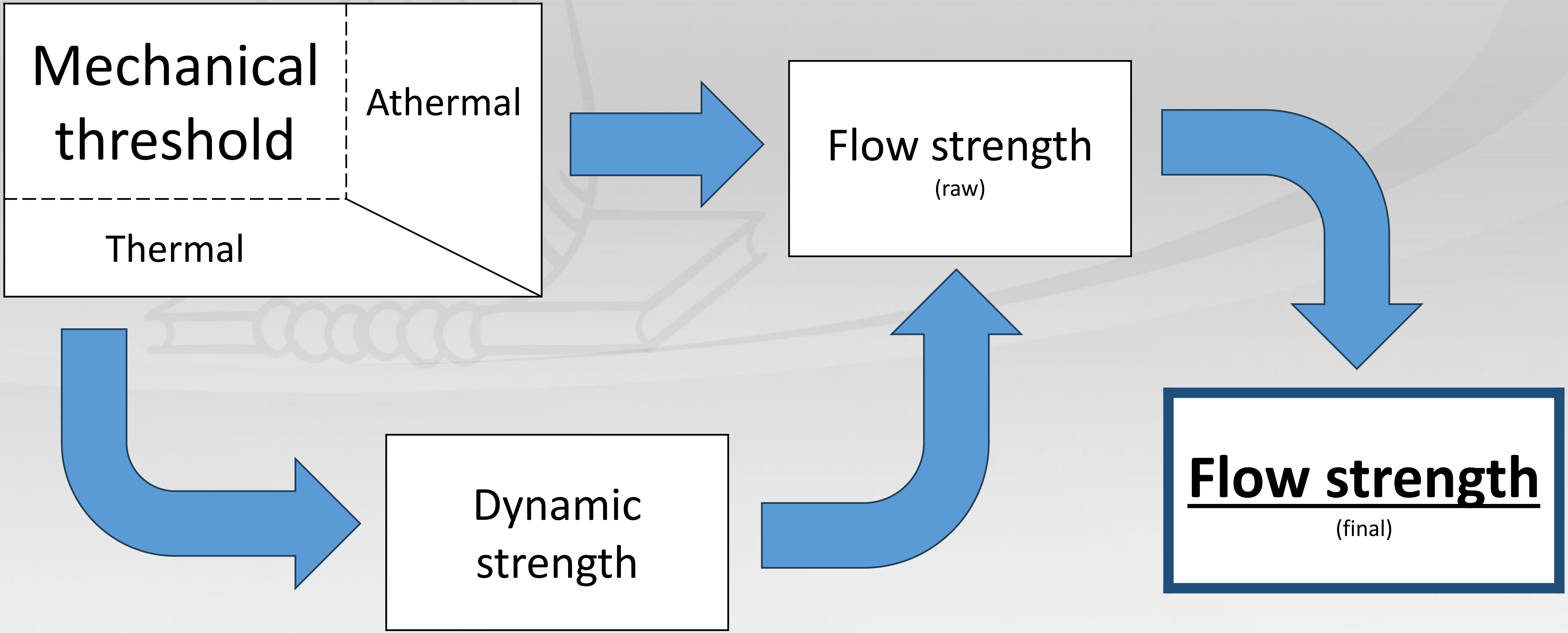
MatCalc
Engineering

Flow curve calculation in MatCalc

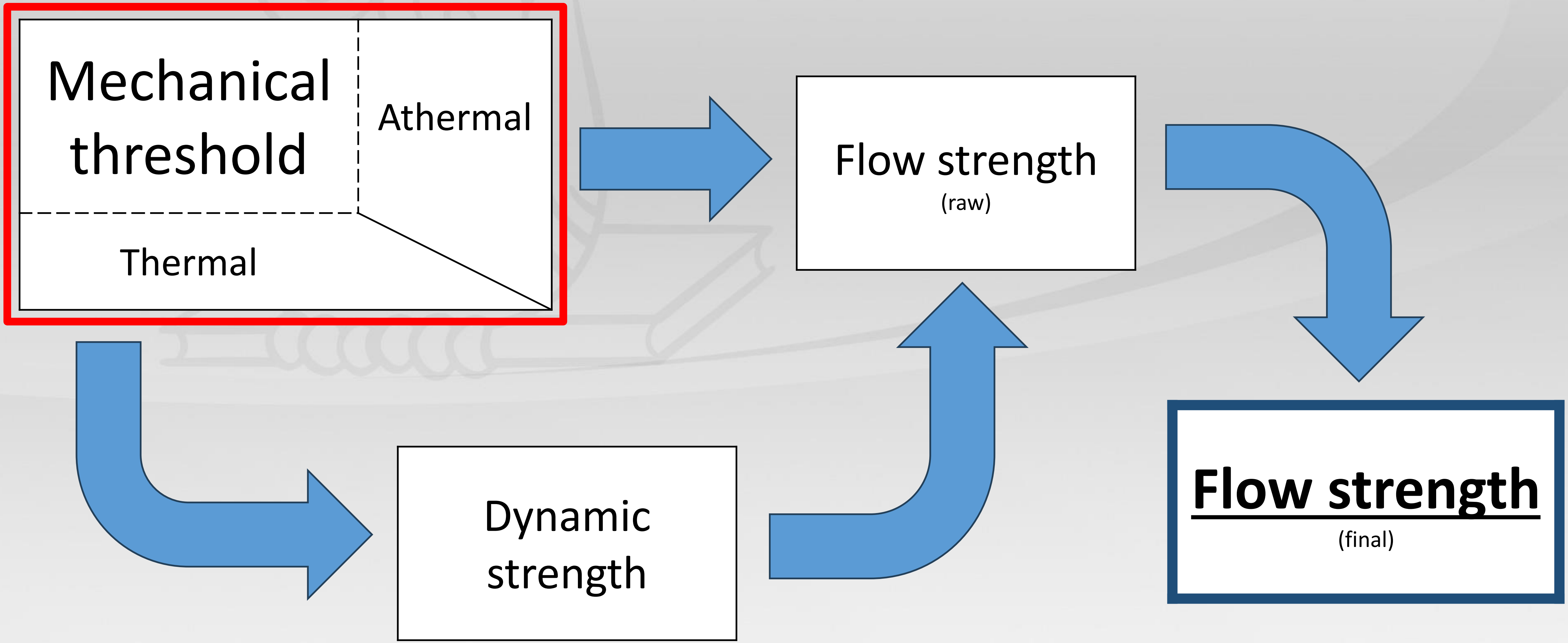
MatCalc 6.04.1004

P. Warczok

Overview


Mechanical threshold
Athermal
Thermal
Flow strength
(raw)
Dynamic strength
Flow strength
(final)

Overview


Mechanical threshold
Athermal
Thermal
Flow strength
(raw)
Dynamic strength
Flow strength
(final)

Mechanical threshold

- Yield stress at temperature 0 K
- Microstructure dependent

$$\sigma_0 = f\left(\rho, d_g, d_{sg}, c_i^m, r_{p_j}, N_{p_j}, \dots\right)$$

- Thermal & athermal contributions

$$\sigma_0 = \sigma_{ath} + \sigma_{th}$$

ρ - Dislocation density [m-2]

d_g - Grain diameter [m]

d_{sg} - Subgrain diameter [m]

c_i^m - Concentration of i-element in matrix

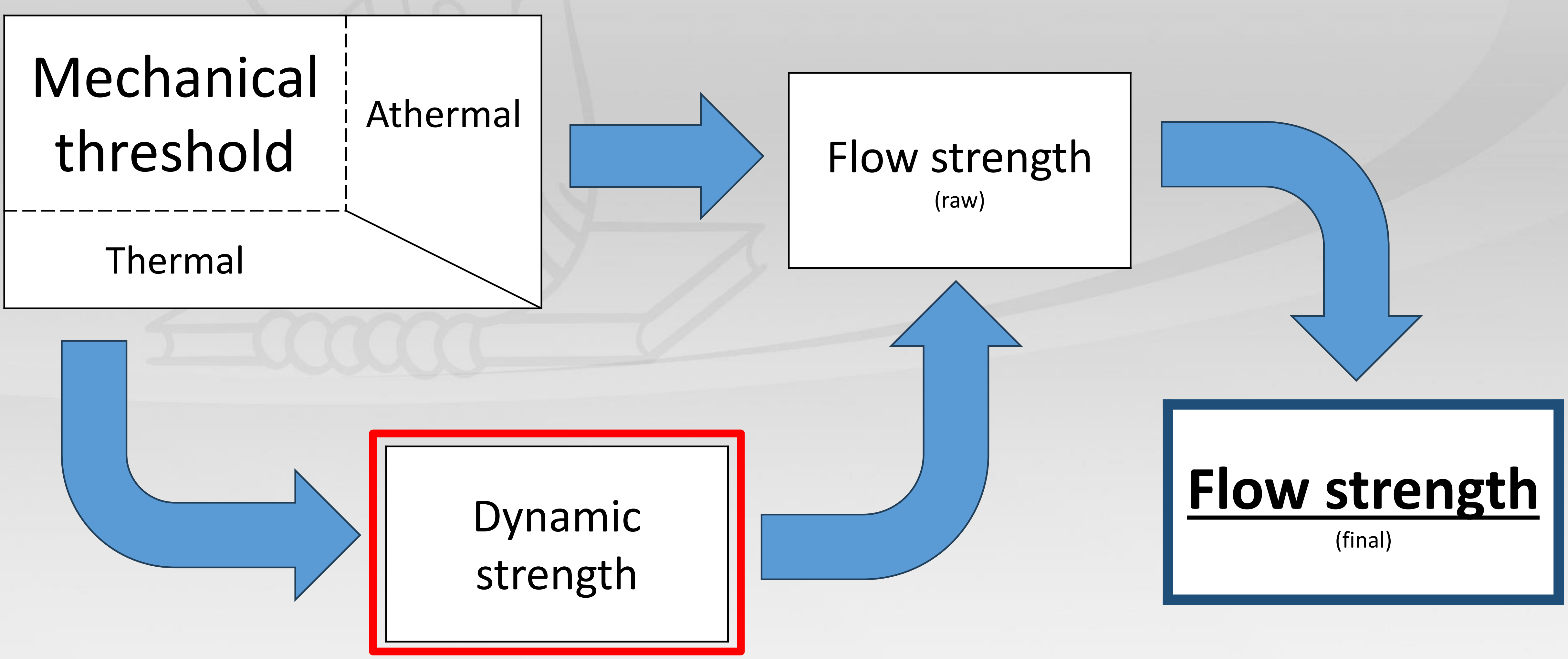
r_{p_j} - Radius of precipitate j [m]

N_{p_j} - Number density of precipitate j [m^{-3}]

σ_{ath} - Athermal contribution [Pa]

σ_{th} - Thermal contribution [Pa]

Overview


Mechanical threshold
Athermal
Thermal
Flow strength
(raw)
Dynamic strength
Flow strength
(final)

Dynamic stress contribution

- Sum of various contributions

$$\sigma_d = (\sigma_{dyn,lt}{}^{-n_{dyn}} + \sigma_{dyn,ht}{}^{-n_{dyn}} + \sigma_{dyn,lt,pbd}{}^{-n_{dyn}} + \cdots$$

$$\ldots + \sigma_{dyn,ht,pbd}{}^{-n_{dyn}} + \sigma_{dyn,NHc}{}^{-n_{dyn}} + \sigma_{dyn,Cc}{}^{-n_{dyn}} + \cdots$$

$$\ldots + \sigma_{dyn,HDc}{}^{-n_{dyn}} + \sigma_{dyn,gbs,gb}{}^{-n_{dyn}} + \sigma_{dyn,gbs,eff}{}^{-n_{dyn}})^{-1/n_{dyn}}$$

$\sigma_{dyn,lt}$ – Low temperature regime

$\sigma_{dyn,ht}$ – High temperature regime

$\sigma_{dyn,NHc}$ – Nabarro-Herring creep

$\sigma_{dyn,Cc}$ – Coble creep

$\sigma_{dyn,HDc}$ – Harper-Dorn creep

$\sigma_{dyn,lt,pbd}$ – Power law breakdown, low temperature regime

$\sigma_{dyn,ht,pbd}$ – Power law breakdown, high temperature regime

$\sigma_{dyn,gbs,gb}$ – Grain boundary sliding, lattice diffusion regime

$\sigma_{dyn,gbs,eff}$ – Grain boundary sliding, grain boundary diffusion regime

n_{dyn} – Exponent

Dynamic stress contribution

- Sum of various contributions

$$\sigma_d = (\sigma_{dyn,lt}{}^{-n_{dyn}} + \sigma_{dyn,ht}{}^{-n_{dyn}} + \sigma_{dyn,lt,pbd}{}^{-n_{dyn}} + \cdots$$

$$\ldots + \sigma_{dyn,ht,pbd}{}^{-n_{dyn}} + \sigma_{dyn,NHc}{}^{-n_{dyn}} + \sigma_{dyn,Cc}{}^{-n_{dyn}} + \cdots$$

$$\ldots + \sigma_{dyn,HDc}{}^{-n_{dyn}} + \sigma_{dyn,gbs,gb}{}^{-n_{dyn}} + \sigma_{dyn,gbs,eff}{}^{-n_{dyn}})^{-1/n_{dyn}}$$

- Strain rate absence → $\sigma_d = 0$
- All but $\sigma_{dyn,lt}$ and $\sigma_{dyn,ht}$ contributions dependent on diffusivity in material

Dynamic stress contribution

- Sum of various contributions

variable	value
prec_domain strength	
TYS_DYN$*	
TYS_DYN$matrix	1,39036e+07

$$\sigma_d = \left(\sigma_{dyn,lt}{}^{-n_{dyn}} + \sigma_{dyn,ht}{}^{-n_{dyn}} + \sigma_{dyn,lt,pbd}{}^{-n_{dyn}} + \cdots\right.$$

$$\ldots + \sigma_{dyn,ht,pbd}{}^{-n_{dyn}} + \sigma_{dyn,NHc}{}^{-n_{dyn}} + \sigma_{dyn,Cc}{}^{-n_{dyn}} + \cdots$$

$$\left.\ldots + \sigma_{dyn,HDc}{}^{-n_{dyn}} + \sigma_{dyn,gbs,gb}{}^{-n_{dyn}} + \sigma_{dyn,gbs,eff}{}^{-n_{dyn}}\right)^{-1/n_{dyn}}$$

- Strain rate absence → $\sigma_d = 0$
- All but $\sigma_{dyn,lt}$ and $\sigma_{dyn,ht}$ contributions dependent on diffusivity in material

Low temperature

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Minimal value limit for $\dot{\varepsilon} \geq 10^{-18}$ s^{-1}

$$\sigma_{dyn,lt} = \sigma_{th} \left(\frac{\dot{\varepsilon}}{A_{\varepsilon_0} b c_{snd} \rho_{eq}} \right)^{RT/\Delta F_{\sigma_0}^{lt}}$$

b	–	Burgers vector [m]
R	–	Gas constant [$Jmol^{-1}K^{-1}$]
T	–	Temperature [K]
c_{snd}	–	Speed of sound [ms^{-1}]
σ_{th}	–	Mechanical threshold, thermal contribution [Pa]
$\Delta F_{\sigma_0}^{lt}$	–	Yield stress activation energy, low temperature[$Jmol^{-1}$]
ρ_{eq}	–	Equilibrium dislocation density [m^{-2}]
A_{ε_0}	–	Scaling factor for strain rate limit
$\dot{\varepsilon}$	–	Strain rate [s^{-1}]

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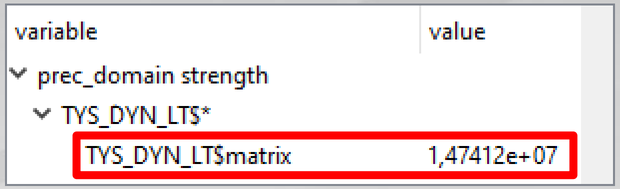
Engineering

Low temperature

Minimal value limit
for $\dot{\varepsilon} \geq 10^{-18}$ s^{-1}

$$\sigma_{dyn,lt} = \sigma_{th} \left(\frac{\dot{\varepsilon}}{A_{\varepsilon_0} b c_{snd} \rho_{eq}} \right)^{RT/\Delta F^{lt}_{\sigma_0}}$$



b – Burgers vector [m]

R – Gas constant [Jmol^{-1}K^{-1}]

T – Temperature [K]

c_{snd} – Speed of sound [ms^{-1}]

σ_{th} – Mechanical threshold, thermal contribution [Pa]

$\Delta F^{lt}_{\sigma_0}$ – Yield stress activation energy, low temperature[Jmol^{-1}]

ρ_{eq} – Equilibrium dislocation density [m^{-2}]

A_{ε_0} – Scaling factor for strain rate limit

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

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High temperature

Minimal value limit for $\dot{\varepsilon} \geq 10^{-18}$ s^{-1}

$$\sigma_{dyn,ht} = \left[\sigma_{th} \frac{bRT(\alpha_{int} M_T G)^2}{2 c_{snd} \Delta F_{\sigma_0}^{ht}} exp\left(\frac{\Delta F_{\sigma_0}^{ht}}{RT}\right) \dot{\varepsilon}^{n_{eps\_dot}}\right]^{n_{ht}}$$

G – Shear modulus [Pa]

M_T – Taylor factor

b – Burgers vector [m]

R – Gas constant [Jmol^{-1}K^{-1}]

T – Temperature [K]

c_{snd} – Speed of sound [ms^{-1}]

σ_{th} – Mechanical threshold, thermal contribution [Pa]

$\Delta F_{\sigma_0}^{ht}$ – Yield stress activation energy, high temperature [Jmol^{-1}]

α_{int} – Strengthening coefficient for internal dislocations

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

n_{eps_dot} – Strain rate exponent

n_{ht} – Exponent

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High temperature

Minimal value limit for $\dot{\varepsilon} \geq 10^{-18}$ s^{-1}

$$\sigma_{dyn,ht} = \left[\sigma_{th}\frac{bRT(\alpha_{int}M_TG)^2}{2c_{snd}\Delta F^{ht}_{\sigma_0}} exp\left(\frac{\Delta F^{ht}_{\sigma_0}}{RT}\right)\dot{\varepsilon}^{n_{eps\_dot}}\right]^{n_{ht}}$$

variable	value
prec_domain strength	
TYS_DYN_HT$*	
TYS_DYN_HT$matrix	2,64128e+08

- G – Shear modulus [Pa]
- M_T – Taylor factor
- b – Burgers vector [m]
- R – Gas constant [Jmol^{-1}K^{-1}]
- T – Temperature [K]
- c_{snd} – Speed of sound [ms^{-1}]

- σ_{th} – Mechanical threshold, thermal contribution [Pa]
- $\Delta F^{ht}_{\sigma_0}$ – Yield stress activation energy, high temperature [Jmol^{-1}]
- α_{int} – Strengthening coefficient for internal dislocations
- $\dot{\varepsilon}$ – Strain rate [s^{-1}]
- n_{eps_dot} – Strain rate exponent
- n_{ht} – Exponent

Low temperature, power law breakdown

$$\sigma_{dyn,lt,plb} = G A_{lt,plb,1}\, arsinh\left[\left(A_{lt,plb,2}\frac{M_T k_B T}{G D_{disl} f_{pipe} b}\dot{\varepsilon}\right)^{n_{lt,plb}}\right]$$

$A_{lt,plb,1}$ – Scaling factor (10^{-3}; hardcoded)

$A_{lt,plb,2}$ – Scaling factor (10^{128}; hardcoded)

G – Shear modulus [Pa]

M_T – Taylor factor

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

D_{disl} – Diffusion coefficient along dislocations (reference element) [m^2s^{-1}]

f_{pipe} – Correction factor for pipe diffusion

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

$n_{lt,plb}$ – Exponent (5; hardcoded)

Low temperature, power law breakdown

$$\sigma_{dyn,lt,plb} = G A_{lt,plb,1}\, arsinh\left[\left(A_{lt,plb,2}\frac{M_T k_B T}{G D_{disl} f_{pipe} b}\dot{\varepsilon}\right)^{n_{lt,plb}}\right]$$

variable	value
prec_domain strength	
TYS_DYN_POW_LT_BD$*	
TYS_DYN_POW_LT_BD$matrix	inf

$A_{lt,plb,1}$ – Scaling factor (10^{-3}; hardcoded)

$A_{lt,plb,2}$ – Scaling factor (10^{128}; hardcoded)

G – Shear modulus [Pa]

M_T – Taylor factor

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

D_{disl} – Diffusion coefficient along dislocations (reference element) [m^2s^{-1}]

f_{pipe} – Correction factor for pipe diffusion

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

$n_{lt,plb}$ – Exponent (5; hardcoded)

High temperature, power law breakdown

$$\sigma_{dyn,ht,plb} = G A_{ht,plb,1}\, arsinh\left[\left(A_{ht,plb,2}\frac{M_T k_B T}{G D_{eff} b}\dot{\varepsilon}\right)^{n_{ht,plb}}\right]$$

- $A_{ht,plb,1}$ – Scaling factor (10^{-3}; hardcoded)
- $A_{ht,plb,2}$ – Scaling factor (10^{16}; hardcoded)
- G – Shear modulus [Pa]
- k_B – Boltzmann constant [JK^{-1}]
- T – Temperature [K]
- M_T – Taylor factor
- D_{eff} – Effective diffusion coefficient (reference element) [m^2s^{-1}]
- b – Burgers vector [m]
- $\dot{\varepsilon}$ – Strain rate [s^{-1}]
- $n_{ht,plb}$ – Exponent (3; hardcoded)

High temperature, power law breakdown

$$\sigma_{dyn,ht,plb} = G A_{ht,plb,1}\, arsinh\left[\left(A_{ht,plb,2}\frac{M_T k_B T}{G D_{eff} b}\dot{\varepsilon}\right)^{n_{ht,plb}}\right]$$

variable	value
prec_domain strength	
TYS_DYN_POW_HT_BD$*	
TYS_DYN_POW_HT_BD$matrix	3,32355e+09

$A_{ht,plb,1}$ – Scaling factor (10^{-3}; hardcoded)

$A_{ht,plb,2}$ – Scaling factor (10^{16}; hardcoded)

G – Shear modulus [Pa]

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

M_T – Taylor factor

D_{eff} – Effective diffusion coefficient (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

$n_{ht,plb}$ – Exponent (3; hardcoded)

Nabarro-Herring creep

$$\sigma_{dyn,NHc} = \frac{M_T k_B T d_g^2}{42 D_{eff} b^3} \dot{\varepsilon}$$

M_T – Taylor factor

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

d_g – Grain diameter [m]

D_{eff} Effective diffusion coefficient (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

Nabarro-Herring creep

$$\sigma_{dyn,NHc} = \frac{M_T k_B T d_g^2}{42 D_{eff} b^3} \dot{\varepsilon}$$

variable	value
prec_domain strength	
TYS_DYN_NHC$*	
TYS_DYN_NHC$matrix	4,81362e+14

M_T – Taylor factor

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

d_g – Grain diameter [m]

D_{eff} Effective diffusion coefficient (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

Coble creep

$$\sigma_{dyn,Cc} = \frac{M_T k_B T d_g^3}{42\pi \delta_{gb} D_{gb} b^3} \dot{\varepsilon}$$

M_T – Taylor factor

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

d_g – Grain diameter [m]

δ_{gb} – Grain boundary thickness (10^{-9}; hardcoded) [m]

D_{gb} – Diffusion coefficient along grain boundaries (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

Coble creep

$$\sigma_{dyn,Cc} = \frac{M_T k_B T d_g^3}{42\pi \delta_{gb} D_{gb} b^3} \dot{\varepsilon}$$

variable	value
prec_domain strength	
TYS_DYN_COC$*	
TYS_DYN_COC$matrix	5,63809e+13

- M_T – Taylor factor
- k_B – Boltzmann constant [JK^{-1}]
- T – Temperature [K]
- d_g – Grain diameter [m]
- δ_{gb} – Grain boundary thickness (10^{-9}; hardcoded) [m]
- D_{gb} – Diffusion coefficient along grain boundaries (reference element) [m^2s^{-1}]
- b – Burgers vector [m]
- $\dot{\varepsilon}$ – Strain rate [s^{-1}]

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Harper-Dorn creep

$$\sigma_{dyn,HDc} = G\left(A_{HDc}\frac{M_T k_B T}{D_{eff} b}\dot{\varepsilon}\right)^{n_{HDc}}$$

A_{HDc} – Scaling factor (10^{64}; hardcoded)

G – Shear modulus [Pa]

M_T – Taylor factor

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

D_{eff} – Effective diffusion coefficient (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

n_{HDc} – Exponent (1; hardcoded)

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Harper-Dorn creep

$$\sigma_{dyn,HDc} = G\left(A_{HDc}\frac{M_T k_B T}{D_{eff} b}\dot{\varepsilon}\right)^{n_{HDc}}$$

variable	value
prec_domain strength	
TYS_DYN_HDC$*	
TYS_DYN_HDC$matrix	1,03742e+69

A_{HDc} – Scaling factor (10^{64}; hardcoded)

G – Shear modulus [Pa]

M_T – Taylor factor

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

D_{eff} – Effective diffusion coefficient (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

n_{HDc} – Exponent (1; hardcoded)

Grain boundary sliding, grain boundary diffusion regime

$$\sigma_{dyn,gbs,gb} = G\left(A_{gbs,gb}\,\frac{k_B T d_g^3}{G D_{gb} b^4}\,\dot{\varepsilon}\right)^{n_{gbs,gb}}$$

$A_{gbs,gb}$ – Scaling factor (10^{64}; hardcoded)

G – Shear modulus [Pa]

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

d_g – Grain diameter [m]

D_{gb} – Diffusion coefficient along grain boundaries (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

$n_{gbs,gb}$ – Exponent (1/2; hardcoded)

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Grain boundary sliding, grain boundary diffusion regime

$$\sigma_{dyn,gbs,gb} = G\left(A_{gbs,gb}\frac{k_B T d_g^3}{G D_{gb} b^4}\dot{\varepsilon}\right)^{n_{gbs,gb}}$$

variable	value
prec_domain strength	
TYS_DYN_GBS_GB$*	
TYS_DYN_GBS_GB$matrix	2,22256e+45

$A_{gbs,gb}$ – Scaling factor (10^{64}; hardcoded)

G – Shear modulus [Pa]

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

d_g – Grain diameter [m]

D_{gb} – Diffusion coefficient along grain boundaries (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

$n_{gbs,gb}$ – Exponent (1/2; hardcoded)

Grain boundary sliding, lattice diffusion regime

$$\sigma_{dyn,gbs,eff} = G\left(A_{gbs,d}\frac{k_B T d_g^2}{G D_{eff} b^3}\dot{\varepsilon}\right)^{n_{gbs,eff}}$$

$A_{gbs,d}$ – Scaling factor (10^{64}; hardcoded)

G – Shear modulus [Pa]

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

d_g – Grain diameter [m]

D_{eff} – Effective diffusion coefficient (reference element) [m^2s^{-1}]

b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

$n_{gbs,eff}$ – Exponent (1/2; hardcoded)

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Grain boundary sliding, lattice diffusion regime

$$\sigma_{dyn,gbs,eff} = G\left(A_{gbs,d}\,\frac{k_B T d_g^2}{G D_{eff} b^3}\,\dot{\varepsilon}\right)^{n_{gbs,eff}}$$

variable	value
prec_domain strength	
TYS_DYN_GBS_DISL$*	
TYS_DYN_GBS_DISL$matrix	1,74384e+45

$A_{gbs,d}$ – Scaling factor (10^{64}; hardcoded)

G – Shear modulus [Pa]

k_B – Boltzmann constant [JK^{-1}]

T – Temperature [K]

d_g – Grain diameter [m]

D_{eff} – Effective diffusion coefficient (reference element) [m^2s^{-1}]

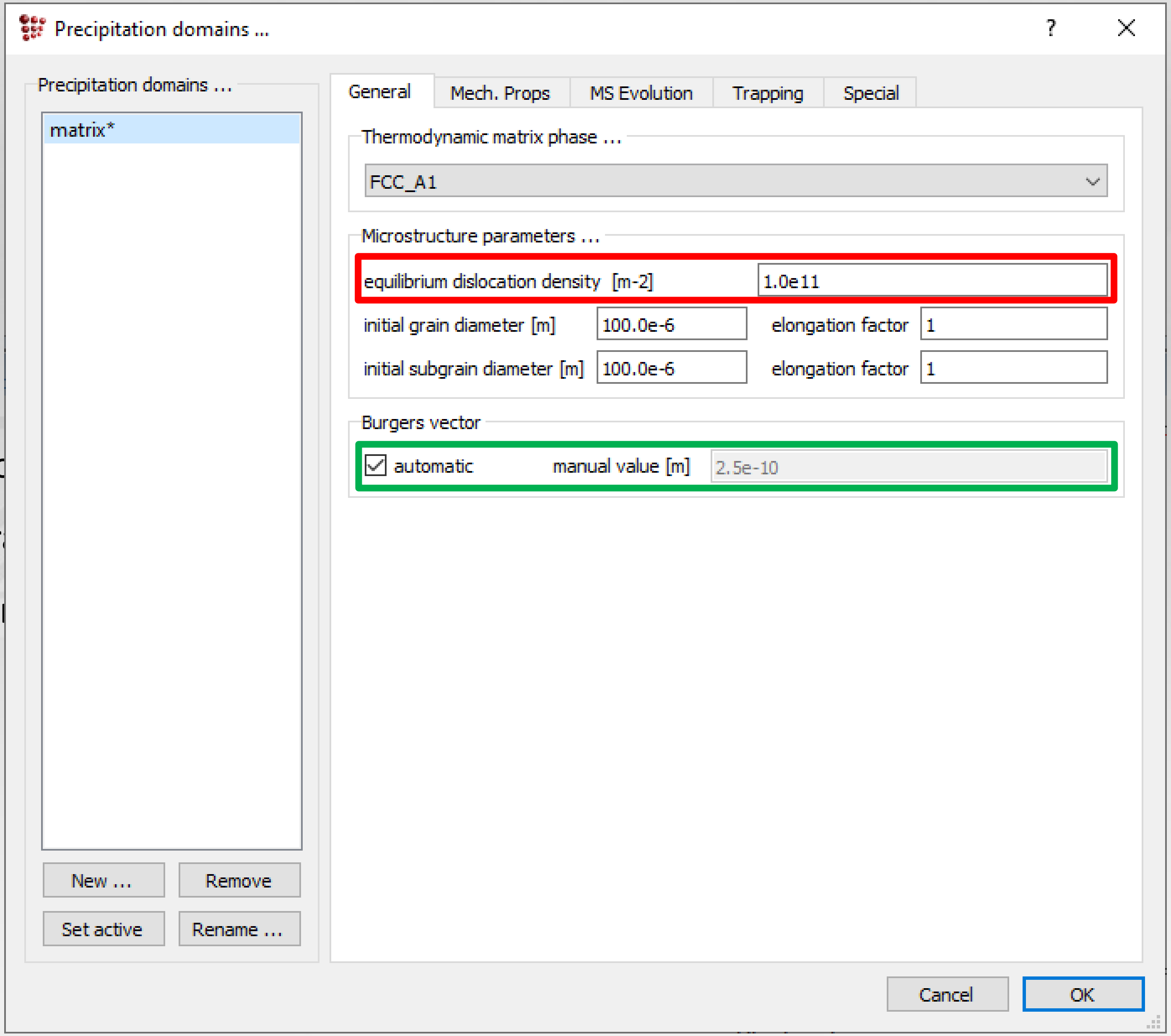
b – Burgers vector [m]

$\dot{\varepsilon}$ – Strain rate [s^{-1}]

$n_{gbs,eff}$ – Exponent (1/2; hardcoded)

Some input values

- ρ_{eq} – Equilibrium dislocation density [m^{-2}]
- b – Burgers vector [m]
- M_T – Taylor factor
- c_{snd} – Speed of sound [ms^{-1}]
- α_{int} – Strengthening coefficient for internal disl
- $\Delta F_{\sigma_0}^{lt}$ – Yield stress activation energy, low temper
- $\Delta F_{\sigma_0}^{ht}$ – Yield stress activation energy, high temper
- A_{ε_0} – Scaling factor for strain rate limit
- n_{ht} – Exponent, high temperature
- n_{dyn} – Exponent, coupling
- n_{eps_dot} – Strain rate exponent



Some input values

ρ_{eq} – Equilibrium dislocation density [m^{-2}]

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M_T – Taylor factor

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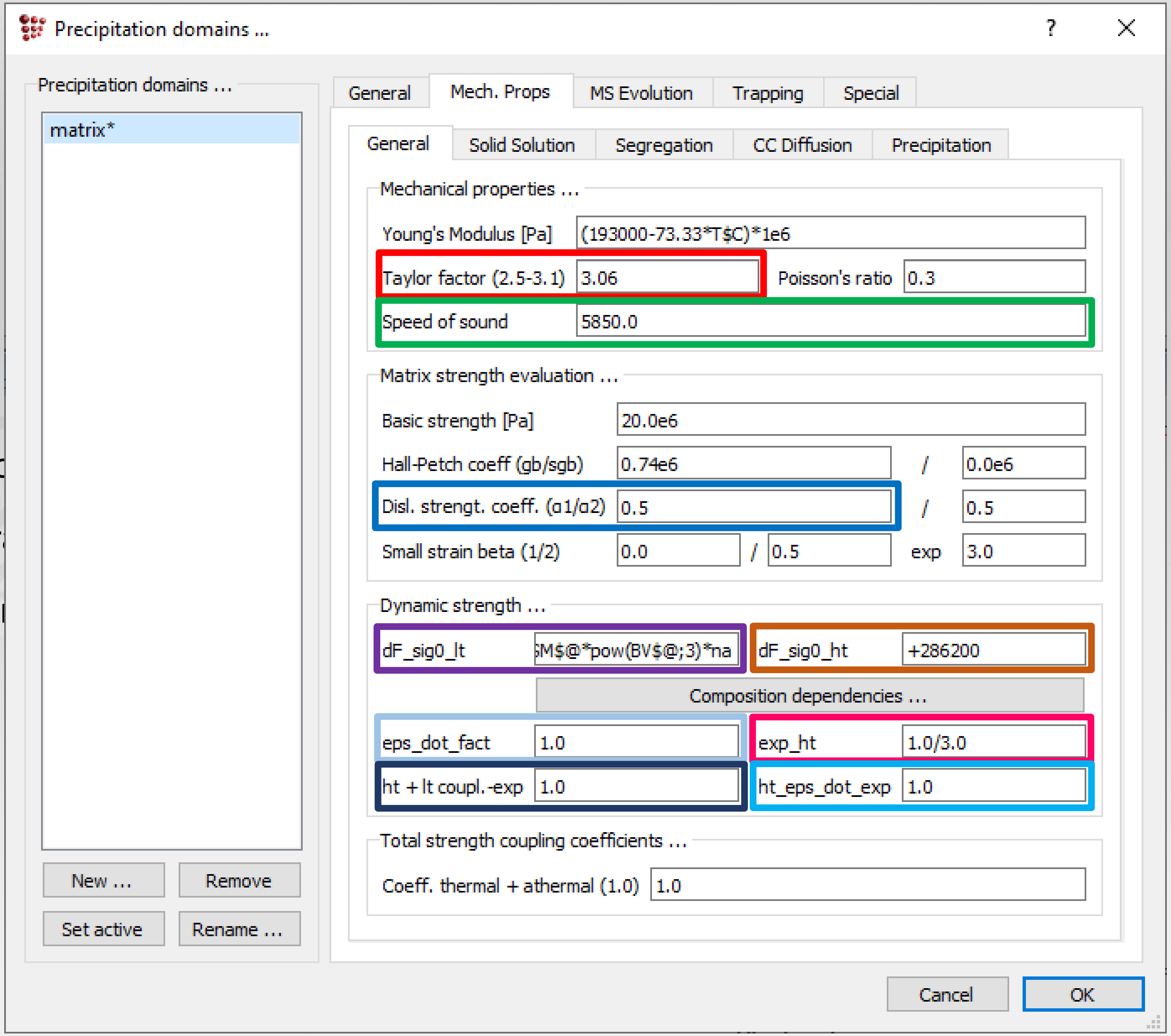
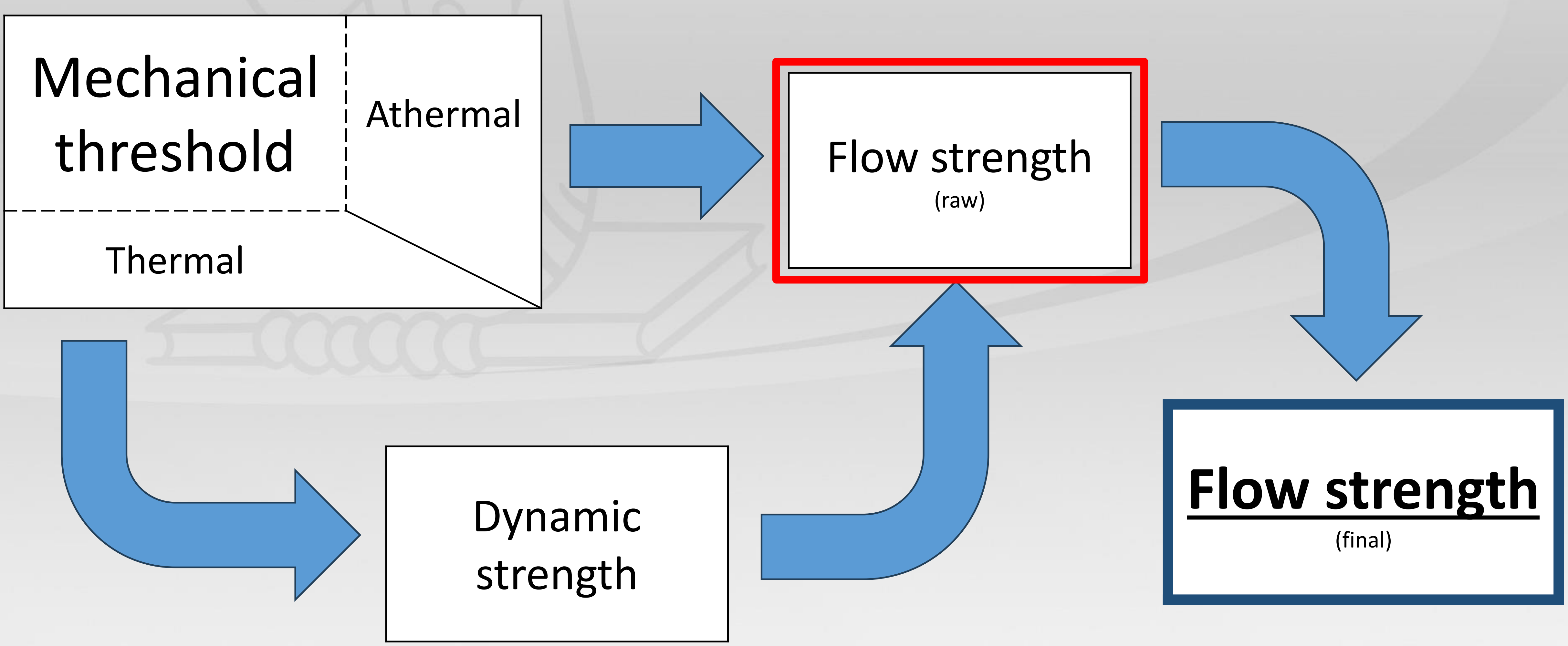


Overview


Mechanical threshold
Athermal
Thermal
Flow strength
(raw)
Dynamic strength
Flow strength
(final)

Flow stress (raw)

- Sum of the athermal and dynamic contributions

$$\sigma = \sigma_{ath} + \sigma_{dyn}$$

- Strain rate absence → $\sigma = 0$
- Values for small strains most likely overestimated - might need correction

Flow stress (raw)

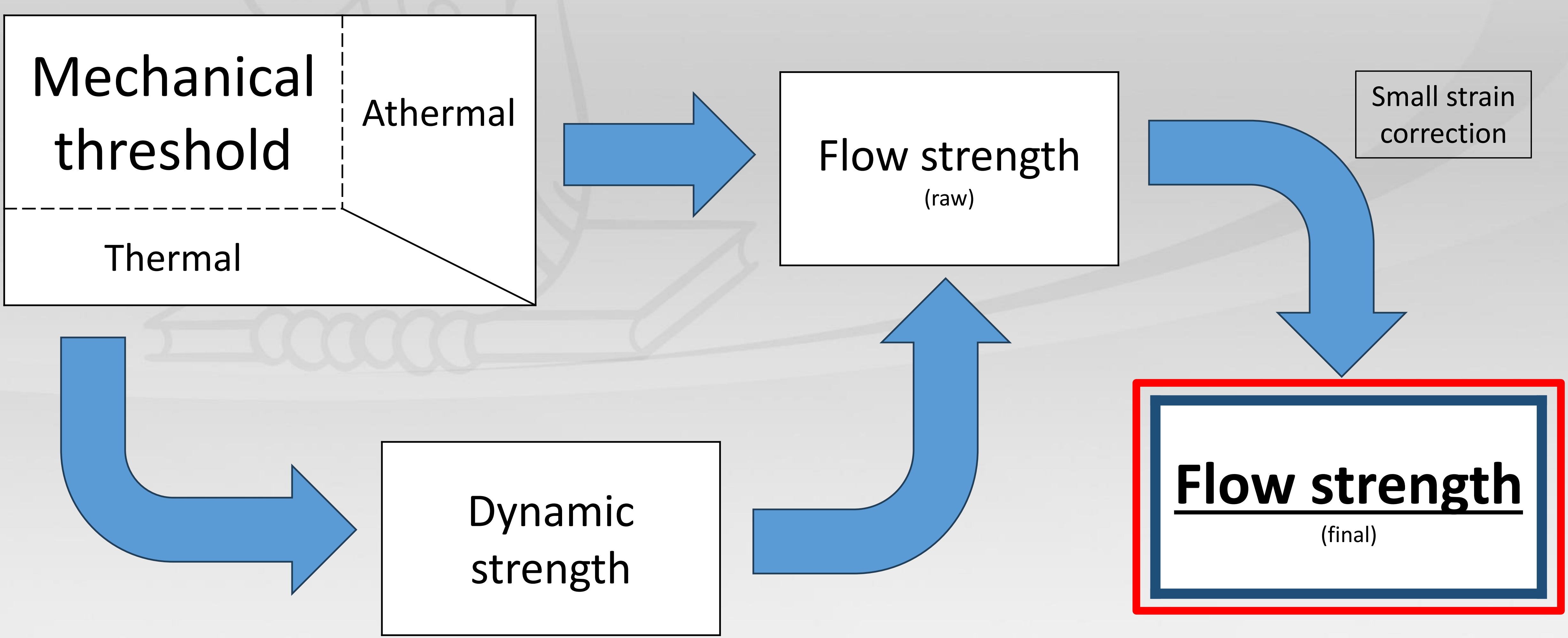
- Sum of the athermal and dynamic contributions

$$\sigma = \sigma_{ath} + \sigma_{dyn}$$

variable	value
prec_domain strength	
TYS_NB$*	
TYS_NB$matrix	2,40202e+08

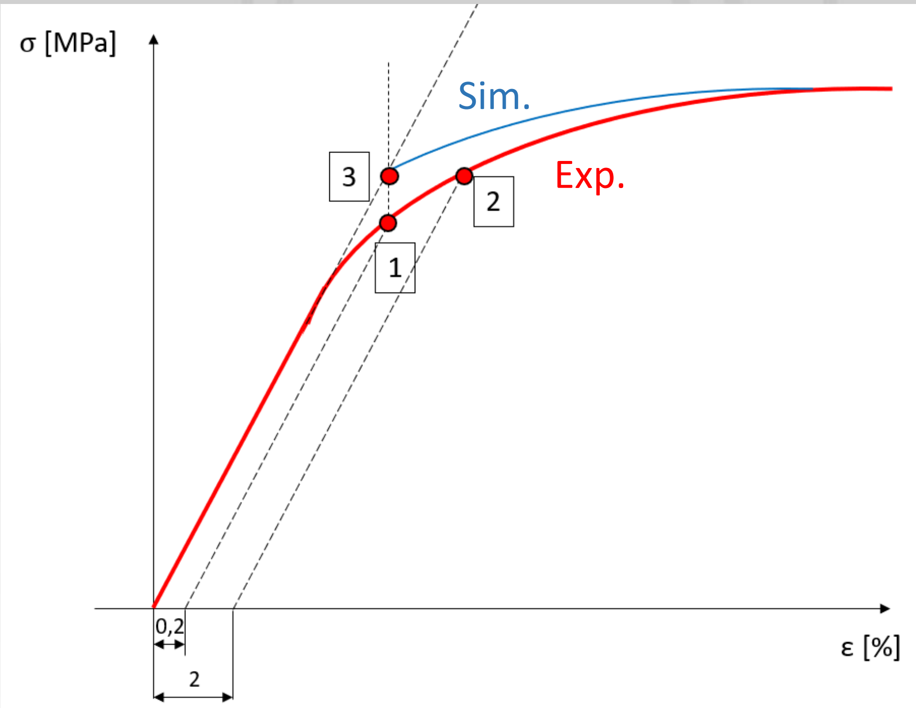
- Strain rate absence → $\sigma = 0$
- Values for small strains most likely overestimated - might need correction

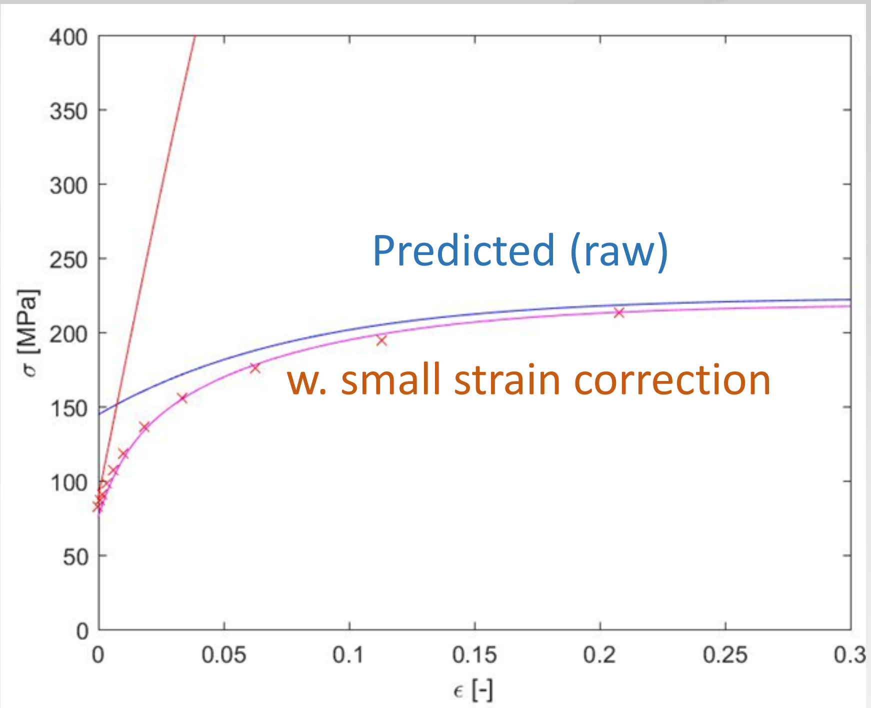
Overview


Mechanical threshold
Athermal
Thermal
Flow strength
(raw)
Small strain correction
Dynamic strength
Flow strength
(final)

„Small strain“ correction

- Models are strictly valid for a fixed microstructure (fixed dislocation density)
- In practice → Relevant for materials with strain > 2%





B. Viernstein, 2020 (unpublished)

„Small strain“ correction

- Models are strictly valid for a fixed microstructure (fixed dislocation density)
- In practice → Relevant for materials with strain > 2%
- Correction for small strains with a dislocation density saturation function β

$$\beta = \sqrt{\beta_1 \frac{\rho}{\rho_{sat}} + \beta_2}$$

$$\sigma_\beta^{-n} = \sigma^{-n} + (\beta\sigma)^{-n}$$

$$\sigma_\beta = \sigma(1 + \beta^{-n})^{-1/n}$$

ρ - Current dislocation density

ρ_{sat} - Saturated dislocation density

β_1, β_2 - Coefficients

n - Exponent

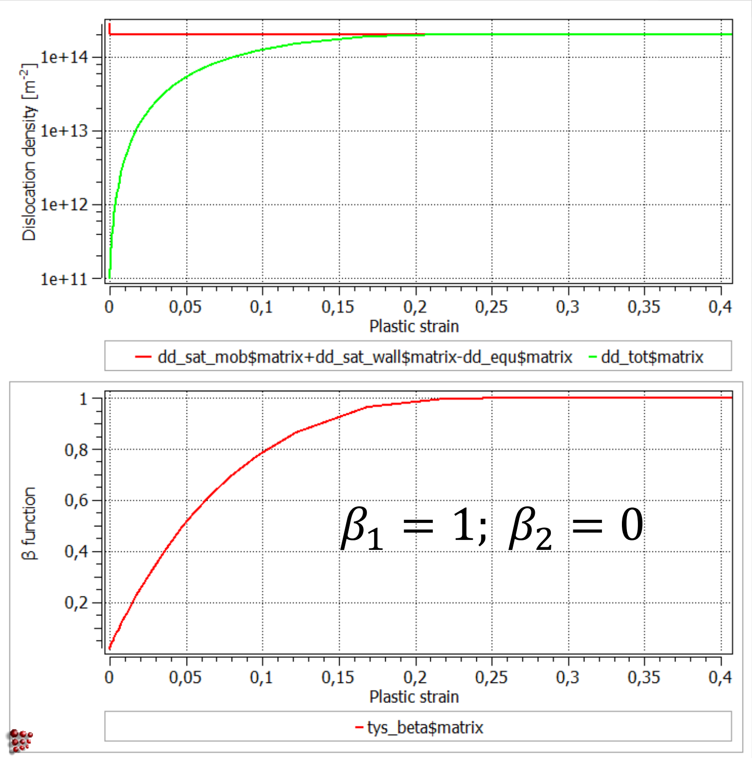
„Small strain“ correction

- Models are strictly valid for a fixed microstructure (fixed dislocation density)
- Relevant for materials with strain > 2%
- Correction for small strains with a dislocation density saturation function β

$$\beta = \sqrt{\beta_1 \frac{\rho}{\rho_{sat}} + \beta_2}$$

$$\sigma_\beta^{-n} = \sigma^{-n} + (\beta\sigma)^{-n}$$

$$\sigma_\beta = \sigma(1 + \beta^{-n})^{-1/n}$$



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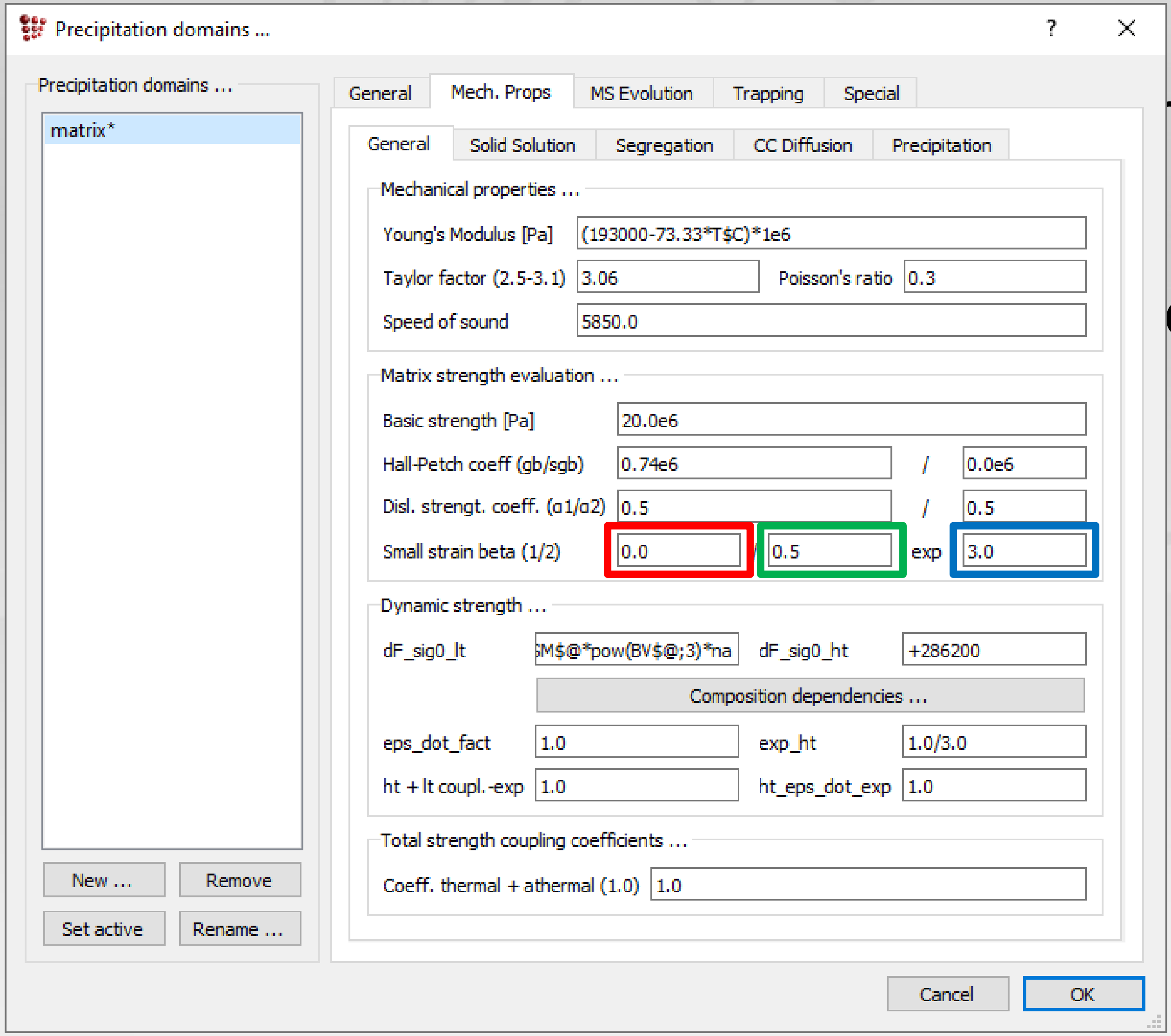
„Small strain“ correction



rostructure (fixed dislocation density)

cation density saturation function β

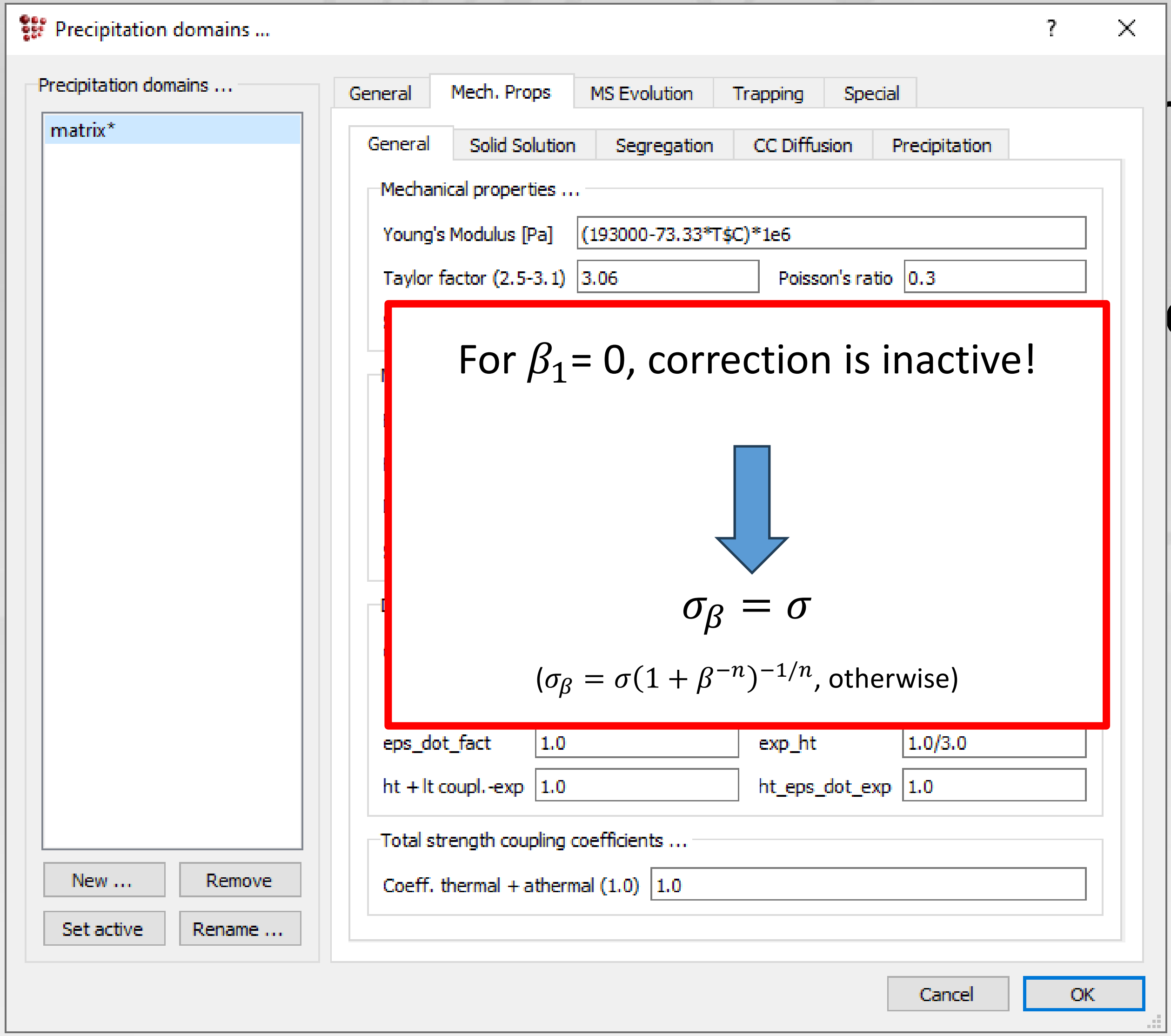
ρ - Current dislocation density

ρ_{sat} - Saturated dislocation density

β_1, β_2 - Coefficients

n - Exponent

„Small strain“ correction



For $\beta_1 = 0$, correction is inactive!

$$\sigma_\beta = \sigma$$

($\sigma_\beta = \sigma(1+\beta^{-n})^{-1/n}$, otherwise)

rostructure (fixed dislocation density)

cation density saturation function β

ρ - Current dislocation density

ρ_{sat} - Saturated dislocation density

β_1, β_2 - Coefficients

n - Exponent

„Small strain“ correction

- Models are strictly valid for a fixed microstructure (fixed dislocation density)
- Relevant for materials with strain > 2%
- Correction for small strains with a dislocation density saturation function β

$$\beta = \sqrt{\beta_1 \frac{\rho}{\rho_{sat}} + \beta_2}$$

$$\sigma_\beta^{-n} = \sigma^{-n} + (\beta\sigma)^{-n}$$

$$\sigma_\beta = \sigma(1 + \beta^{-n})^{-1/n}$$

variable	value
prec_domain strength	
TYS$*	
TYS$matrix	1,90543e+08
TYS_BETA$*	
TYS_BETA$matrix	1,00025

Acknowledgments

- Johannes Kreyca
- Bernhard Viernstein
- Yao Shan

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Thank you for your attention!