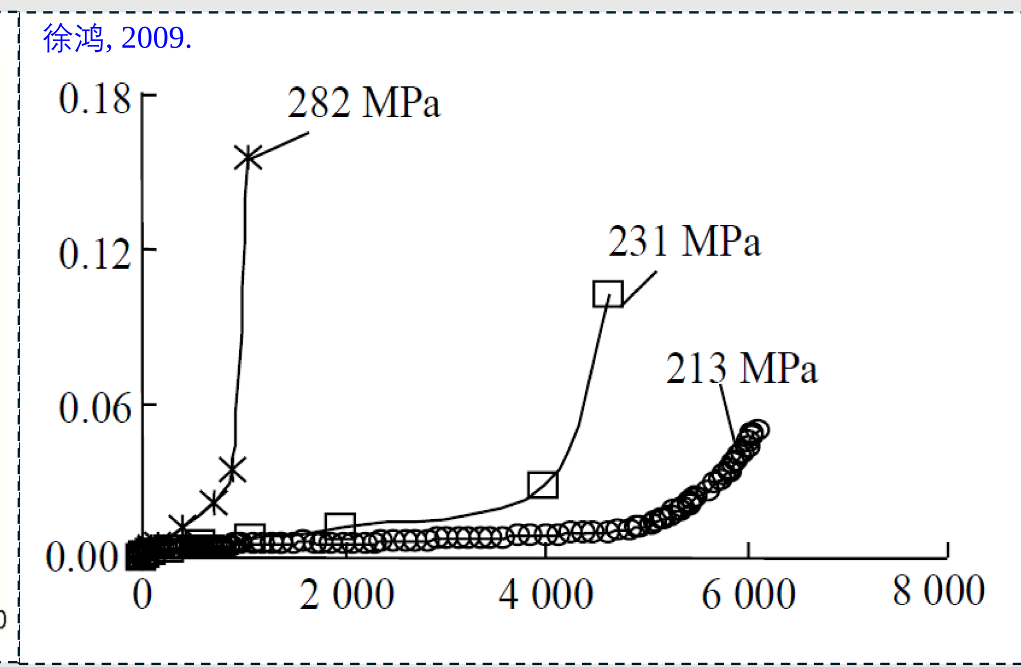
- Tertiary stage: Damage by Rabotnov-Kachanov equation

$$\dot{D}_c = k_3\left(\frac{Y(\sigma^d * k_4)}{S_c}\right)^{s_c}\frac{1}{(1-D)^k}$$

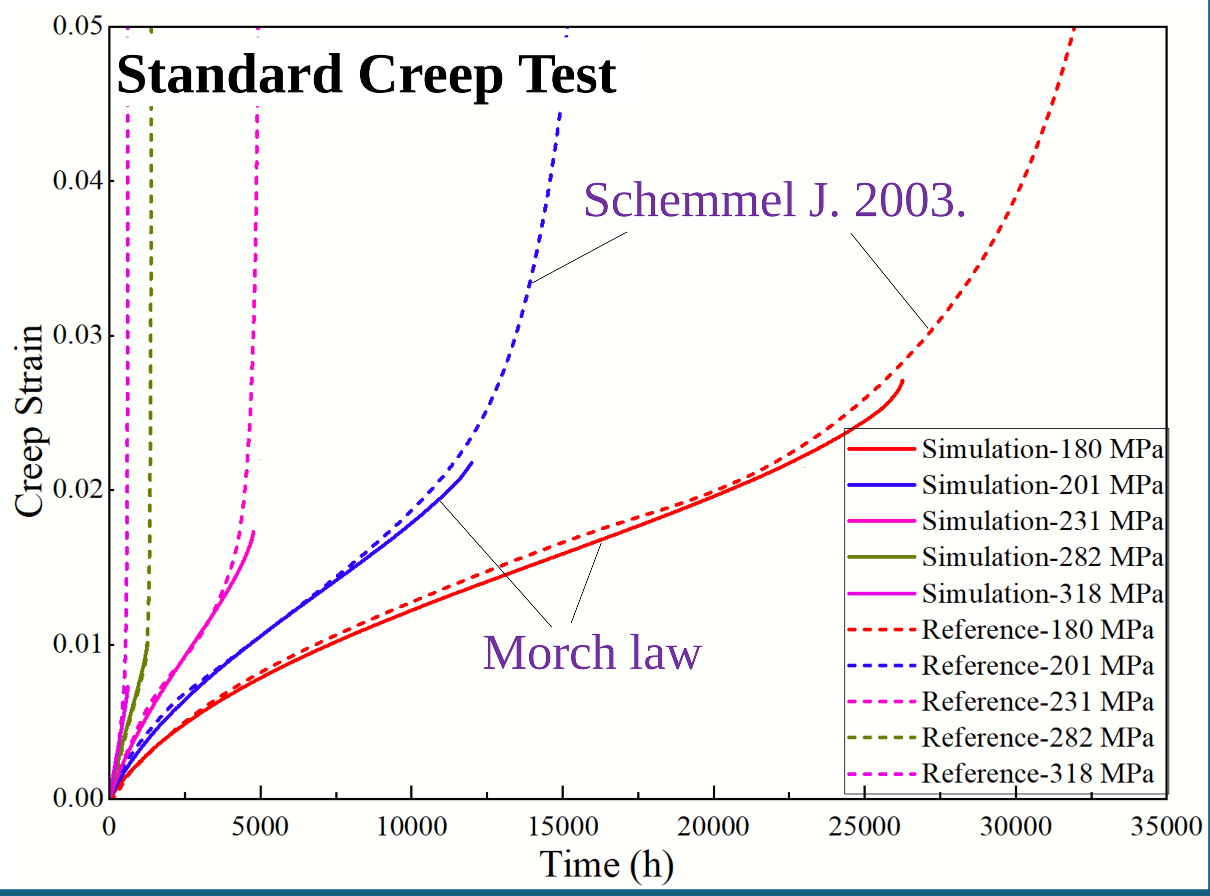
Creep curves of 30 CrMoNiV5-11 (550 °C) found in literature

Creep strain Vs. Time (h)

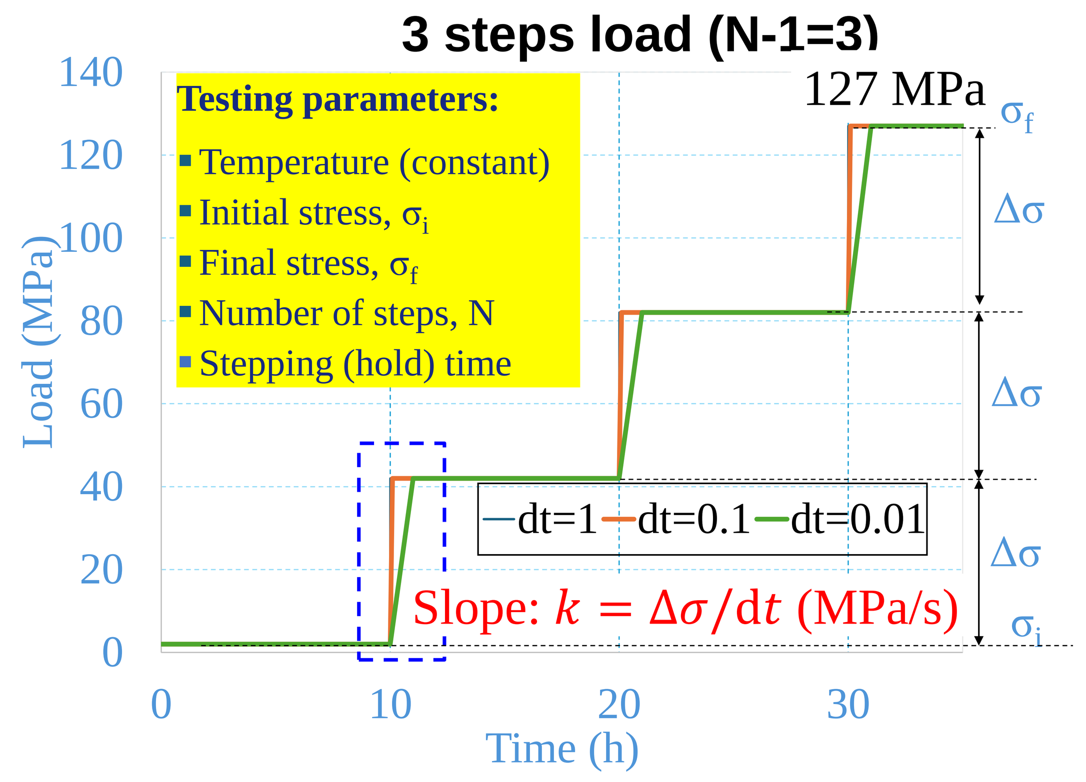


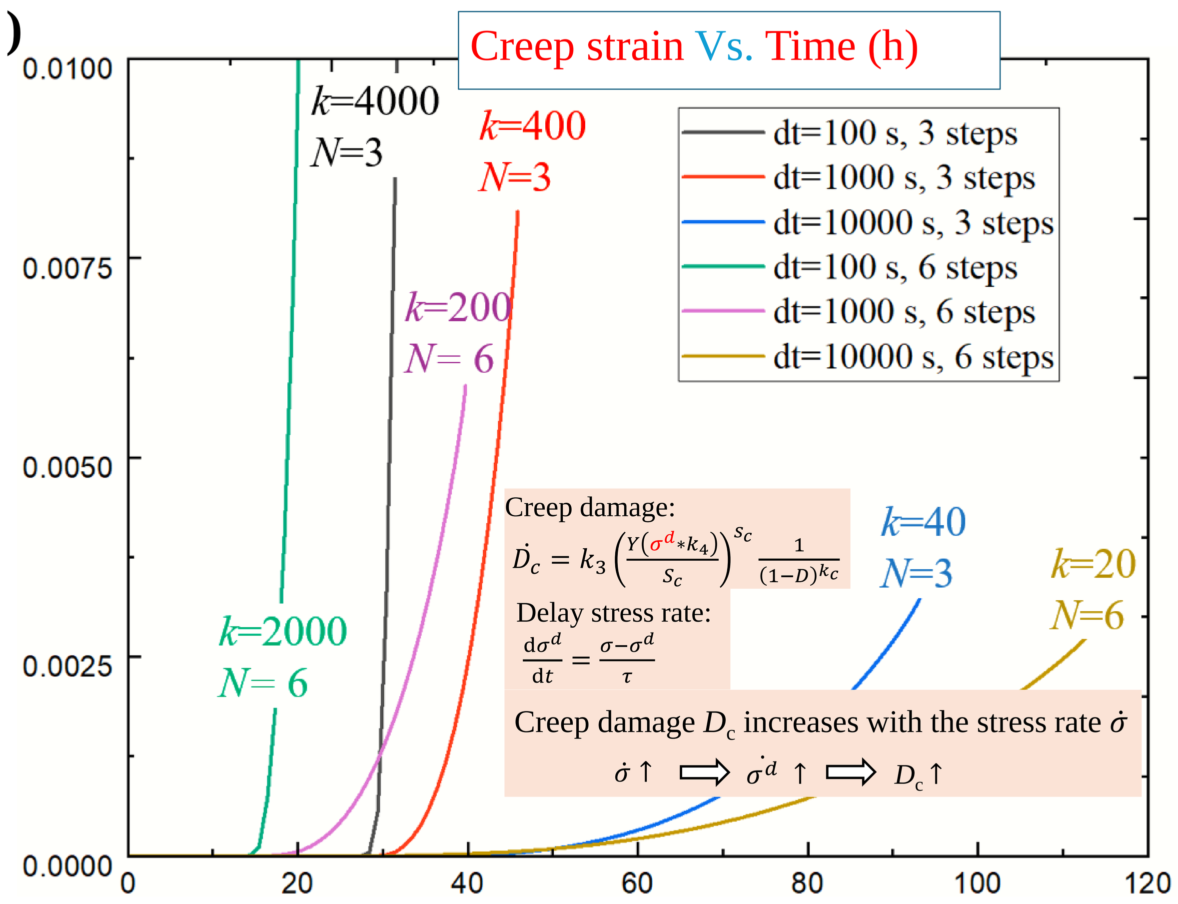


Validation of Morch Law & its identified dataset



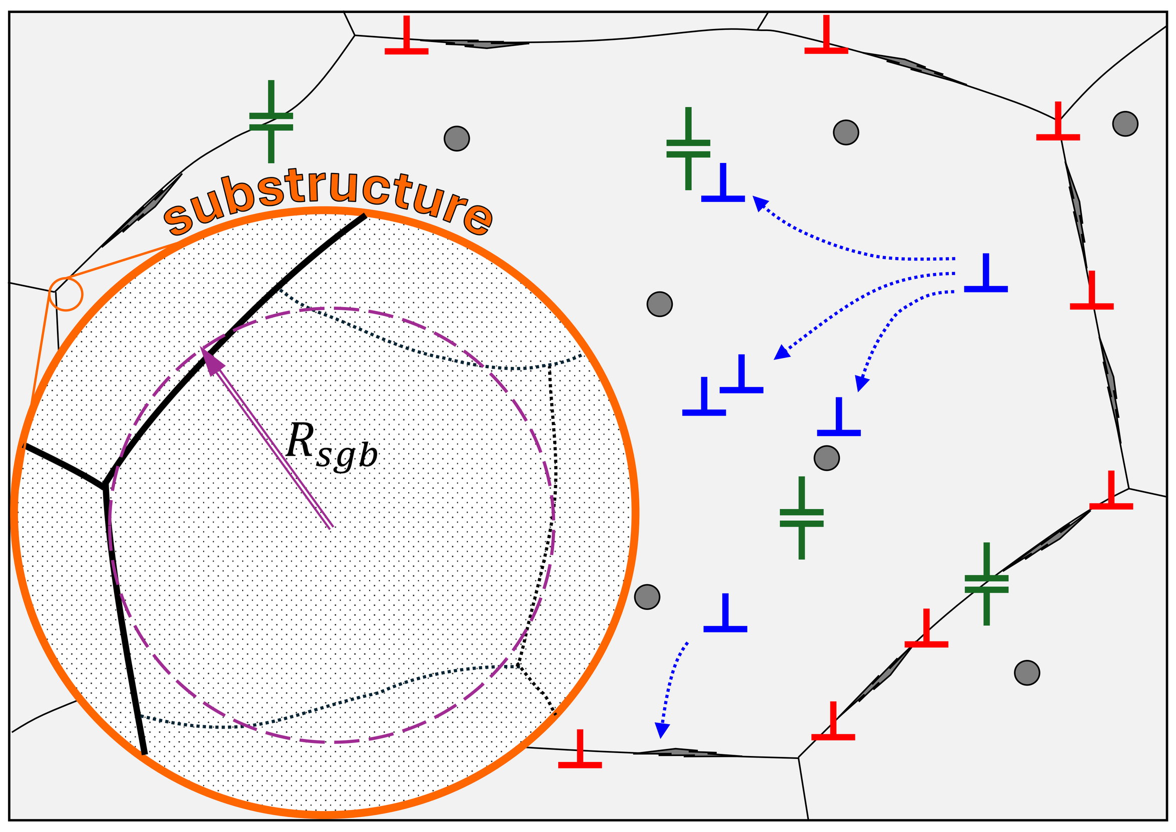
SSM (numerical predictions, next step exp [Rothwell J, 2010])





The creep behavior is impacted by step number and slope k

Creep deformation ⇆ Microstructure evolution



Microstructural features

Dislocation types

- ⊥ mobile (ρ_m)
- static (or dipole) (ρ_s)
- ⊥ boundary (ρ_b)

Precipitates

- Intragranular
- Intergranular

mean subgrain radius (R_{sgb})

solute atoms ( )

A common physical framework: The **Orowan equation**

$$\dot{\varepsilon} = \frac{\rho_m \cdot b \cdot v}{m_T}$$

- Creep strain rate (s^{-1}) — $\dot{\varepsilon}$
- Mobile dislocation density (m^{-2}) — ρ_m
- Burgers vector (m) — b
- Velocity (ms^{-1}) — v
- Taylor factor (−) — m_T

Improved damage model

Cavity (Riedlsperger, 2020): $\dot{D}_{cav} = A\varepsilon\dot{\varepsilon}$

Rabotnov-Kachanov equation (Lemaitre + Morch): $\dot{D}_c = k_3\left(\frac{Y(\sigma^d * k_4)}{S_c}\right)^{s_c}\frac{1}{(1-D)^{k_c}}$

$$\dot{D}_{cav} = A\varepsilon\dot{\varepsilon}\frac{1}{((1 - s_c D_{cav}) * S_c)^{k_c}}$$

Creep strain rate: $$\frac{d\varepsilon}{dt} = \frac{b\rho_m v_{eff}}{m_T((1 - D_{cav}) * K_c)^n}$$

Input data:

Particle kinetics

- Type of precipitate,
- location of nucleation, …
- N_p: Number density of particles (m^{-3})
- r_p: Mean radius of particles (m^{-3})

Loadings

Stress + Temperature

Material parameters (see next slides)

- Experimental data
- Adjustable parameters

Creep strain curves