HSNV129 - Test of compression-dilation for study of the coupling thermics-cracking

Summary:

One applies to an element of volume obeying the law of Mazars (local and not-local version) a thermomechanical loading in order to check the good taking into account of the dependence of the parameters materials with the temperature as well as the taking into account of thermal dilation. The loading is homogeneous and also breaks up: compression with imposed displacement and constant temperature, then application of a cycle of heating-cooling.

1 Problem of reference

1.1 Geometry and boundary conditions

Element of volume materialized by a unit cube on side (m):

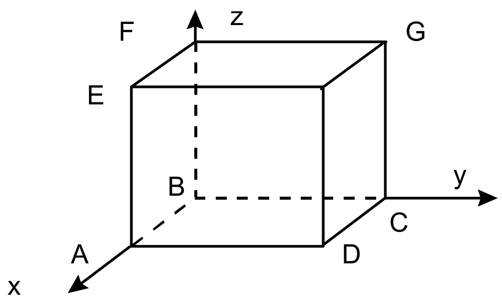

Figure 1.1-a: Geometry

The loading is such as one obtains a uniform stress and strain state in volume.
Blockings are the following:

- face $ABCD$: $DZ=0$
- face $BCGF$: $DX=0$
- face $ABFE$: $DY=0$
- face $EFGH$: displacement $Uz(t)$

The temperature $T(t)$ is supposed to be uniform on the cube; the temperature of reference is worth $0°C$.
Uz and T vary according to time in the following way:

moment t	0	100	200	300
$Uz(t)$	$0m.$	$-10^{-3}m.$	$-10^{-3}m.$	$-10^{-3}m.$
$T(t)$	$0°C$	$0°C$	$200°C$	$0°C$

A purely mechanical loading is thus carried out, then one heats by blocking the direction Uz, before cooling. This makes it possible to check the separation of the thermal and mechanical deformations as well as the non-recouvrance of the mechanical properties after heating.

1.2 Properties of material

For the model of Mazars, the following parameters were used (value with $0°C$) :

Elastic behavior:

$$E=32\ 000\ MPa\ ,\ \nu=0.2,\ \alpha=1.2\ 10^{-5}\ °C^{-1}$$

Thermal characteristics:

$$\lambda=2.2\ W\ m^{-1}\ K^{-1}\ ,\ C_p=2.2\ 10^6\ J\ m^{-3}\ K^{-1}$$

Damaging behavior:

$$\varepsilon_{d0}=1.0\ 10^{-4}\ ;\ A_c=1.15\ ;\ A_t=1.0\ ;\ B_c=2000.\ ;\ B_t=10\ 000\ ;\ k=0.7$$

It is considered in addition that E and B_c vary with the temperature. Their evolution is given on the figures [Figure 1.2-a] and [Figure 1.2-b].

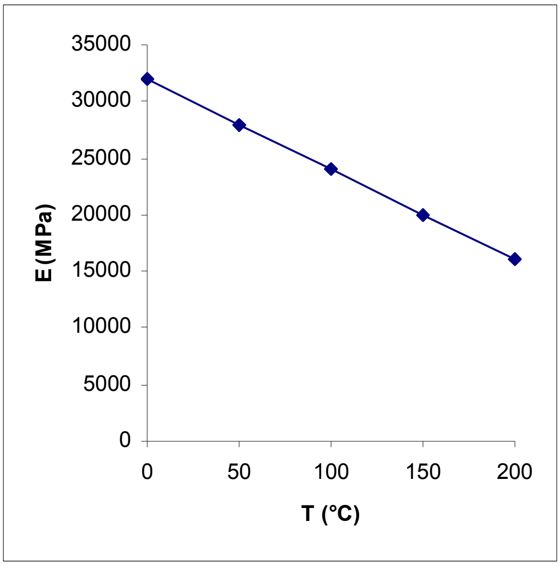

Figure 1.2-a: Evolution of the Young modulus with the temperature

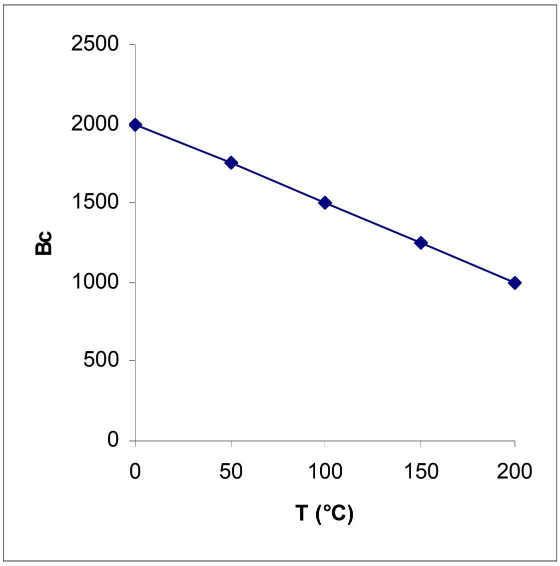

Figure 1.2-b: Evolution of B_C with the temperature

2 Reference solution

One can analytically determine the solution of the posed problem.
One notes:

- ε_0 deformation applied in the direction z,
- ε_1, ε_2 and ε_3 principal deformations

2.1 First stage of the loading: simple compression

- The tensor of the deformations is worth: $\begin{bmatrix} -\nu\varepsilon_0 & 0 & 0 \\ 0 & -\nu\varepsilon_0 & 0 \\ 0 & 0 & \varepsilon_0 \end{bmatrix}$ with $\varepsilon_0 < 0$
- The equivalent deformation is worth consequently: $\tilde{\varepsilon} = \sqrt{\langle \varepsilon_1^e \rangle_+^2 + \langle \varepsilon_2^e \rangle_+^2 + \langle \varepsilon_3^e \rangle_+^2} = -\nu\varepsilon_0\sqrt{2}$
- Since $\tilde{\varepsilon} > \varepsilon_{d0}$, there is evolution of the damage which is worth:

$$D = 1 - \frac{\varepsilon_{d0}(1 - A_c)}{\tilde{\varepsilon}} - \frac{A_c}{\exp[B_c(\tilde{\varepsilon} - \varepsilon_{d0})]}$$

- Finally the constraint σ_{zz} is worth:

$$\sigma_{zz} = E(1 - D)\varepsilon_0$$

2.2 Second phase of the loading: thermal dilation in plane deformations

- The tensor of the total deflections is worth:

$$\begin{bmatrix} -\nu\varepsilon_0 + \alpha(T - T_{ref})(1+\nu) & 0 & 0 \\ 0 & -\nu\varepsilon_0 + \alpha(T - T_{ref})(1+\nu) & 0 \\ 0 & 0 & \varepsilon_0 \end{bmatrix} \text{ with } \varepsilon_0 < 0 \text{ fixed}$$

- Elastic strain being worth $\boldsymbol{\varepsilon}^e = \boldsymbol{\varepsilon} - \alpha(T - T_{ref})\mathbf{I}_d$, the equivalent deformation is worth:

$$\tilde{\varepsilon} = \sqrt{2}\nu(\alpha(T - T_{ref}) - \varepsilon_0)$$

- The damage is worth:

$$D = MAX\left[D^-, 1 - \frac{\varepsilon_{d0}(1 - A_c)}{\tilde{\varepsilon}} - \frac{A_c}{\exp[B_c(\tilde{\varepsilon} - \varepsilon_{d0})]}\right]$$

- Finally the constraint σ_{zz} is worth:

$$\sigma_{zz} = E(1 - D)[\varepsilon_0 - \alpha(T - T_{ref})]$$

Note:

- *In a given state, the parameters materials used are those definite at the maximum temperature seen by material and not at the current temperature.*
- *The evaluation of the damage D fact of intervening the concept of maximum reaches during the history of the loading; the solution is thus not completely analytical but implies a discretization. If there is no influence of thermics, it is enough to take $\tilde{\varepsilon}$ equivalent with the maximum equivalent deformation reached. When one takes into account the thermal aspect, the heating can contribute "to decrease" or "to delay" the damage with deformation given; it is the case with the evolution of B_c reserve. In this case, it is necessary in makes rather finely discretize the loading to have the good value of damage D (which indeed presents a maximum in our case).*

3 Modeling A

3.1 Characteristics of modeling

Modeling 3D
Element MECA_HEXA8

3.2 Characteristics of the grid

Many nodes: 8
Many meshs and types: 1 HEXA8

3.3 Features tested

The law of behavior MAZARS_FO combined with ELAS_FO.

3.4 Sizes tested and results

The damage is compared D and the constraint σ_{zz} at various moments

Identification		Reference	Aster	% difference
$t=50$	D	0	0	-
	σ_{zz} (MPa)	– 16.0	– 16.0	2.33 10^{-14}
$t=100$	D	0.1702	0.1702	0,007
	σ_{zz} (MPa)	– 26.5532	– 26.5532	6.46 10^{-5}
T = 150	D	0.4247	0.4247	– 0,005
	σ_{zz} (MPa)	– 30.3768	– 30.3769	2.91 10^{-4}
T = 200	D	0.4626	0.4625	– 0,014
	σ_{zz} (MPa)	– 29.2327	– 29.2382	0,019
T = 250	D	0.4626	0.4625	– 0,014
	σ_{zz} (MPa)	– 18.9153	– 18.9188	0,019
T = 300	D	0.4626	0.4625	– 0,014
	σ_{zz} (MPa)	– 8.5979	– 8.5994	0,018

3.5 Notice

Actually, the maximum damage, i.e. 0.4626 is reached at time $t\approx 180\,s$. Then, it does not evolve any more because of the reduction of B_c when the temperature increases.

4 Modeling B

4.1 Characteristics of modeling

The use of the delocalized version of the model of Mazars passes by the use of modeling `3D_GRAD_EPSI` and the use of quadratic elements implies.
The test is carried out with a worthless characteristic length.

Modeling `3D_GRAD_EPSI`
Element `MGCA_HEXA20`

4.2 Characteristics of the grid

Many nodes: 20
Many meshs and types: 1 HEXA20

4.3 Features tested

The law of behavior `MAZARS_FO` combined with `ELAS_FO` within the framework of local modeling not - `3D_GRAD_EPSI`.

4.4 Sizes tested and results

The damage is compared D and the constraint σ_{zz} at various moments

Identification		Reference	*Aster*	% difference
$t=50$	D	0	0	-
	σ_{zz} (MPa)	– 16.0	– 16.0	2.33 10 $^{-14}$
$t=100$	D	0.1702	0.1702	0,007
	σ_{zz} (MPa)	– 26.5532	– 26.5532	6.46 10 $^{-5}$
$t=150$	D	0.4247	0.4247	– 0,005
	σ_{zz} (MPa)	– 30.3768	– 30.3770	8.06 10 $^{-4}$
$t=200$	D	0.4626	0.4625	– 0,014
	σ_{zz} (MPa)	– 29.2327	– 29.2382	0,019
$t=250$	D	0.4626	0.4625	– 0,014
	σ_{zz} (MPa)	– 18.9153	– 18.9188	0,019
$t=300$	D	0.4626	0.4625	– 0,014
	σ_{zz} (MPa)	– 8.5979	– 8.5994	0,018

4.5 Notice

Actually, the maximum damage, i.e. 0.4626 is reached at time $t \approx 180\,s$. Then, it does not evolve any more because of the reduction of B_c when the temperature increases.

5 Summary of the results

One obtains the analytical solution with a precision lower than 0.02% what makes it possible to be assured the good establishment of the model of Mazars including when the temperature intervenes. Let us point out the choices which were made for the coupling cracking-thermics and which are checked here:

- linear thermal dilation,
- evolution of the damage only under the effect of the elastic strain and not thermal,
- dependence of the parameters materials with the maximum temperature, i.e. not-reversibility of the modifications of the mechanical properties when the concrete is heated then cooled.