ZZZZ264 – Validation of the order POST_ENDO_FISS

Summary:

This CAS-test makes it possible to validate the order POST_ENDO_FISS, which allows the search for a way of cracking and the opening of crack starting from a mechanical calculation of damage. Three CAS-tests are proposed:

- the way of cracking on an analytical field,
- opening of crack on study calculated with the law ENDO_SCALAIRE/GRAD_VARI,
- opening of crack on study calculated with the law MAZARS/GRAD_EPSI.

1 Problem of reference: research of the way of cracking on an analytical result

1.1 Generation of the field

In this first test one searches the way of cracking on an artificial field, i.e. created analytically and nonresulting from a mechanical calculation. The advantage is that the way of cracking is known *a priori*, therefore one can compare it with the way resulting from the order.

With Figure 1.1-1, the artificial field is shown on which one will test the order, on the field x, y.

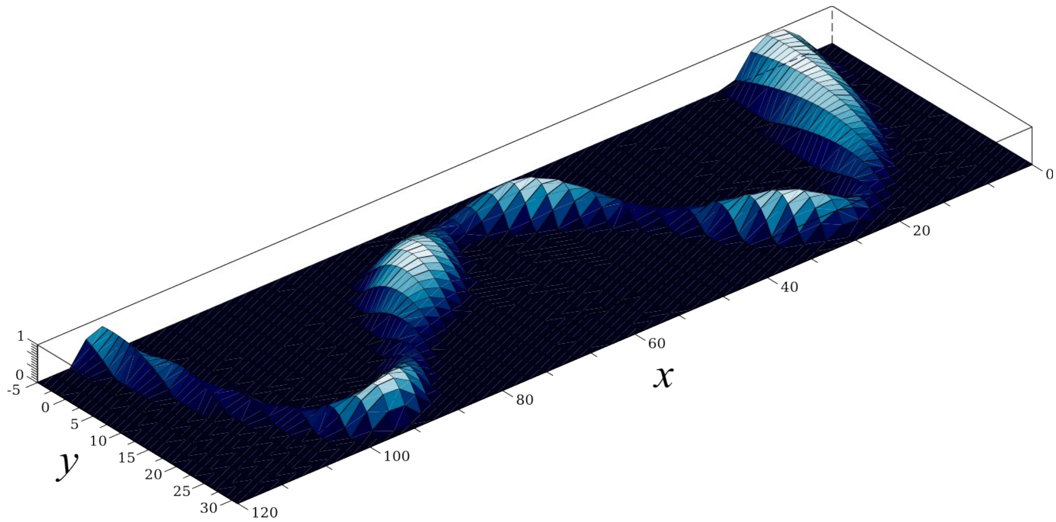

Figure 1.1-1 : field post-to be treated discretized on the grid.

For the generation of the field, one initially fixed the way of cracking, then the field is given by a function defined on the orthogonal profile in the crack of each one of its points.

The way of cracking is the polynomial of degree 4 which passes by the points:
$P1=(10.,0.)$, $P2=(35.,20.)$, $P3=(60.,0.)$, $P4=(85.,20.)$, $P5=(110.,0.)$

On the orthogonal profile of curvilinear X-coordinate r, a parabolic profile is defined $z=-a_1 r^2+a_2$ limited in a lower position with the minimal value $valmin$ field (here, 10^{-6}). The resulting field is equal everywhere to $valmin$, except in the vicinity of the crack; one thus creates a "damaged" zone artificial.

The width of the damaged zone as well as the value of the field are variable along the crack:

$$a_1=-0.04\cos(0.1(x-x_{P_1}))+0.0667 \quad \text{éq 1.1-1}$$

$$a_2=(\cos(0.3(x-x_{P_1}))+2)/3 \quad \text{éq 1.1-2}$$

The field described was discretized on a grid with rectangular meshs of size $dx=2.45$, $dy=1$, on a field 120×40.

In the CAS-test, one directly gives file MED containing the field post-to be treated, contained in a structure given of standard result (`evol_noli`), and created previously using the orders `CREA_CHAMP` and `CREA_RESU`, in order to make the CAS-test faster. Like the order treats only fields with nodes, analytical field is stored in the field with nodes DEPL, under the component DX (the field VARI_NOEU, which contains the damage normally, is indeed not available in CREA_CHAMP).

1.2 Parameters of the order

The parameters used for the research of the way of cracking are the following:

LONG_ORTH = 20,
NOT = 2,
LONG_REG = 4,
THRESHOLD = 10^{-3}
ANGL_MAX = 180

2 Modeling A

2.1 Way of cracking found

The way of cracking found by the order is given in Figure 2.1-1. In Figure 2.1-2, the crack is superimposed on the map of the field.

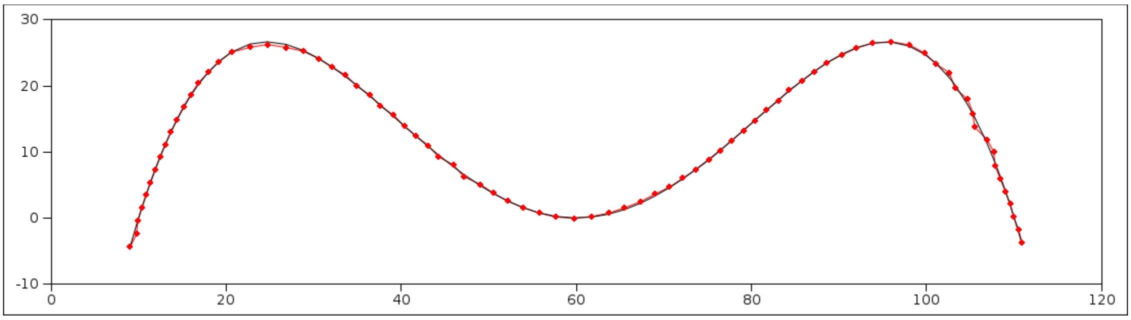

Figure 2.1-1: Theoretical way of cracking (black) compared with that provided by the order.

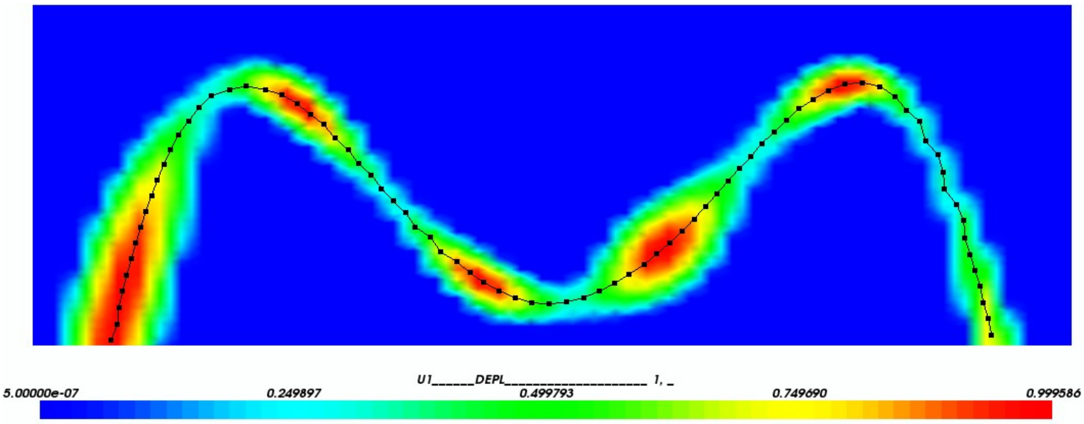

Figure 2.1-2: way of cracking superimposed to the field post-treaty.

2.2 Sizes tested and results

One tests the distance between the points found by the algorithm and the theoretical curve. This distance, stored in the command file of the CAS-test in the table `TAB_FISS`, the absolute error represents in each point. We check whereas the maximum error is lower than a certain precision. The test is made in absolute, because one compared to a worthless distance. The required precision is 0.05, the CAS-test is analytical.

2.3 Remarks

The found way is very satisfactory. The procedure reproduces well the strong curves of the way, as well as the variations in the value of the field.

The precision is dependent with the damaged bandwidth, as one sees it on the right part of Figure 2.1-2 : the error is larger where the damaged bandwidth is exiguous.

However, normally the damage resulting from a mechanical calculation is wide on several elements, so that convergence compared to refinement is checked, which limits this kind of error.

3 Problem of reference: opening of crack on a study with law of damage

In this CAS-test, POST_ENDO_FISS research at the same time the way of cracking and the opening of crack on a mechanical CAS-test. The mechanical study is carried out beforehand which consists of a tensile specimen calculated respectively with the law of damage ENDO_SCALAIRE then MAZARS. This mechanical calculation is not included with the case test, because of important time necessary for calculation. Thus, a file MED containing the mechanical results is read, then the ordering of postprocessing is applied. Lastly, the opening of crack is compared with the displacement imposed on the free edge.

3.1 Geometry, grid and loading.

It is about a test-tube bi--notched in traction. Dimensions of the test-tube are $1\,m \times 2\,m$; the ray of the notch (semicircular) is $6\,cm$. At an end of the test-tube, a displacement is imposed until rupture, when the resulting force applied is worthless. Displacements of the other end are blocked in the direction of application of the loading.

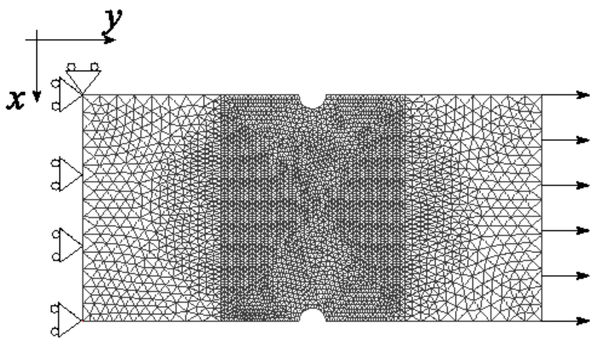

Figure 3.1-1: geometry, grid and boundary conditions of the tensile specimen.

3.2 Properties of material and models of preliminary mechanical calculations

3.2.1 Law **ENDO_SCALAIRE**

The law ENDO_SCALAIRE [R5.03.25] is used, with regularization in gradient of internal variables [R5.04.01] and in plane deformations: modeling D_PLAN_GRAD_VARI.

Elastic parameters:

$E = 40000\,MPa$ Young modulus

$\nu = 0{,}25$ Poisson's ratio

Parameters of damage :

$D = 0.1\,m$ Half-width of the damaged band

$G_f = 100\,N/m$ Energy of rupture

$SY = 2.8\,MPa$ Tensile strength

3.2.2 Law **MAZARS**

The law MAZARS [R7.01.08] is used, with regularization in gradient of deformations [R5.04.02] and in plane constraints: modeling C_PLAN_GRAD_EPSI.

Elastic parameters:

$E=40000\,MPa$	Young modulus
$\nu=0{,}25$	Poisson's ratio

MAZARS (modeling B):

$\varepsilon_{d0}=SY/E=7\text{E-5}$	Threshold of damage
$A_t=1$	Parameter for traction
$B_t=13000$	Parameter for traction
$A_c=1.09$	Parameter for compression
$B_c=1600$	Parameter for compression
$\beta=1.06$	Parameter to improve the answer in shearing
$NON\ LOCAL=0.1\,m$	Length characteristic of the model nonlocal

3.3 Parameters of postprocessing POST_ENDO_FISS

The research of the way of cracking is carried out on the field of damage. We thus use the component $V1$ field VARI_NOEU (because the order takes as starter only fields with Nœuds).
Mean size of the mesh in the damaged zone east $0.02\,m$.

Parameters used:
LONG_ORTH = $2\,m$
NOT = $0.02\,m$
LONG_REG = $0.02\,m$
THRESHOLD = 0.5
LIM_FPZ = 0.8
All the other parameters have the value by default.

It is also possible to use the component VARI field DEPL, which also stores the variable of damage and is a nodal field (thus usable directly by the order). It is in the same way necessary a projection of this field on a linear grid, which will be him given as starter of POST_ENDO_FISS, that to make coherent the interpolation of the component VARI with that of the grid (thus linear).

The command file gives an example of use of the field VARI_NOEU/V1 as well as DEPL/VARI.

Concerning modeling C, the research of the way of cracking is carried out on the equivalent deformation, because the field of damage does not make it possible to identify a true maximum (it is too “flat”). We thus use the component $V4$ field VARI_NOEU.

Parameters used in POST_ENDO_FISS are the same one as in modeling B, except the following:

THRESHOLD = 0.0001
LIM_FPZ = 0.0001

4 Modeling B

4.1 Mechanical results

Method of piloting per elastic prediction (PRED_ELAS) is used. Curved force-displacement obtained is in Figure 4.1-1 . The test-tube at the moment C is completely broken, residual force being close to zero. It is at this moment that the opening of crack will be calculated. The pace of displacements and the damage are given in the Figures 4.1-2 and 4.1-3 .

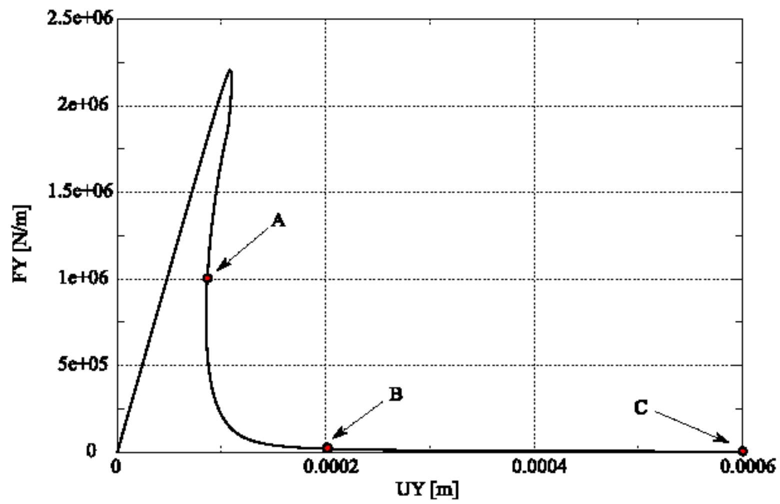

Figure 4.1-1: Curve force-displacement, bi--notched test-tube (law ENDO_SCALAIRE).

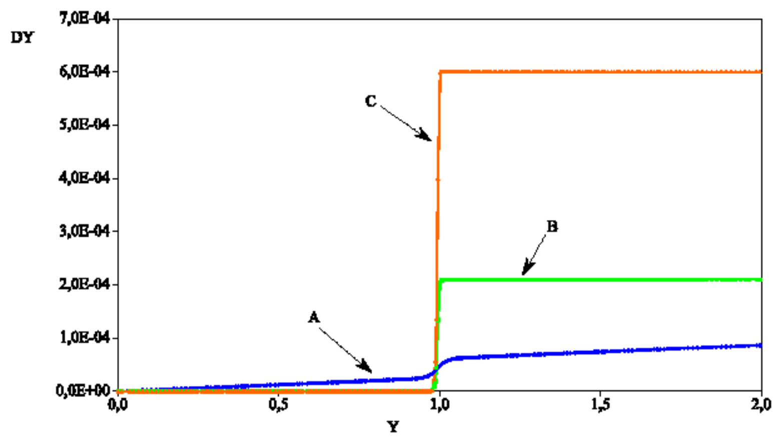

Figure 4.1-2: Displacements on the longitudinal axis of the test-tube (law ENDO_SCALAIRE).

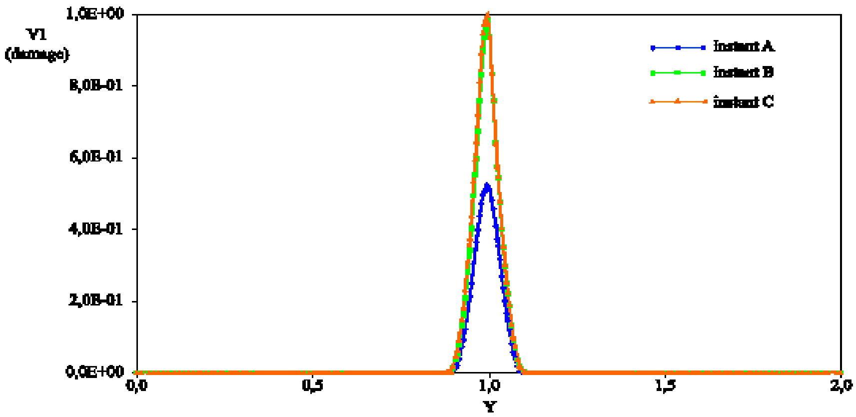

Figure 4.1-3: Damage on the longitudinal axis of the test-tube (law `ENDO_SCALAIRE`).

4.2 Sizes tested and results

The way of cracking found with **the moment** C is shown in Figure 4.2-1 for the component `VARI` field `DEPL`. The way found with the field `VARI_NOEU` is similar.

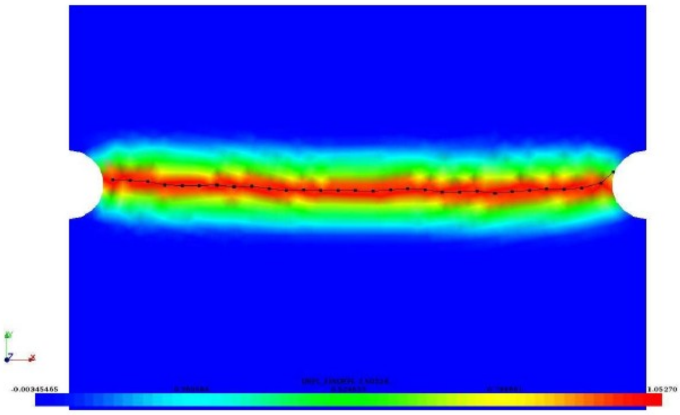

Figure 4.2-1: way of cracking in the bi--notched test-tube (law `ENDO_SCALAIRE`).

At the end of calculation, either the way of cracking, or the opening of crack are tested.

Concerning the way of cracking, that Ci must be a priori on the axis of symmetry of the test-tube, on the axis x . One tests whereas the maximum distance to this axis of the points found by the order is lower than a certain precision. An analytical CAS-test is envisaged, with precision (absolute) equalizes with $1.5 \times taille\ élément = 0.03\ m$.

Concerning the opening of crack, this one must be equal to rupture with imposed displacement. One thus proposes an analytical CAS-test, with relative precision of 10%, and a CAS-test of nonregression with precision 5%.

In short, if the field is used `VARI_NOEU`, component $V1$ for the research of the way of cracking:

Quantity tested	Type of test	Precision requested	Precision of the CAS-test

DY	Analytical	$0.03\,m$	$0.0129\,m$
Opening	Analytical	$10\ \%$	$4.69\ \%$
Opening	Not regression	$5\ \%$	$4.69\ \%$

If the field is used `DEPL`, component `VARI` for the research of the way of cracking:

Quantity tested	**Type of test**	**Precision requested**	**Precision of the CAS-test**
DY	Analytical	$0.03\,m$	$0.0128\,m$
Opening	Analytical	$10\ \%$	$4.97\ \%$
Opening	Not regression	$5\ \%$	$4.97\ \%$

4.3 Remarks

way of cracking found is satisfactory, however the precision found is in extreme cases of the allowed precision for the analytical CAS-test. That is with the fact that the law `ENDO_SCALAIRE` locate much the damage when one approaches the rupture (endommagement=1). According to the analytical solutions indeed, the damage is worth 1 that on the crack. That requires very fine grids in the band of localization. In Figure 4.2-1 , a way of more precise cracking could have been obtained following a mechanical calculation using a finer grid.

Foropening of crack, the source of error are related to:
1) way of cracking not perfectly rectilinear,
2) residual force on the test-tube close but nonequal to zero.

5 Modeling C

5.1 Mechanical results

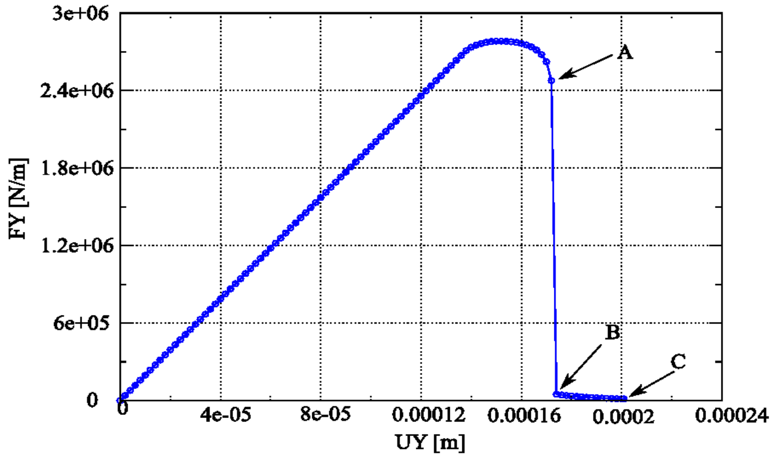

Figure 5.1-1: Curve force-displacement, bi--notched test-tube (law MAZARS).

No method of piloting is used. Curved force-displacement obtained is in Figure 5.1-1. The test-tube at the moment C is completely broken, the residual force being close to zero. It is at this moment that the opening of crack will be calculated. The pace of displacements, the damage and the equivalent deformation are given in the Figures 5.1-2, 5.1-3 and 5.1-4.

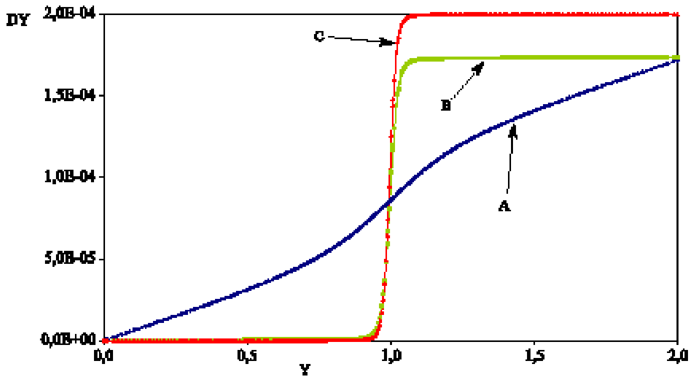

Figure 5.1-2: Displacement on the longitudinal axis of the test-tube (law MAZARS).

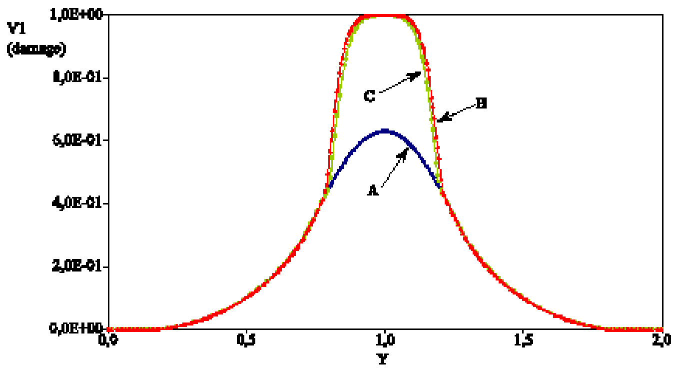

Figure 5.1-3: Damage on the longitudinal axis of the test-tube (law MAZARS).

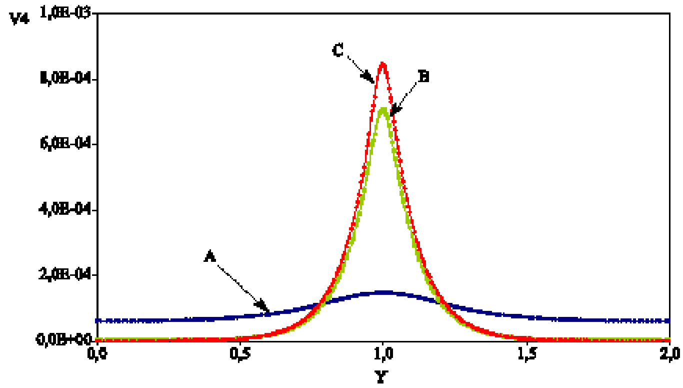

Figure 5.1-4: Equivalent deformation on the longitudinal axis of the test-tube (law MAZARS).

5.2 Sizes tested and results

The way of cracking found with **the moment** C is similar to that of Figure 4.2-1.
The quantities tested are the same ones as in modeling B.

In short:

Quantity tested	**Type of test**	**Precision requested**	**Precision of the CAS-test**
DY	Analytical	$0.03\,m$	$2.58\cdot10^{-3}\,m$
Opening	Analytical	$10\ \%$	$0.683\ \%$
DY	Not-regression	$0.01\,m$	$2.58\cdot10^{-3}\,m$
Opening	Not regression	$1\ \%$	$0.683\ \%$

5.3 Remarks

The way of cracking found is more precise than for modeling B. That is due to the law of damage used, which is less localised with the rupture.