Model damage of MAZARS

Summarized:

This documentation the model presents behavior of MAZARS which makes it possible to describe the behavior elastic-endommageable of the concrete. This model is 3D, isotropic and leans on a criterion of damage written in strain and describing dissymmetry traction and compression. The model initial, account of the restoration of stiffness in the event of "reclosing of cracks does not return" and plastic strains does not take into account the possible ones or viscous effects which can be observed during strains of a concrete. The version implemented in Code_Aster takes account of the last improvements. This reformulation of the Mazars model of the years 1980 makes it possible to better describe the behavior of the concrete in bi--compression and pure shears.
The version $1D$ model makes it possible to give an account of the restoration of stiffness in the event of reclosing of cracks.

Three versions of the model are established:
- the local version (with risk of dependence on the discretization)
- the NON-local version where the damage is controlled by the deformation gradient. It is also possible to take into account the dependence of the parameters of the model with the temperature, the hydration and drying.
- the local $1D$ version, only used with the multifibre beams [R5.03.09].

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1 Introduction

1.1 an elasto-damageable constitutive law

The model of behavior MAZARS [biberon10] is a model simple, considered robust, based on the mechanics ofdamage [biberon21] , which makes it possible to describe the reduction in the stiffness of the material under the effect of the creation of microscopic cracks in the concrete. It leans on only one scalar local variable D describing the isotropic damage of way, but distinguishing despite everything the damage from tension and the damage from compression. **The version implemented under Aster corresponds to the reformulation of 2012** [biberon32] . The major modification compared to the model of origin [biberon10] is the introduction of a new local variable, noted Y, corresponding to the maximum during reaches the loading by the equivalent strain defined in the years 1980. So the damage is not any more the local variable in the model revisited. Moreover, its law of evolution is simplified in order to eliminate the notions of damage from tension and compression.

Contrary to model ENDO_ISOT_BETON, this model does not allow to translate the phenomenon of reclosing of the cracks (restoration of stiffness). In addition, the model of MAZARS plastic strains does not take into account the possible ones or viscous effects which can be observed during strains of a concrete.

The version $1D$ of the model of MAZARS is described in the document [R5.03.09] "nonlinear Behavior models". In this specific case, the model is able to give an account of the phenomenon of reclosing of cracks. The version $1D$ of the model, is usable only with the multifibre beams.

1.2 Limits of the local approach and methods of regularization

Like all the lenitive models, the model of MAZARS raises difficulties related to the phenomenon of localization of the strains.

Physically, the heterogeneity of the microstructure of the induced concrete of the remote interactions enters the formed cracks [biberon43]. Thus, the strains locate in a metal strip, called tape of localization, to form macro-cracks. The state of the stresses in a material point cannot be any more only described by the characteristics at the point but must also take into account its environment. In the case of the model local, no indication is included concerning the scale of cracking. Consequently, no information is given about the bandwidth of localization which becomes then null. This leads to a structural mechanics behavior with fracture without dissipation of energy, physically unacceptable.

Mathematically, the localization returns the problem to be solved badly posed because softening causes a loss of ellipticity of the differential equations which describe the process of strains [biberon54]. The numerical solutions do not converge towards physically acceptable solutions in spite of refinements of mesh.
Numerically, one observes a dependence of the solution to the network extremely prejudicial (cf [R5.04.02]).

A method of regularization thus becomes necessary. Several are possible. The choice which was made here is to regularize in deformation gradient, and to thus use a strain tensor regularized $\bar{\boldsymbol{\varepsilon}}$ which checks the characteristic equation [R5.04.02]:

$$\boldsymbol{\varepsilon}=\bar{\boldsymbol{\varepsilon}}-L_c^2\nabla^2\bar{\boldsymbol{\varepsilon}} \quad \textbf{(éq 1.2-1)}$$

where the scalar L_c (characteristic length) is the dimension a length.

Note:

Let us announce that this model NON-room does not correspond to the version initially proposed by J.Mazars and G.Pijaudier-Pooch 5] and who is in particular established in CAST3M, where the delocalization is obtained by means of like equivalent strain, the average of the local equivalent strain on a volume V :

$$\bar{\varepsilon}(x)=\frac{1}{V_r(x)}\int_{\Omega}\psi(x-s)\,\varepsilon_{eq}(s)\,ds$$

where Ω is the volume of structure

$V_r(x)$ is representative volume with point: x $V_r=\int_{\Omega}\psi(x-s)ds$

$\psi(x-s)$ is a weight function: $\psi(x-s)=\exp\left(-\frac{4\|x-s\|^2}{l_c^2}\right)$

l_c is an internal length (traditionally estimated at three times size of the largest aggregate).

Numerical tests made it possible to connect the 2 parameters of delocalization l_c and L_c in the case of the model of Mazars. The following relation was obtained: $4\mathrm{L}_c\simeq l_c$

The model of MAZARS is thus available in *Code_Aster* under 2 versions:

- the local version of the model for which the dependence of the solution to the network is observable as for all the lenitive models.
- a nonlocal version which uses a strain tensor regularized (known as also "nonlocal"), modelization of the type GRAD_EPSI.

1.3 Coupling with the thermal

For certain studies, it can be interesting to be able to take into account the modification of materials parameters under the effect of the temperature. This is possible in *Aster* (MAZARS_FO combined or not with ELAS_FO). The assumptions made for the coupling with the thermal are the following ones:

- thermal thermal expansion is supposed to be linear is:

$$\boldsymbol{\varepsilon}^{th}=\alpha(T-T_{ref})\mathbf{I_d} \quad \textbf{(éq 1.3-1)}$$

  with α = constant or function of the temperature,
- one does not take into account thermomechanical interactions, i.e. one does not model the effect of the mechanical stress state on the thermal strain of the concrete,
- concerning the evolution of materials parameters with the temperature, one considers that those depend not on the current temperature but on the maximum temperature $Tmax$ seen by the material during its history, (effect quoted in the literature),
- only elastic strain (mechanical) induced of the damage.

Note:

Because of data-processing stresses, the initial value of $Tmax$ is initialized to 0. Consequently, one cannot use the materials parameters definite ones for negative temperatures (if necessary, one can however circumvent this problem while returning all the temperatures in Kelvin instead of $°C$).

1.4 Model of Mazars in the presence of a field of drying or hydration

the use of ELAS_FO and/or MAZARS_FO under operator DEFI_MATERIAU makes it possible to make depend materials parameters on drying or the hydration.

In addition, the strains related on the shrinkage of endogenous $\boldsymbol{\varepsilon}_{re}$ and the shrinkage desiccation $\boldsymbol{\varepsilon}_{rd}$ are taken into account in the model, in the form (linear) following (cf [R7.01.12]) :

$$\boldsymbol{\varepsilon}_{re}=-\beta\xi\,\mathbf{I_d} \quad \textbf{(éq 1.4-1)}$$

$$\boldsymbol{\varepsilon}_{rd}=-\kappa(C_{ref}-C)\,\mathbf{I_d} \quad \textbf{(éq 1.4-2)}$$

where ξ is the hydration, C the water concentration (field of drying in the terminology *Code_Aster*), C_{ref} the initial water concentration (or drying of reference). Finally β is the endogenous coefficient of shrinkage and κ the coefficient of shrinkage of desiccation to informing in DEFI_MATERIAU, factor key word ELAS_FO, operands B_ENDO and K_DESSIC. As one said to the preceding paragraph, the choice which was made in the model installation of MAZARS, it is that only the elastic strain induced of the damage. Consequently, if one models a concrete test-tube which dries or which is hydrated freely and uniformly, one will obtain well a non-zero strain field and a stress field perfectly no one.

One initially presents the writing of the model then some data on the identification of the parameters. To finish, one exposes the principles of numerical integration in *Code_Aster*.

2 The models of Model

2.1 MAZARS of Origin of Mazars

The model of MAZARS was elaborate in the frame of the damage mechanics. This model is detailed in the thesis of MAZARS [biberon10]
the stress is given by the following relation:

$$\boldsymbol{\sigma}=(1-D)\mathbf{E}\boldsymbol{\varepsilon}^{\mathrm{e}} \quad \textbf{(éq 2.1-1)}$$

with :

- E the matrix of Hooke,
- D the variable of damage
- $\boldsymbol{\varepsilon}^e$ elastic strain $\boldsymbol{\varepsilon}^{\mathrm{e}}=\boldsymbol{\varepsilon}-\boldsymbol{\varepsilon}^{th}-\boldsymbol{\varepsilon}^{rd}-\boldsymbol{\varepsilon}^{re}$
- $\boldsymbol{\varepsilon}^{th}=\alpha(T-T_{ref})\mathbf{I_d}$ thermal thermal expansion
- $\boldsymbol{\varepsilon}^{re}=-\beta\xi\mathbf{I_d}$ endogenous shrinkage (related to the hydration)
- $\boldsymbol{\varepsilon}_{rd}=-\kappa(C_{ref}-C)\mathbf{I_d}$ the shrinkage of desiccation (related to drying)

D is the variable of damage. It is understood enters 0, materials healthy, and 1, broken material. The damage is controlled by the equivalent strain ε_{eq} which makes it possible to translate a triaxial state by an equivalence in a uniaxial state. As the extensions are paramount in the phenomenon of cracking of the concrete, the introduced equivalent strain is defined starting from the positive eigenvalues of the tensor of the strains, that is to say:

$$\varepsilon_{eq}=\sqrt{\langle\boldsymbol{\varepsilon}\rangle_+:\langle\boldsymbol{\varepsilon}\rangle_+}$$

where in the principal reference of the strain tensor: **(éq 2.1-2)**

$$\varepsilon_{eq}=\sqrt{\langle\varepsilon_1\rangle_+^2+\langle\varepsilon_2\rangle_+^2+\langle\varepsilon_3\rangle_+^2}$$

knowing that the positive part $\langle\,\rangle_+$ is defined so that if ε_i is the principal strain in the direction i :

$$\begin{cases}\langle\varepsilon_i\rangle_+=\varepsilon_i & \text{si} \quad \varepsilon_i\geq 0\\ \langle\varepsilon_i\rangle_+=0 & \text{si} \quad \varepsilon_i<0\end{cases} \quad \textbf{(éq 2.1-3)}$$

Remark:

In the case of a thermomechanical loading, only the elastic strain $\boldsymbol{\varepsilon}^e=\boldsymbol{\varepsilon}-\boldsymbol{\varepsilon}^{th}$ contributes to the evolution of the damage from where: $\varepsilon_{eq}=\sqrt{\langle\varepsilon^e\rangle_+:\langle\varepsilon^e\rangle_+}$.

ε_{eq} is an indicator of the state of tension in the material which generates the damage. This quantity defines the surface of load f such as:

$$f=\varepsilon_{eq}-K(D)=0 \quad \textbf{(éq 2.1-4)}$$

(4)

with $K(D)=\varepsilon_{d0}$ if $D=0$. ε_{d0} the strain threshold of damage.
When the equivalent strain reaches this value, the damage is activated. D is defined like a combination of two damaging modes defined by D_t and D_c , variable between 0 and 1 depending on the state of associated damage, and corresponding respectively to the damage in tension and compression. The relation binding these variables is the following one:

$$D=\alpha_t^{\beta}D_t+\alpha_c^{\beta}D_c \quad \textbf{(éq 2.1-5)}$$

(5)

β is a coefficient which was introduced later on to improve behavior in shears. Usually its value is fixed at 1.06. The coefficients α_t and α_c carry out a restrain between the damage and the compactness of tension or. When the tension is activated $\alpha_t = 1$ whereas $\alpha_t = 0$ and conversely in compression.
A characteristic of this model is its explicit writing what implies that all the quantities are calculated directly without using an algorithm of linearization like that of Newton-Raphson. Thus, the laws of evolution of the damages D_t and D_c are expressed only from the equivalent strain ε_{eq}

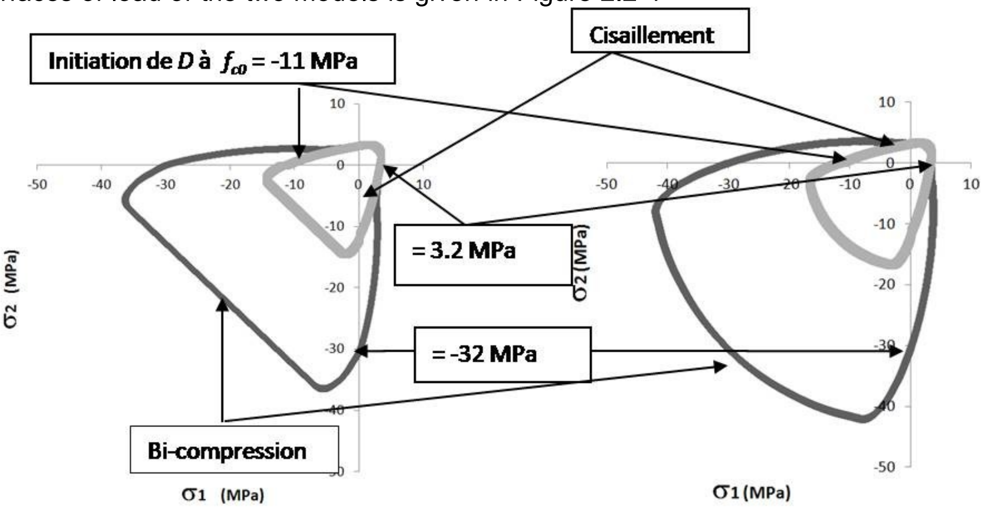
$$D_t = 1 - \frac{(1-A_t)\varepsilon_{d0}}{\varepsilon_{eq}} - A_t \exp\left(-B_t\left(\varepsilon_{eq} - \varepsilon_{d0}\right)\right) \quad \textbf{(éq 2.1-6)}$$

$$D_c = 1 - \frac{(1-A_c)\varepsilon_{d0}}{\varepsilon_{eq}} - A_c \exp\left(-B_c\left(\varepsilon_{eq} - \varepsilon_{d0}\right)\right) \quad \textbf{(éq 2.1-7)}$$

with A_t, A_c, B_t, and B_c, of materials parameters to identify. These parameters make it possible to modulate the shape of the curved post-peak. They are obtained using traction tests and from a compression test.

2.2 Model Revisited of Mazars

Although usually employed, the model of Origin of Mazars during has gaps in the modelization of the behavior of the concrete loadings in shears and bi--compression. A comparison between surfaces of load of the two models is given in Figure 2.2-4



2.2-4 a) of Origin of Mazars **b) Models Revisited of Mazars**

Figure 2.2-1 : Comparison of surfaces of initiation of damage and fracture of the Mazars models in the plane $\sigma_3 = 0$ and a concrete C30

Thus, a new formulation is proposed through 2 major modifications:

1.improvement of the behavior in bi--compression,
2.simplification and improvement of behavior in shears.

The model of Mazars of origin of the years 1980 [biberon10] the strength of the concrete in bi--compression underestimates largely. The first modification made by the model Revisited thus improves behavior in bi--compression. This goal is reached by correcting the equivalent strain when at least a principal stress is negative, using a variable γ :

$$\varepsilon_{eq}^{corrigée} = \gamma\, \varepsilon_{eq} = \gamma \sqrt{\langle \boldsymbol{\varepsilon} \rangle_+ : \langle \boldsymbol{\varepsilon} \rangle_+} \qquad \textbf{(éq 2.2-1)}$$

with:

$$\begin{cases} \gamma = -\dfrac{\sqrt{\sum_i \langle \tilde{\sigma}_i \rangle_-^2}}{\sum_i \langle \tilde{\sigma}_i \rangle_-} & \text{si au moins une contrainte effective est négative} \\ \gamma = 1 & \text{sinon} \end{cases}$$ (limited between 0 and 1) **(éq 2.2-2)**

the effective stress within the meaning of the damage mechanics is defined by:

$$\tilde{\underline{\underline{\sigma}}} = \frac{\underline{\underline{\sigma}}}{1-D} \qquad \textbf{(éq 2.2-3)}$$

the definition of < > - is similar to (éq 2.1-3) :

$$\begin{cases} \langle \tilde{\sigma}_i \rangle_- = \tilde{\sigma}_i & \text{si} \quad \tilde{\sigma}_i \le 0 \\ \langle \tilde{\sigma}_i \rangle_- = 0 & \text{si} \quad \tilde{\sigma}_i > 0 \end{cases} \qquad \textbf{(éq 2.2-4)}$$

where $\tilde{\sigma}_i$ is a principal effective stress.

The improvement of behavior in shears is reached by the introduction of a new local variable: Y. It corresponds to the maximum reached during the loading of the equivalent strain. Its initial value Y_0 is ε_{d0}. Y is defined by the following equation:

$$Y = \max\left(\varepsilon_{d0}, \max\left(\varepsilon_{eq}^{corrigée}\right)\right) \qquad \textbf{(éq 2.2-5)}$$

the loading function is:

$$f = \varepsilon_{eq}^{corrigée} - Y \qquad \textbf{(éq 2.2-6)}$$

the evolution of the damage is given by:

$$D = 1 - \frac{(1-A)\, Y_0}{Y} - A \exp\left(-B\left(Y - Y_0\right)\right) \qquad \textbf{(éq 2.2-7)}$$

In this statement, in fact the variables A and B make it possible to reproduce the quasi brittle behavior of the concrete in tension and the behavior hammer-hardened in compression. To represent the experimental results as well as possible, the following laws of evolution were selected for A and B :

$$A = A_t\left(2\mathrm{r}^2(1-2\mathrm{k}) - r(1-4\mathrm{k})\right) + A_c\left(2\mathrm{r}^2 - 3\mathrm{r} + 1\right) \qquad \textbf{(éq 2.2-8)}$$

and

$$B = r^2 B_t + \left(1 - r^2\right) B_c \qquad \textbf{(éq 2.2-9)}$$

where the statement of r is:

$$r=\frac{\sum_i \langle \tilde{\sigma}_i \rangle_+}{\sum_i |\tilde{\sigma}_i|} \quad \text{(éq 2.2-10)}$$

It appears in these equations a new variable r which informs us about the stress state. When r is equal to 1 (corresponding to the sector of the tensions), the variables A and B are equivalent to the param beings A_t and B_t . Therefore, (éq 2.2-7) is identical to (éq 2.1-6) . Conversely, if r is null (corresponding to the sector of compressions), then $A=A_c$, $B=B_c$ and (éq 2.2-7) is identical to (éq 2.1-7) .

Figure 2.2-2 gives in the plane $\sigma_3=0$ the evolution according to the sign of the principal stresses of the variables A B , r and γ .

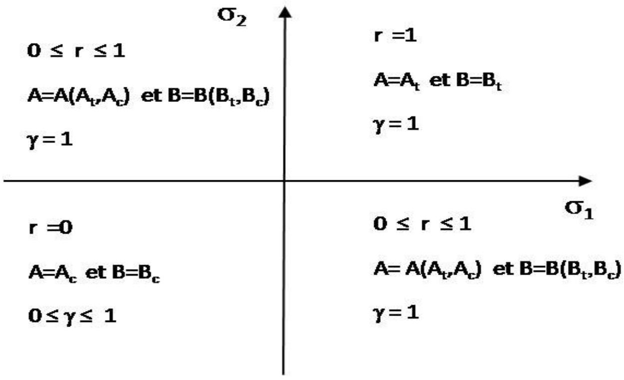


Figure 2.2-2 : Evolution of the variables A , B , r and γ in the plane $\sigma_3=0$

In the equation (éq 2.1-6) a new parameter appears: k . It introduces an asymptote with the curve $\sigma-\varepsilon$ in shears and it is defined by:

$$k=\frac{A_{cisaillement}}{A_t} \quad \text{(éq 2.2-11)}$$

where $A_{cisaillement}$ defines the residual stress in pure shears. It is similar to A_t for this case of loading. The value advised for k is of 0.7 . The value of k lower than 1 is very useful in the modelization of the effects of friction between the concrete and the reinforcements in reinforced concrete structures because it induces a residual shearing stress. For the value $k=1$ formulates finds the behavior of the model of Origin (Figure 2.2-3).

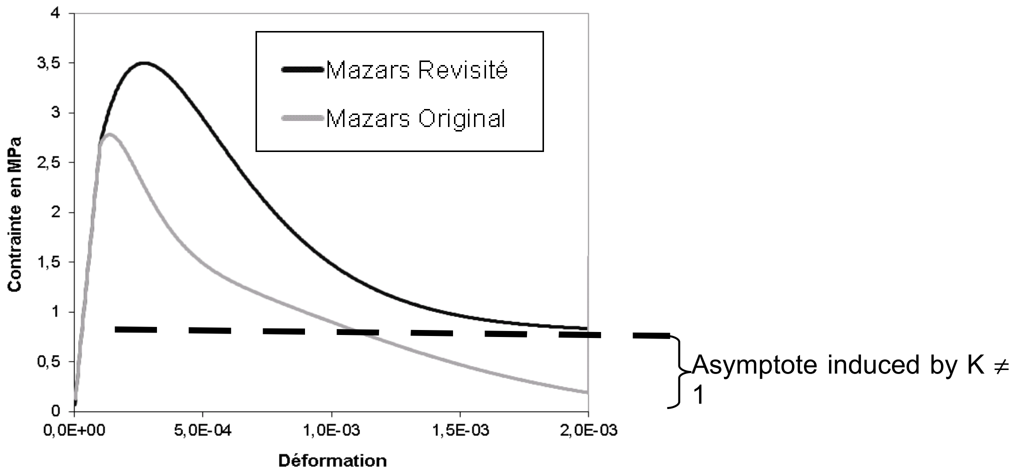


Figure 2.2-3 : Stress-strain curve during a test of pure shears on a Gauss point

The model of Origin underestimates the strength of the concrete in pure shears. This new formulation makes it possible to increase this strength in pure shears passing from $2.5\,MPa \quad 3.5\,Mpa$ for a concrete C30. This value depends on those on materials parameters entered (A_t , A_c , B_t , and B_c).

The local response of the Revisited model of Mazars under loading successive of tension compression is given by Figure 2.2-4.

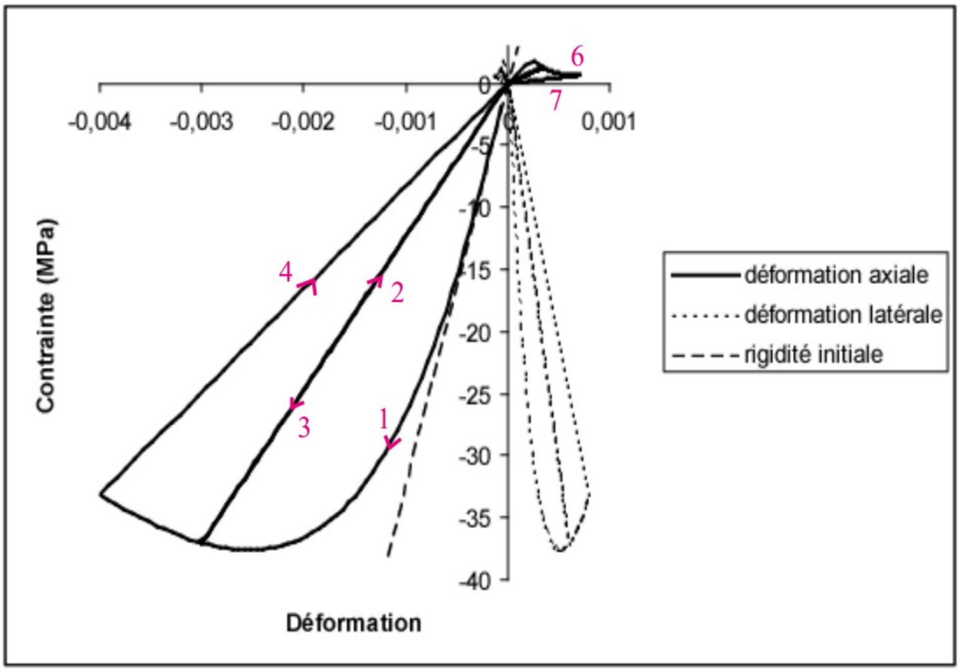


Figure 2.2-4 : Response stress-strain of the model of Mazars for a request 1D.

Figure 2.2-4 makes it possible to visualize a certain number of characteristics of the model of `MAZARS`, namely:

- the damage affects the stiffness of the concrete,
- there are no unrecoverable deformations,
- the responses in tension and compression are quite dissymmetrical,

Note : The models Mazars d' Origine and Revisited do not take into account the unilateral character of the concrete to during knowing the reclosing of crack the transition of a state of tension in a compactness.

3 Identification

In addition to the thermoelastic parameters E, ν, α, the model of MAZARS Revisited utilizes 6 material parameters: $A_c, B_c, A_t, B_t, \varepsilon_{d0}, k$.

- ε_{d0} is the threshold of damage. It acts obviously on the stress with the peak but also on the shape of the curved post-peak. Indeed, the fall of stress is of as much less brutal than ε_{d0} is small. In general ε_{d0} is understood in 0.5 and $1.5 10^{-4}$.

The coefficients A and B make it possible to modulate the shape of the curved post-peak. They are defined by the equations (éq 2.2-8) and (éq 2.2-9) which depend on the parameters of the model of Origin of Mazars (A_t , B_t , A_c and B_c) and of r :

- A introduced a horizontal asymptote which is the axis of ε for $A=1$ and the horizontal one passing by the peak for $A=0$ (cf [Figure 3-1]). In the field as of tensions, A is equivalent to A_t (and reciprocally in the field as of compressions $A=A_c$). In general, A_c lies between 1 and 2. and A_t 0.7 and 1.
- B according to its value can correspond to a sharp fall of stress ($B>10000$) or a preliminary phase of increase in stress followed, after transition by a maximum, of a more or less fast decrease as one can see it on [Figure 3-2]. In the field as of tensions, B is equivalent to B_t (and reciprocally in the field as of compressions $B=B_c$). In general B_c is understood enters 1000 and 2000 B_t enters 9000 and 21000.
- k introduces a horizontal asymptote in pure shears on stress-strain curve if its value is different from 1 for $A_t=1$, (éq 2.2-11). The advised value is 0.7.

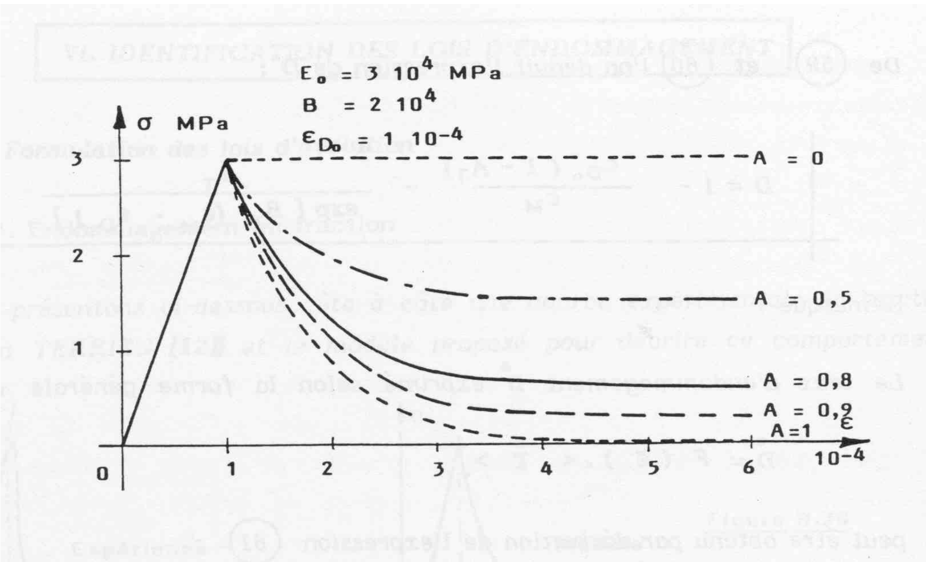


Figure 3-1: Influence parameter A_t

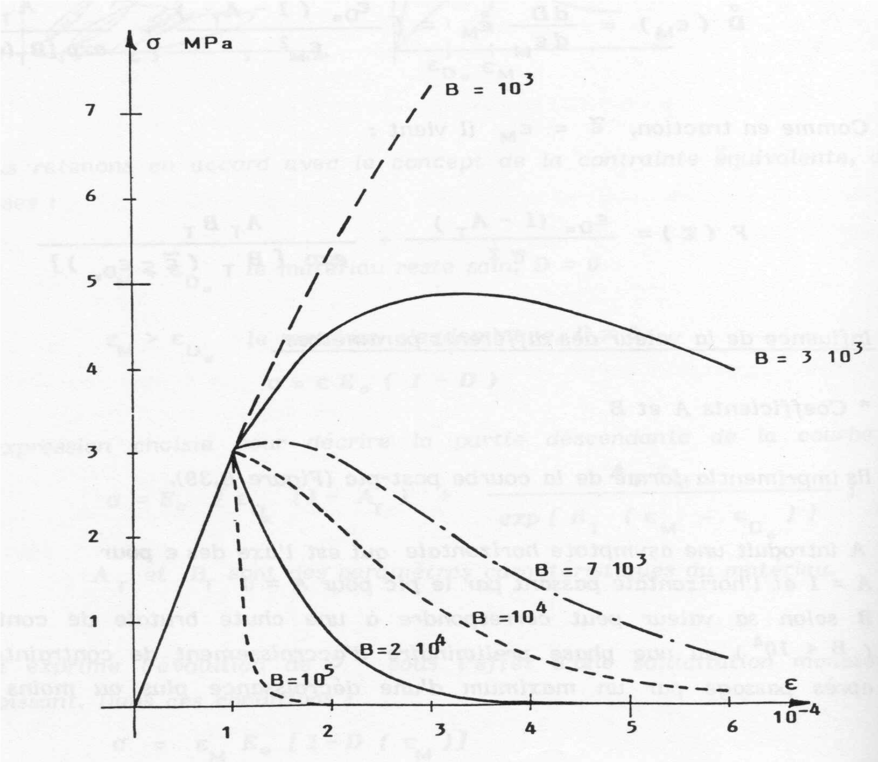


Figure 3-2: Influence parameter B_t

a layer to obtain a set of parameters is to have the uniaxial test results in compression and tension (for the tension one can use other type of tests, of the "Brazilian" tests of splitting for example).

If one uses the regularization in deformation gradient (see §1.21.2), it is recommended to fix the parameters of the model at the same time characteristic length L_c. Some authors (confer 6,) also suggests gauging L_c to use experimental tests of them on several sizes of the specimens; indeed, the characteristic length is dependant in keeping with the energy zone of dissipation which could be at the origin of scale effect structural.

4 Numerical resolution

4.1 Evaluating of the local variable *Y*

The computation of Y is very simple and follows an explicit diagram. The stages are the following ones:

- Computation of the elastic strain and thermal
- Computation of the principal elastic stresses and evaluating of γ (éq 2.2-2).
- Computation of the equivalent strain ((éq 2.1-2) and (éq 2.2-1)).
- Computation of the variables r *,* A *and* B
- Computation of the local variable Y *(éq 2.2-5).*

If $Y \leq Y^-$ then $Y^+ = Y^-$.

If $Y > Y^-$ *then* $Y^+ = Y$.

Note: Currently the variable stored at the time as of computations is ε_{eq} in order not to modify the existing couplings with UMLV. A condition on the strictly increasing evolution of the damage allows this simplification if γ varies.

4.2 Evaluating of the damage

the damage is calculated in all the cases with the equation (éq 2.2-7).

$$D = 1 - \frac{(1-A) Y_0}{Y} - A \exp\left(-B\left(Y - Y_0\right)\right) \quad \text{(éq 2.2-7)}$$

It is important to specify that we force D to be ranging between 0 and 1 because it is possible to have values outwards this framing following the choice of materials parameters as for the model of origin.

4.3 Computation of the stress

After evaluating of D , we calculate simply:

$$\boldsymbol{\sigma} = (1 - D) \mathbf{A} \boldsymbol{\varepsilon}^{\mathrm{e}} \quad \textbf{(éq 4.3-1)}$$

4.4 Computation of the tangent matrix

One of the disadvantage of the model of Mazars is the absence of tangent matrix. It is not possible to calculate this matrix because of the use of the MacCauley operator in the computation of the equivalent strain (éq 2.1-2), of γ (éq 2.2-2) and r . However it is possible to use a radial approximation during loading.

We seek the tensor $\mathbf{M}$ such as $\dot{\boldsymbol{\sigma}} = \mathbf{M} \dot{\boldsymbol{\varepsilon}}$ knowing that $\boldsymbol{\sigma} = (1 - D) \mathbf{A} \boldsymbol{\varepsilon}$. The matrix is thus the sum of two terms, one with constant damage, the other due to the evolution of the damage:

$$\dot{\boldsymbol{\sigma}} = (1 - D) \mathbf{A} \dot{\boldsymbol{\varepsilon}} - \mathbf{A} \boldsymbol{\varepsilon} \dot{D} \quad \textbf{(éq 4.4-1)}$$

the first term is easy, it acts of the operator of Hooke, multiplied by the factor $1 - D$.

The second requires the evaluating of the increment of damage $\dot{D}$.

If a radial loading is imposed, the variables γ r , A and B are constant. While posing:

$$\dot{D} = \frac{\partial D}{\partial Y} \frac{\partial Y}{\partial\left(\gamma \varepsilon_{eq}\right)} \frac{\partial\left(\gamma \varepsilon_{eq}\right)}{\partial \varepsilon} \dot{\varepsilon} \quad \textbf{(éq 4.4-2)}$$

With

$$\frac{\partial Y}{\partial\left(\gamma\varepsilon_{eq}\right)}\frac{\partial\left(\gamma\varepsilon_{eq}\right)}{\partial\varepsilon}=\frac{\gamma\langle\varepsilon\rangle_+}{\varepsilon_{eq}} \qquad \textbf{(éq 4.4-3)}$$

Under this condition of radial loading, the increment of strain is written:

$$\dot{D}=\left[\frac{(1-A)Y_0}{Y^2}+AB\exp\left(B\left(Y-Y_0\right)\right)\right]\frac{\gamma\langle\varepsilon\rangle_+}{\varepsilon_{eq}}\dot{\varepsilon} \qquad \textbf{(éq 4.4-4)}$$

Note:

1. *Being given made simplifications, in the general case the tangent matrix is not consistent. Also, it can happen that the reactualization of the tangent matrix during iterations of Newton does not help with convergence. In this case, it is enough to use only the secant matrix by imposing `STAT_NON_LINE (NEWTON = _F (REAC_ITER =0))`.*
2. *In the general case, the tangent matrix is NON-symmetric. It is possible to do it thanks to key word `SOLVEUR=_F (SYME = "YES")` of `STAT_NON_LINE`.*
3. *Concerning the nonlocal approach, the processing of the boundary conditions is such that one could be brought, in the case of symmetric structures, with treating the computation of the group of structure and not of the "representative" part (cf [R5.04.02]).*
4. *The analytical statement of the tangent matrix is valid only for radial loadings ($dr=d\gamma=0$). In the other cases, the quadratic convergence of the method is not guaranteed any more.*

4.5 Stored local variables

We indicate in the table according to the local variables stored in each Gauss point for the model of MAZARS :

Physical	local variable Meaning
$V1$	D : variable of indicating
$V2$	damage of damage (0 so elastic, 1 if damaged i.e. as soon as D is not null any more)
$V3$	$Tmax$: maximum θ temperature attack at the point of gauss
$V4$	$\varepsilon_{eq}=\sqrt{\langle\boldsymbol{\varepsilon}\rangle_+:\langle\boldsymbol{\varepsilon}\rangle_+}$ equivalent strain

Table 4.5-1: Stored local variables.

5 Functionalities and checking

the constitutive law MAZARS, key word COMP_INCR of STAT_NON_LINE, associated material MAZARS is usable in Code_Aster with various modelizations:

- classical version: 3D, D_PLAN, AXIS, C_PLAN (established analytical formulation, not to use method DEBORST)
- NON-local version: 3D_GRAD_EPSI , D_PLAN_GRAD_EPSI , C_PLAN_GRAD_EPSI ,
- coupled with the models of THHM (confer [R7.01.11]).

The model of MAZARS can be coupled with the model of creep BETON_UMLV_FP (confer [R7.01.06]) via key word KIT_DDI. This is true as well for the local version as thelocal one.

The constitutive law is checked by the following tests:

COMP007 b	[V6.07.107]	Test of compression-thermal expansion for study of the coupling thermal-cracking
HSNV129	[V7.22.129]	Test of compression-thermal expansion for study of the coupling thermal-cracking
SSLA103	[V3.06.103]	Computation of the shrinkage of desiccation and the endogenous shrinkage on a cylinder
SSNP113	[V6.03.113]	Rotation of principal stresses (model of MAZARS)
SSNP161	[V6.03.161]	biaxial Tests of Kupfer
SSNV157	[V6.04.157]	Test of the method of delocalization per regularization of the strain on a variable bar of section in tension
SSNV169	[V6.04.169]	Coupling creep-damage
WTNV121	[V7.31.121]	Damping of the concrete with a damage model

Table 5-1 : Existing benchmarks

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Author (S) or contributor	**(S), organization Description of**	**the modifications 6.4 S.MICHEL-PONNELLE**
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	, Marina BOTTONI Addition of the coupling	UMLV-MAZARS + file 11150 + 4th local variable 11.0 Marina BOTTONI
	11.2 François	
HAMON	Reformulation	of the Mazars model