HSNV104 - Thermoplasticity and metallurgy in plane strains with restoration of Summarized

hardening:

One treats the determination of the mechanical evolution of a right-angled parallelepiped in plane strains subjected to known and $T_{(t)}$ uniform evolutions $Z_{(t)}$ thermal and metallurgical (the metallurgical transformation is of bainitic type).

The elements used are two-dimensional elements in plane strains and the behavior model is the plasticity of von Mises with linear isotropic hardening. One takes account of the restoration of hardening, but not of the plasticity of transformation.

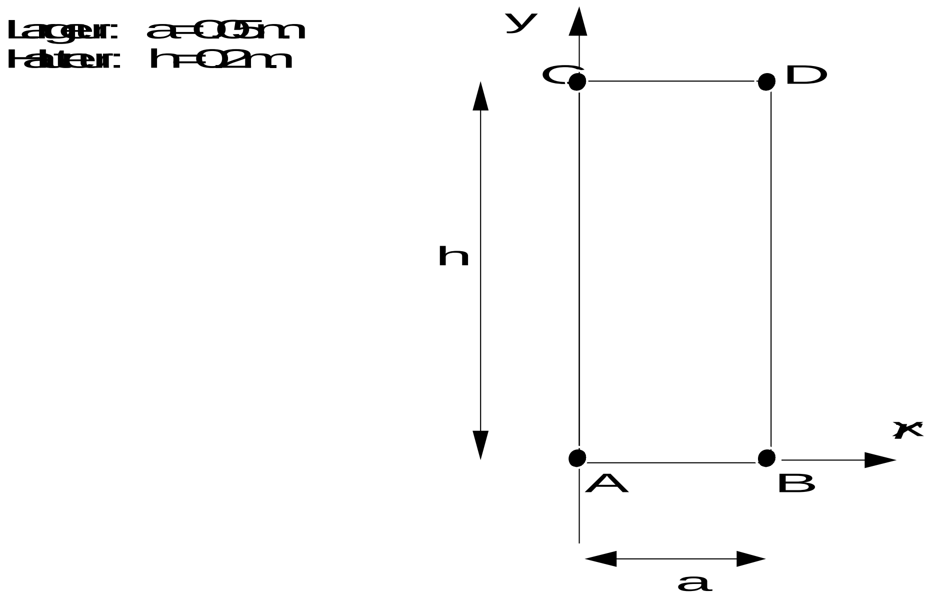
The coefficient of thermal expansion α depends on the metallurgical composition.

The reference solution is obtained by the analytical resolution of the problem.

The results provided by *Code_Aster* are very satisfactory with errors lower than $0{,}8\%$.

1 Problem of reference

1.1 Geometry



1.2 Properties of the materials

$E=2.0\text{E}+11\text{Pa}$ $\alpha^{fbm}=20.0\text{E}-06\,°C^{-1}$ $notons\, H_{(T)}=\dfrac{\alpha_{(T)}E_{(T)}}{E_{(T)}-\alpha_{(T)}}$

$\alpha_o^{aust}=20.0\text{E}-06\,°C^{-1}$ $H^{aust}=2000.0\text{E}+06\text{Pa}$

$\nu=0.3$ $\epsilon_{ref_{fbm}}=2.52\text{E}-03$ $H^{fbm}=2000.0\text{E}+06\text{Pa}$

$T^{ref}=900\,°C$ $cp=2.0\text{E}+06\,J.m^{-3}.°C^{-1}$

$\lambda=9999.9\,W.m^{-1}.°C^{-1}$

$*^{aust}$	=	characteristic relating to the austenitic phase,
$*^{fbm}$	=	characteristic relating to the phases ferritic, bainitic and martensitic,
α^{fbm}	=	thermal coefficient of thermal expansion of the phases ferritic, bainitic and martensitic,
α^{aust}	=	coefficient of thermal expansion of the austenitic phase
$\epsilon_{ref_{fbm}}$	=	strain of the phases ferritic, bainitic and martensitic with the reference temperature, austenite being regarded as not deformed with this temperature. That translated the difference in compactness between cubic crystallographic structures with centered sides (austenite) and cubic centered (ferrite).

TRC to model a metallurgical evolution of bainitic type, on all structure, of the form:

$$Z_{fbm}=\begin{cases} 0.0 & si\, t\le\tau_1 \quad \tau_1=60\text{sec} \\ \dfrac{t-\tau_1}{\tau_2-\tau_1} & si\, \tau_1\le t\le\tau_2 \quad \tau_2=112\text{sec} \\ 1.0 & si\, \tau_2\le t \end{cases}$$

Model of plasticity of transformation: $\dot{\epsilon}^{pt}=K^{fbm}F(Z_{fbm})\langle\dot{Z}_{fbm}\rangle$

with $F(Z_{fbm})=Z_{fbm}(Z-Z_{fbm})$

one thus does not take account of the plasticity of transformation one takes $K^{fbm}=0$

Notations: $T_{(\tau_1)}=T_1$
$T_{(\tau_2)}=T_2$

1.3 Boundary conditions and loadings

- $u_Y=0$ on the side AB ; $u_X=0$ in A .
- $T=T^0+\mu t$, $\mu=-5°C.s^{-1}$ on all structure.
- The loading on the structure is due to the phenomena of thermal and metallurgical thermal expansion constrained in the direction z by the condition of plane strains.

1.4 Initial conditions

$T^0=900°C=T^{ref}$

2 Reference solution

2.1 Method of calculating used for the reference solution

Before transformation, thermoelastic solution until in t_1 such as in t_1 :

$$\sigma_{zz} = -E\varepsilon^{th} = \sigma_y \quad \Leftrightarrow T - T^o = \frac{-\sigma_y^{aust}}{E\alpha + a} = -100°C$$
$$\Leftrightarrow t_1 = 20s$$

donc pour $t \le t_1$ $\qquad \sigma_{zz} = -E\alpha_\gamma\left(T - T^o\right)$

Before transformation, and for $t \ge t_1$, thermoelastoplastic solution such as:

$$\begin{cases} \varepsilon_{zz} = \varepsilon_{zz}^{th} + \varepsilon_{zz}^{p} + \dfrac{\sigma}{E} = 0 \\ \sigma_{zz} = R_0 \varepsilon_{zz}^{p} + \sigma_y \end{cases}$$

$$\text{d'où} \quad \sigma\left(\frac{1}{R_0^{\text{aust}}} + \frac{1}{E}\right) = \frac{\sigma_y^{aust}}{R_0^{aust}} - \alpha_\gamma (T - T^0) \quad et \quad \varepsilon_{zz}^{p} = p = \frac{\sigma - \sigma}{R_0^{aust}}$$

During the transformation, one is in elastic mode, one thus has an elastic solution thermo - with phase change.

$$\sigma = -E\left[\alpha(T - T^0) + Z\varepsilon_{réf_{fbm}} + \varepsilon_{zz}^{p}(\tau_1)\right]$$

After the transformation, there is always a thermoelastic solution until in t_2.

In t_2 : $\sigma_{zz} = R\left(T, Z, \varepsilon^{eff}\right) + \sigma_y(T, Z)$

Because of the restoration of hardening and owing to the fact that one was in elastic mode during all the transformation: $R=0$ before replastification.

One thus has in t_2 :

$$\sigma_{zz} = -E\left[\alpha(T - T^0) + \varepsilon_{réf_{fbm}} + \varepsilon_{zz}^{p}(\tau_1)\right] = \sigma_y^{fbm} \Leftrightarrow (T - T^0) = -\frac{\left[\sigma_y^{fbm} + E(\varepsilon_{réf_{fbm}} + \varepsilon_{zz}^{p}(\tau_1))\right]}{E\alpha}$$
$$\Leftrightarrow (T - T^0) = -624°C \qquad t_2 \approx 125s$$

For $T < 276°C$ there is a thermoelastoplastic solution such as:

$$\begin{cases} \varepsilon_{zz} = \varepsilon^{th} + \dfrac{\sigma}{E} + \varepsilon_{zz}^{p}(t) \\ \sigma_{zz} = R_0\left[\varepsilon_{zz}^{p}(t) - \varepsilon_{zz}^{p}(\tau_1)\right] + \sigma_y \end{cases}$$

$$\text{d'où} \quad \sigma\left(\frac{1}{R_0^{fbm}} + \frac{1}{E}\right) = \frac{\sigma_y^{fbm}}{R_0^{fbm}} - \alpha(T - T^0) - \varepsilon_{réf_{fbm}} - \varepsilon_{zz}^{p}(\tau_1)$$

2.2 Results of reference

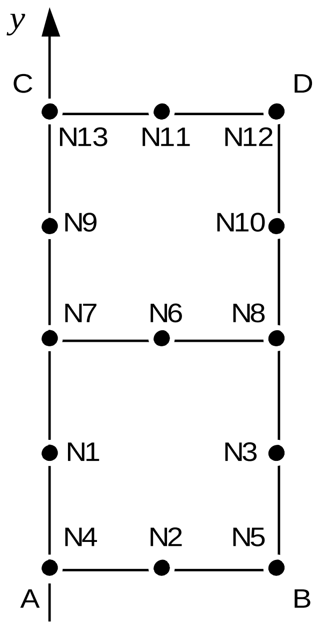
σ_{zz}, $\varepsilon_{\gamma}^{eff}$ et $\varepsilon_{\alpha}^{eff}$ à $t=60s$
σ_{zz}, $\varepsilon_{\gamma}^{eff}$ et $\varepsilon_{\alpha}^{eff}$ à $t=89s$
σ_{zz}, $\varepsilon_{\gamma}^{eff}$ et $\varepsilon_{\alpha}^{eff}$ à $t=112s$
σ_{zz}, $\varepsilon_{\gamma}^{eff}$ et $\varepsilon_{\alpha}^{eff}$ à $t=176s$

2.3 bibliographical References

1. DONORE A.M. - WAECKEL F. - Influence of structure transformations in the elastoplastic constitutive laws Notes HI-74/93/024.
2. DONORE.A.M. - WAECKEL.F. - RAZAKANAIVO.A. - Doc. Aster [R4.04.02]. Modelization

3 A Characteristic

3.1 of the modelization



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

3.2 of the mesh Many

nodes: 13. Number of meshes
and types: 2 meshes QUAD8, 6 meshes SEG3. Quantities

3.3 tested and Standard Identification

results of Reference	Reference	Tolerance	() ANALYTIQUE %
σ_{zz} $t=60s$	4.0792E8	0.10 ANALYTIQUE	
$\varepsilon_{\gamma}^{eff}$ $t=60s$	3.9604E-	3 0.02 ANALYTIQUE	
$\varepsilon_{\alpha}^{eff}$ $t=60s$	0. 0.00 ANALYTIQUE		
σ_{zz} $t=89s$	7.0684E8	0.80 ANALYTIQUE	
$\varepsilon_{\gamma}^{eff}$ $t=89s$	3.9604E-	3 0.02 ANALYTIQUE	
$\varepsilon_{\alpha}^{eff}$ $t=89s$	0. 0.00 ANALYTIQUE		
σ_{zz} $t=112s$	9.4392E8	0.05 ANALYTIQUE	
$\varepsilon_{\gamma}^{eff}$ $t=112s$	0. 0.00 ANALYTIQUE		
$\varepsilon_{\alpha}^{eff}$ $t=112s$	0. 0.00 ANALYTIQUE		
σ_{zz} $t=176s$	12.101E8	0.10 ANALYTIQUE	
$\varepsilon_{\gamma}^{eff}$ $t=176s$	0. 0.00 ANALYTIQUE		

$\varepsilon_{\alpha}^{eff}$	$t=176\text{s}$	5.068921E	– 3 0.04 Remarks

3.4 In this

modelization: The error

$$\varepsilon_{zz}^{pt}(T,Z) \quad = \quad 0$$

on at 89 seconds σ_{zz} comes by way of the mistake made on the numerical description of the metallurgical transformation which is, at this time, of approximately. Summary 56%

4 of the results the results

found with Code_Aster *are very* satisfactory, with percentages of error lower than. 0.8%