ZZZZ264 – Summarized validation of the command

POST_ENDO_FISS:

This benchmark makes it possible to validate the command POST_ENDO_FISS, which allows the search for a way of cracking and the crack opening from a mechanical computation of damage. Three benchmarks are proposed:

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

1 Problem of reference: search way of cracking on result an analytical

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 computation. The advantage is that the way of cracking is known *a priori*, therefore one can of the command compare it with the resulting way.

With Figure 1.1-1, one shows the artificial field on which one will test the command, on the field x, y.

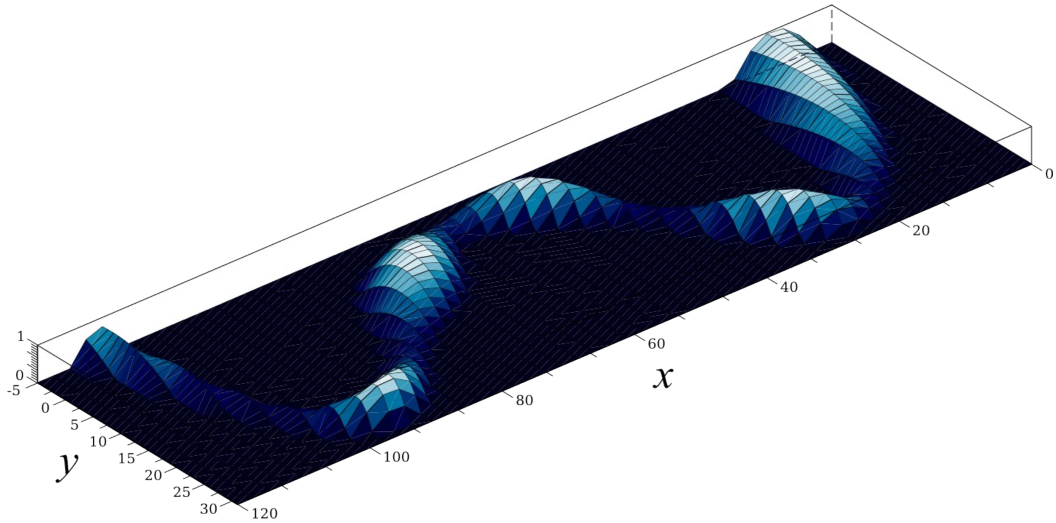

Figure 1.1-1 : field with post-treating discretized on the mesh.

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 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 abscisse r, one defines a in a lower position limited $z=-a_1 r^2+a_2$ parabolic profile in the minimal value $valmin$ of the field (here, 10^{-6}). The resulting field is everywhere equal to $valmin$, except in the vicinity of 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 crack:

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

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

the field described was discretized on a mesh with meshes rectangular of size $dx=2.45$ $dy=1$, on a field 120×40.

In the benchmark, one gives directly med file containing the field to post-treating, contained in a structure given of type result (`evol_noli`), and previously created using commands `CREA_CHAMP` and `CREA_RESU`, in order to make the benchmark faster. Like the command treats only fields at nodes , the analytical field is stored in field at nodes DEPL, under the component DX (field VARI_NOEU, which contains the damage normally, is indeed not available in CREA_CHAMP).

1.2 Parameters of the command

the parameters used for the search of the way of cracking are the following:

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

2 Modelization A

2.1 Way of cracking found

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

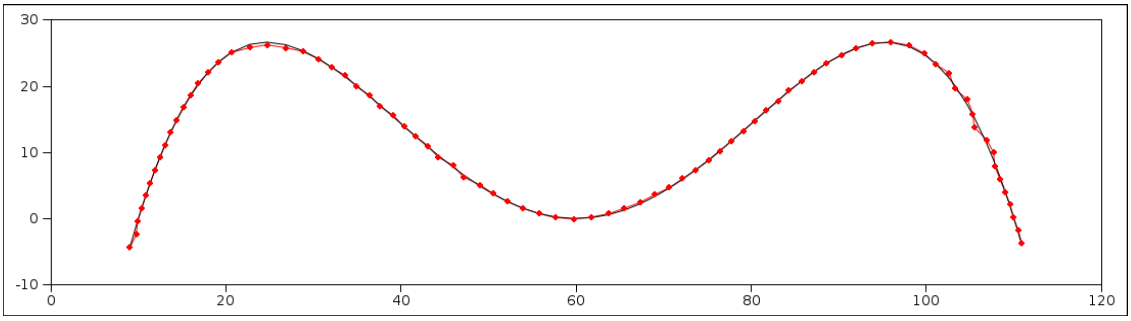

Figure 2.1-1: Theoretical way of cracking (black) compared with that provided by the command.

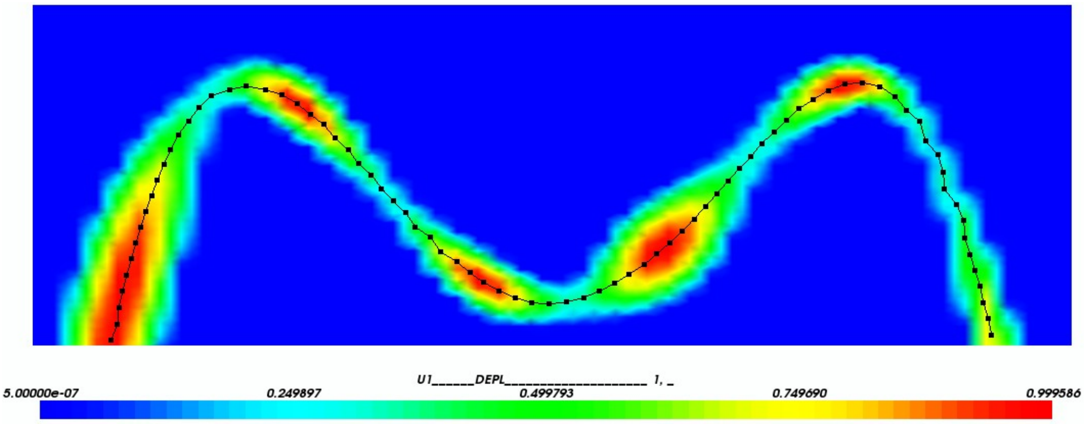

Figure 2.1-2: way of cracking superimposed at the field post-treaty.

2.2 Quantities 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 benchmark in array `TAB_FISS`, represents the absolute error in each point. We check whereas the maximum error is lower than a certain accuracy. The test is made in absolute, because one compared to a distance null. The required accuracy is 0.05, the benchmark is analytical.

2.3 Remarks

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

The accuracy is related to the damaged bandwidth, as one sees it on the straight lines part of Figure 2.1-2 : the error is larger where the damaged bandwidth is exiguous.

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

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

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

3.1 Geometry, mesh and loading.

It is about a test-tube bi--notched in tension. Dimensions of the test-tube are $1\,m\times 2\,m$; the radius of the notch (semicircular) is $6\,cm$. A an end of the test-tube, a displacement is imposed until fracture, when the resultant force applied is null. Displacements of the other end are blocked in the direction of application of the loading.

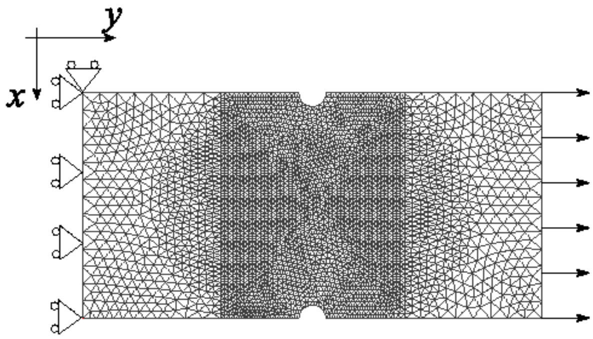

Figure 3.1-1: geometry, mesh and boundary conditions of the tensile specimen.

3.2 Properties of the material and models of preliminary mechanical computations

3.2.1 Model ENDO_SCALAIRE

model ENDO_SCALAIRE [R5.03.25] is used, with regularization in gradient of local variables [R5.04.01] and in plane strains: modelization D_PLAN_GRAD_VARI.

Elastic parameters:

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

Parameters of damage :

$D=0.1\,m$ Half-width of the damaged tape
$G_f=100\,N/m$ Energy of fracture
$SY=2.8\,MPa$ Tensile strength

3.2.2 Model MAZARS

model MAZARS [R7.01.08] is used, with regularization in deformation gradient [R5.04.02] and plane stresses: modelization C_PLAN_GRAD_EPSI.

Elastic parameters:

$E=40000\,MPa$ of Young
$\nu=0,25$ of Fish

MAZARS (modelization B):

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

3.3 Parameters of postprocessing POST_ENDO_FISS

the search of the way of cracking is carried out on the field of damage. We thus use the component $V1$ field VARI_NOEU (because the command takes in entry only fields at nodes).
The mean size of the mesh in the damaged zone is $0.02\,m$.

Parameters used:
LONG_ORTH= $2\,m$
PAS= $0.02\,m$
LONG_REG= $0.02\,m$
SEUIL= 0.5
LIM_FPZ= 0.8
All the other parameters have the value by default.

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

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

Concerning the modelization C, the search of the way of cracking is carried out on the equivalent strain, 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.

The parameters used in POST_ENDO_FISS are the same one as in the modelization B, except the following:

SEUIL=formule 0.0001
LIM_FPZ= 0.0001

4 Modelization B

4.1 mechanical Results

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

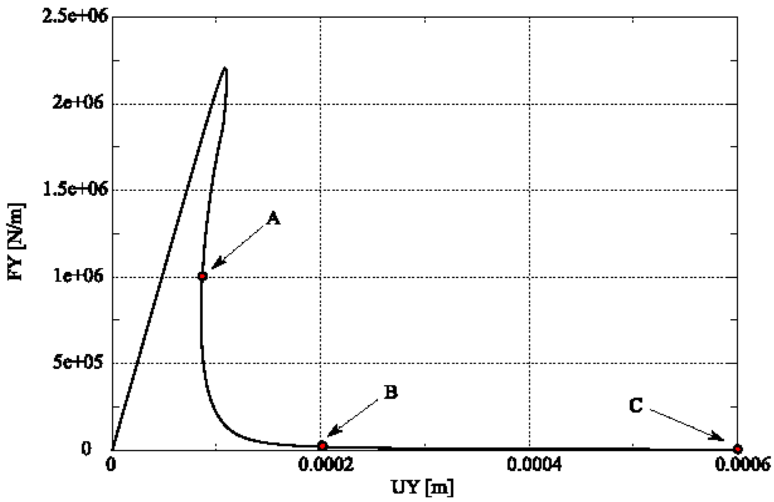

Figure 4.1-1: Curve force-displacement, bi--notched test-tube (model ENDO_SCALAIRE).

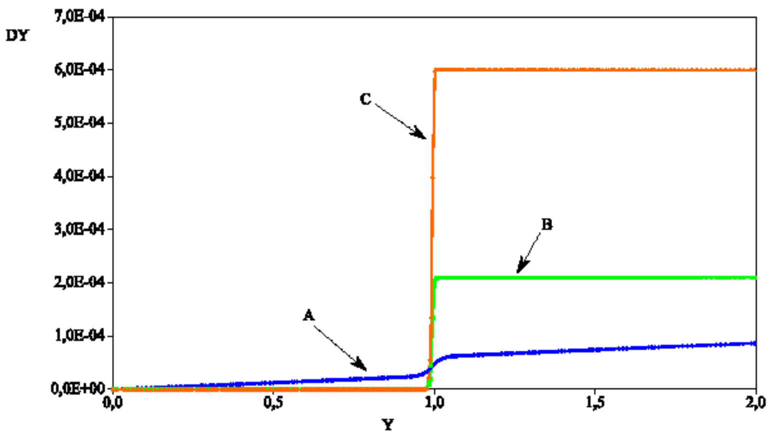

Figure 4.1-2: Displacements on the longitudinal axis of the test-tube (model ENDO_SCALAIRE).

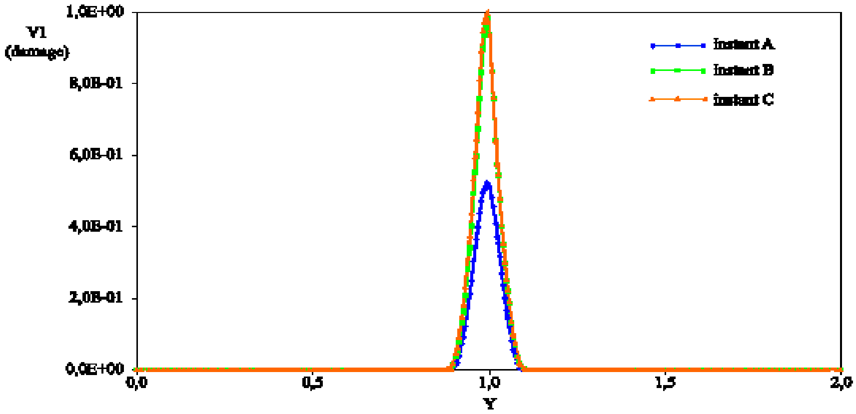

Figure 4.1-3: Damage on the longitudinal axis of the test-tube (model `ENDO_SCALAIRE`).

4.2 Quantities tested and results

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

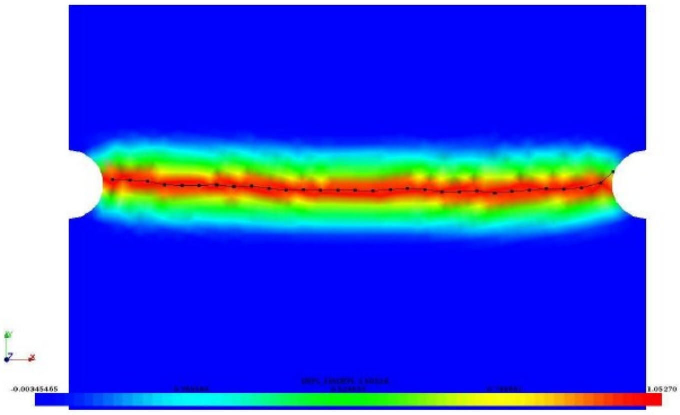

Figure 4.2-1: way of cracking in the bi--notched test-tube (model `ENDO_SCALAIRE`).

At the end of computation, 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 command is lower than a certain accuracy. An analytical benchmark is envisaged, with accuracy (absolute) equal to $1.5 \times taille\ élément = 0.03\ m$.

Concerning the crack opening, this one must be equal to fracture with imposed displacement. One thus proposes an analytical benchmark, with relative accuracy of 10%, and a benchmark of non regression with accuracy 5%.

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

Quantity tested	**Standard of test**	**required Accuracy**	**Accuracy of the Analytical**
DY	benchmark	$0.03\ m$	$0.0129\ m$

formula	Opening	$10\ \%$	$4.69\ \%$
Opening	Non regression	$5\ \%$	$4.69\ \%$

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

Quantity tested	Standard of test	required Accuracy	Accuracy of the Analytical
DY	benchmark	$0.03\,m$	$0.0128\,m$
formula	Opening	$10\ \%$	$4.97\ \%$
Opening	Non regression	$5\ \%$	$4.97\ \%$

4.3 Remarks

the way of cracking found is satisfactory, however the accuracy found is in extreme cases of the allowed accuracy for the analytical benchmark. That is with the fact that model ENDO_SCALAIRE locates much the damage when one approaches the fracture (endommagement=1). According to the analytical solutions indeed, the damage is worth 1 that on crack. That requires very fine meshes in the tape of localization. In Figure 4.2-1 , a path of more precise cracking could have been obtained following a mechanical computation using a finer mesh.

For the crack opening, 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 Modelization C

5.1 mechanical Results

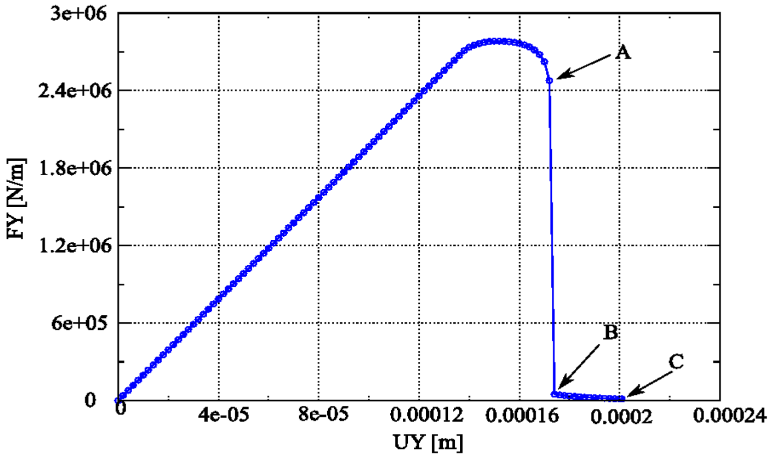

Figure 5.1-1: Curve force-displacement, bi--notched test-tube (model MAZARS).

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

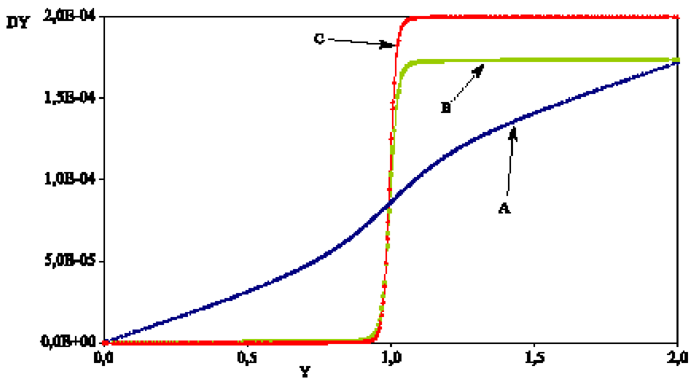

Figure 5.1-2: Displacement on the longitudinal axis of the test-tube (model MAZARS).

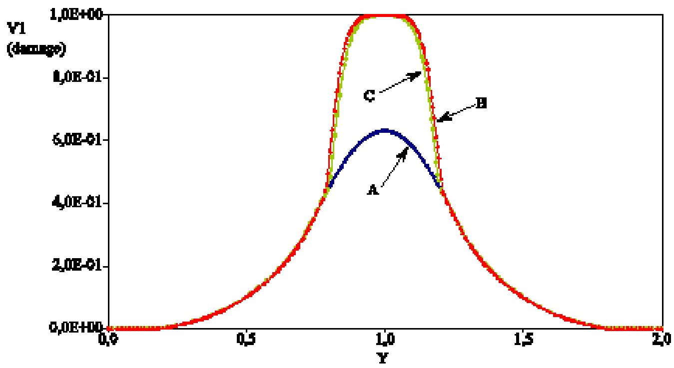

Figure 5.1-3: Damage on the longitudinal axis of the test-tube (model MAZARS).

5.2 Quantities tested and results

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

In short:

Quantity tested	Standard of test	required Accuracy	Accuracy of the Analytical
DY	benchmark	$0.03\,m$	$2.58\cdot 10^{-3}\,m$
formula	Opening	$10\ \%$	$0.683\ \%$
DY	NON-regression	$0.01\,m$	$2.58\cdot 10^{-3}\,m$
formula	Opening	$1\ \%$	$0.683\ \%$

5.3 Remarks

the way of cracking found is more precise than for the modelization B. That is due to the damage model used, which is less localised with the fracture.