HSNV129 - Test of compression-thermal expansion for study of the coupling thermal-cracking

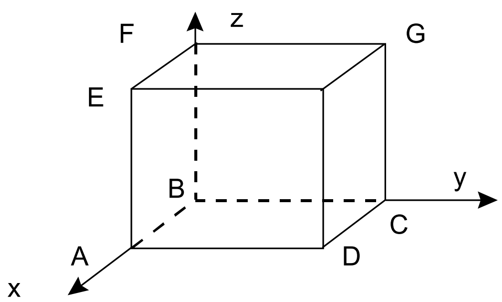
Summarized:

One applies to a volume element obeying the model of Mazars (local and NON-local version) a thermomechanical loading in order to check the good taking into account of the dependence of materials parameters with the temperature as well as the taking into account of thermal thermal expansion. 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

Volume element materialized by a unit cube on side (m):



Appear 1.1-a: Geometry

the loading is such as one obtains a stress state and of uniform strain 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 reference temperature is worth $0°C$.
Uz and T vary according to time in the following way:

time 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 strains and mechanics as well as the non-recouvrance of the mechanical properties after heating.

1.2 Properties of the material

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

Behavior elastic:

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

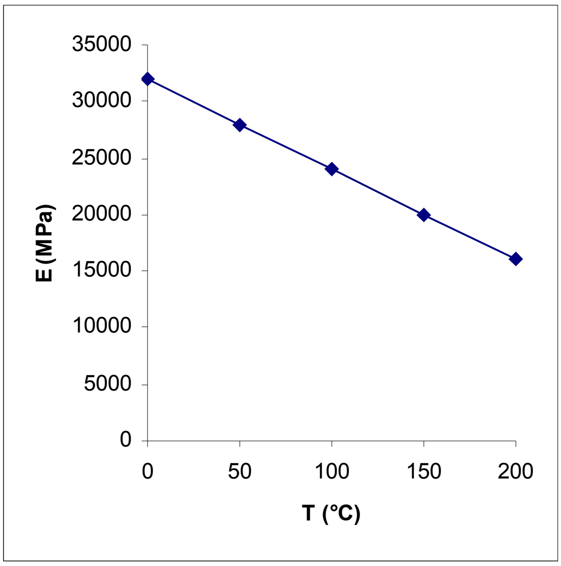
Thermal characteristics:

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

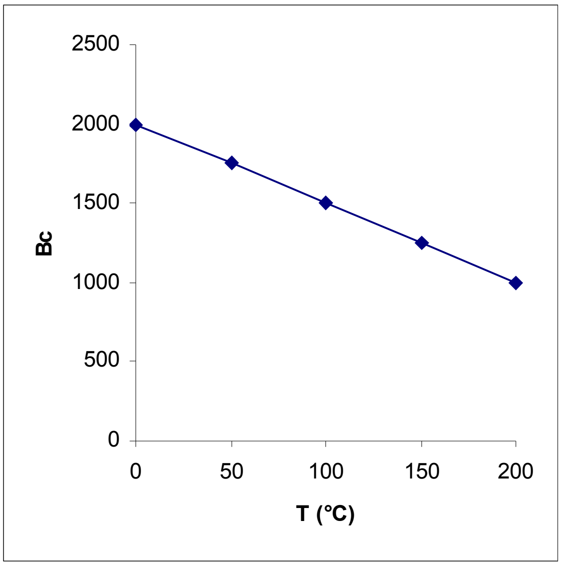
Behavior damaging:

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

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].



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



Appears 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 strain applied in the direction z
- ε_1 , ε_2 and the ε_3 principal strains

2.1 First stage of the loading: simple compression

- the tensor of the strains is worth: $\begin{pmatrix} -\nu\varepsilon_0 & 0 & 0 \\ 0 & -\nu\varepsilon_0 & 0 \\ 0 & 0 & \varepsilon_0 \end{pmatrix}$ with $\varepsilon_0 < 0$
- the equivalent strain 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 stress σ_{zz} is worth:

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

2.2 Second phase of the loading: thermal thermal expansion in plane strains

- the tensor of the total deflections is worth:

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

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

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

- 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 stress σ_{zz} is worth:

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

Note:

- *A a given state, materials parameters used are those definite with the maximum temperature seen by the material and not with the current temperature.*
- *The evaluating of the damage D utilizes the notion 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 the thermal, it is enough to take $\tilde{\varepsilon}$ equivalent with the maximum equivalent strain reached. When one takes into account the thermal aspect, the heating can contribute “to decrease” or “to delay” the damage with strain 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 Modelization A

3.1 Characteristic of the modelization

Modelization 3D
Element MECA_HEXA8

3.2 Characteristic of the mesh

Many nodes: 8
Number of meshes and types: 1 HEXA8

3.3 Functionalities tested

constitutive law MAZARS_FO combined with ELAS_FO.

3.4 Quantities tested and results

One compares the damage D and the stress σ_{zz} at various times

Identification		Reference	*Aster*	% difference
$t=50$	D σ_{zz} (MPa)	0 – 16.0	0 – 16.0	- 2.33 10^{-14}
$t=100$	D σ_{zz} (MPa)	0.1702 – 26.5532	0.1702 – 26.5532	0.007 6.46 10^{-5}
T = 150	D σ_{zz} (MPa)	0.4247 – 30.3768	0.4247 – 30.3769	– 0.005 2.91 10^{-4}
T = 200	D σ_{zz} (MPa)	0.4626 – 29.2327	0.4625 – 29.2382	– 0.014 0.019
T = 250	D σ_{zz} formulates MPa (	) 0.4626 –	18.9153 0.4625 –	18.9188 – 0.014
0.019 T =	D σ_{zz} formulate MPa (	) 0.4626 –	8.5979 0.4625 –	8.5994 – 0.014

3.5 0.018

Remark, itmaximum 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 Modelization B

4.1 Characteristic of the modelization

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

Modelization 3D_GRAD_EPSI
Element MGCA_HEXA20

4.2 Characteristic of the mesh

Many nodes: 20
Number of meshes and types: 1 HEXA20

4.3 Functionalities tested

constitutive law MAZARS_FO combined with ELAS_FO in the frame of the local modelization not - 3D_GRAD_EPSI.

4.4 Quantities tested and results

One compares the damage D and the stress σ_{zz} with various times

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 Remark

Actually, the maximum damage, i.e. 0.4626 are 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 an accuracy lower than 0.02% what makes it possible to be assured the good model installation of Mazars including when the temperature intervenes. Let us point out the choices which were made for the coupling cracking-thermal and which are checked here:

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