HSNV102 - Thermo-metal-worker-plasticity coupled in simple traction

Summary:

One treats the determination of the mechanical evolution of a cylindrical bar subjected to evolutions thermics $T(t)$ and metallurgical $Z(t)$ known and uniform (the metallurgical transformation is of martensitic type).

The elements used are axisymmetric elements and the relation of behavior is plasticity of von Mises with isotropic work hardening (for modeling B, one also takes account of the plasticity of transformation).

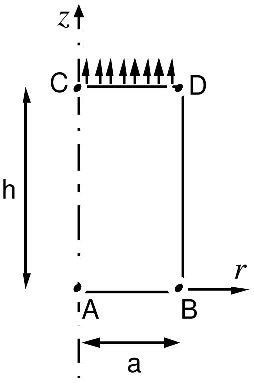
The yield stress and the slope of the traction diagram depend on the temperature and the metallurgical composition.

The dilation coefficient α depends on the metallurgical composition.

The metallurgical transformations take place with $\dot{\varepsilon}^p \neq 0$ (it is in the sense that the test **couples** the plasticity of transformation of classical plasticity).

1 Problem of reference

1.1 Geometry



1.2 Properties of materials

$E = 200\,000.10^6$ Pa	$\sigma_y^{aust} = \sigma_o^{aust} + s^{aust}(T - T^o)$	notons $H(t) = \dfrac{\alpha(t)\cdot E(t)}{E(t) - \alpha(t)}$
$\nu = 0.3$	$\sigma_o^{aust} = 50.\ 10^6$ Pa	$H^{aust} = H_o^{aust} + \lambda^{aust}(T - T^o)$
$\alpha_{fbm} = 15.\ 10^{-6}\ °C^{-1}$	$s^{aust} = 1.3\ 10^6$ Pa.°C^{-1}	$H_o^{aust} = 0$ Pa
$\alpha_{aust} = 23.5\ 10^{-6}\ °C^{-1}$	$\sigma_y^{fbm} = \sigma_o^{fbm} + s^{fbm}(T - T^o)$	$\lambda^{aust} = -1\ 10^6$ Pa.°C^{-1}
$\varepsilon_{ref_{fbm}} = 2.52\ 10^{-3}$	$\sigma_o^{fbm} = 50.\ 10^6$ Pa	$H^{fbm} = H_o^{fbm} + \lambda^{fbm}(T - T^o)$
	$s^{fbm} = 1.\ 10^6$ Pa.°C^{-1}	$H_o^{fbm} = 0$
$cp = 2\,000\,000$ J.m^{-3}.°C^{-1}	$\lambda = 9999.9$ W.m^{-1}.°C^{-1}	$\lambda^{fbm} = -6.\ 10^6$ Pa.°C^{-1}
		$k^f = 0 \quad k^b = k^m = 1.\ 10^{-10}$Pa^{-1}

Note:

Indices or exponents fbm are relating to the parameters materials of the phases ferrito - perlitic, bainitic and martensitic and the indices or exponents $aust$ are relating to austenite.

TRC to model a metallurgical evolution of martensitic type of the form:

$$\begin{cases} 0. & \text{si } t \le \tau_1 \\ 1 - e^{\phi\lambda(t-\tau_1)} & \text{si } \tau_1 \le t < \tau_2 \\ 1. & \text{si } t \ge \tau_2 \end{cases} \qquad \tau_1 = 25\text{ s} \quad \tau_2 = 40\text{ s} \quad \phi = 0.03 \quad \lambda = -10°\text{C.s}^{-1}$$

1.3 Boundary conditions and loadings

- $u_Z = 0$ on the side AB (condition of symmetry).
- traction imposed on the side CD, $p(t) = p_o\ t$, $p_0 = 15.10^6\ Pa$.
- $T = T^o + \mu t$, $\mu = -10\,°C.s^{-1}$ on all the structure.

1.4 Initial conditions

$T^0 = 900\,°C$.

2 Reference solution

2.1 Method of calculating used for the reference solution

Before transformation, thermoelastic solution for $t < \tau_1$ (not of metallurgical transformation $\dot{Z} = 0$).

$$\sigma(t) = p_o t$$

$$\varepsilon_{zz}(t) = \varepsilon^e_{zz}(t) + \varepsilon^{th}_{zz}(t) = \frac{\sigma(t)}{E} + \alpha_{aust}(T - T^o)$$

The yield stress is reached for $\tau_1 = \dfrac{\sigma_o^{aust}}{p_o - s^{aust} \times k} = 25\ s$.

During the transformation, solution thermo-metal-worker-élasto-plastic, for $\tau_1 < t < \tau_2$ with $\tau_2 = 40\ s$.

$$\sigma(t) = p_o t$$

$$\varepsilon_{zz}(t) = \varepsilon^e_{zz}(t) + \varepsilon^{th}_{zz}(t) + \varepsilon^p_{zz}(t) + \varepsilon^{pt}_{zz}(t)$$

$$\varepsilon^e_{zz}(t) = \frac{\sigma(t)}{E}$$

$$\varepsilon^{th}_{zz}(t) = Z_{aust} \times \alpha_{aust}(T - T^o) + Z_{fbm} \times \left[\alpha_{fbm}(T - T^o) + \varepsilon_{ref_{fbm}}\right]$$

$$\varepsilon^p(t) = \frac{\sigma(t) - \left(Z_{aust} \times \sigma_y^{aust}(T) + Z_{fbm} \times \sigma^{fbm}_{y(T)}\right)}{Z_{aust} \times H^{aust}(T) + Z_{fbm} \times H^{fbm}(T)}$$

$$\varepsilon^{pt}(t) = k_m \times \left(p_o \times \tau_1 - \frac{k}{2 \times \lambda \times \phi}\right) - k_m \times \left(p_o \times t - \frac{k}{2 \times \lambda \times \phi}\right)(1 - Z)^2$$

After transformation, thermoelastoplastic solution, for $t > \tau_2$

$$\sigma(t) = p_o t$$

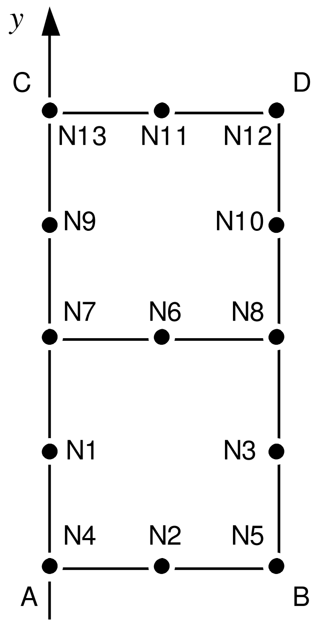
$$\varepsilon_{zz}(t) = \varepsilon^e_{zz}(t) + \varepsilon^{th}_{zz}(t) + \varepsilon^p_{zz}(t)$$

2.2 Results of reference

σ, ε_{zz}, ε^p, χ with $24\ s$, $26\ s$, $40\ s$ and $90\ s$.

3 Modeling A

3.1 Characteristics of modeling



$A=N4$, $B=N5$, $C=N13$, $D=N12$.

3.2 Characteristics of the grid

Many nodes: 13

Many meshs and types: 2 meshs QUAD8, 6 meshs SEG3

4 Results of modeling A

4.1 Values tested

One tests the structural parameters of data results:

Identification	Reference
`INST` for `NUME_ORDRE= 27`	90
`ITER_GLOB for NUME_ORDRE=27`	2

Identification		Reference
ε^p	$t=24\,s$	0
χ	$t=24\,s$	0
σ	$t=24\,s$	$360.\ 10^6$
ε_{zz}	$t=24\,s$	$-3.84\ 10^{-3}$
ε^p	$t=26\,s$	0.0372
χ	$t=26\,s$	1
σ	$t=26\,s$	$390.\ 10^6$
ε_{zz}	$t=26\,s$	$3{,}428\ 10^{-2}$
ε^p	$t=40\,s$	0.0625
χ	$t=40\,s$	1
σ	$t=40\,s$	$600.\ 10^6$
ε_{zz}	$t=40\,s$	0.06198
ε^p	$t=90\,s$	0.0741
χ	$t=90\,s$	1
σ	$t=90\,s$	$1350.\ 10^6$
ε_{zz}	$t=90\,s$	0.069844

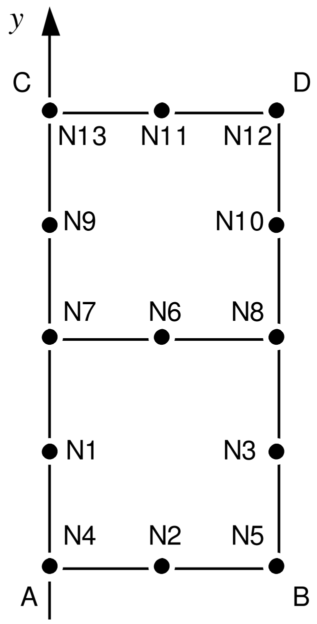
4.2 Remarks

In this modeling:

$$\varepsilon^{pt}(T,Z) = 0$$

5 Modeling B

5.1 Characteristics of modeling



$A=N4$, $B=N5$, $C=N13$, $D=N12$.

5.2 Characteristics of the grid

Many nodes: 13

Many meshs and types: 2 meshs QUAD8, 6 meshs SEG3

6 Results of modeling B

6.1 Values tested

Identification	Reference
ε^p $t=24\,s$	0
χ $t=24\,s$	0
σ $t=24\,s$	360. 10^6
ε_{zz} $t=24\,s$	– 3.84 10^{-3}
ε^p $t=26\,s$	0.0372
χ $t=26\,s$	1
σ $t=26\,s$	390. 10^6
ε_{zz} $t=26\,s$	0.051507
ε^p $t=40\,s$	0.06252
χ $t=40\,s$	1
σ $t=40\,s$	600. 10^6
ε_{zz} $t=40\,s$	0.10197
ε^p $t=90\,s$	0.07407
χ $t=90\,s$	1
σ $t=90\,s$	1350. 10^6
ε_{zz} $t=90\,s$	0.10984

6.2 Remarks

In this modeling, one takes into account the term due to the plasticity of transformation:

$$\dot{\varepsilon}^{pt}(T, Z)\neq 0 \text{ when } \dot{Z}\neq 0$$

7 Summary of the results

Two modelings give very good approximations of the reference solution.