SSNP312 - DMT94.132 Fissures parallel with the interface in a bimetallic test-tube CT

Summary:

This test is resulting from the validation independent of version 3 in breaking process.

It is about a two-dimensional test in statics (plane deformations) which relates to the calculation of a crack parallel with the interface between two materials, for a noncommonplace geometry in limited field.

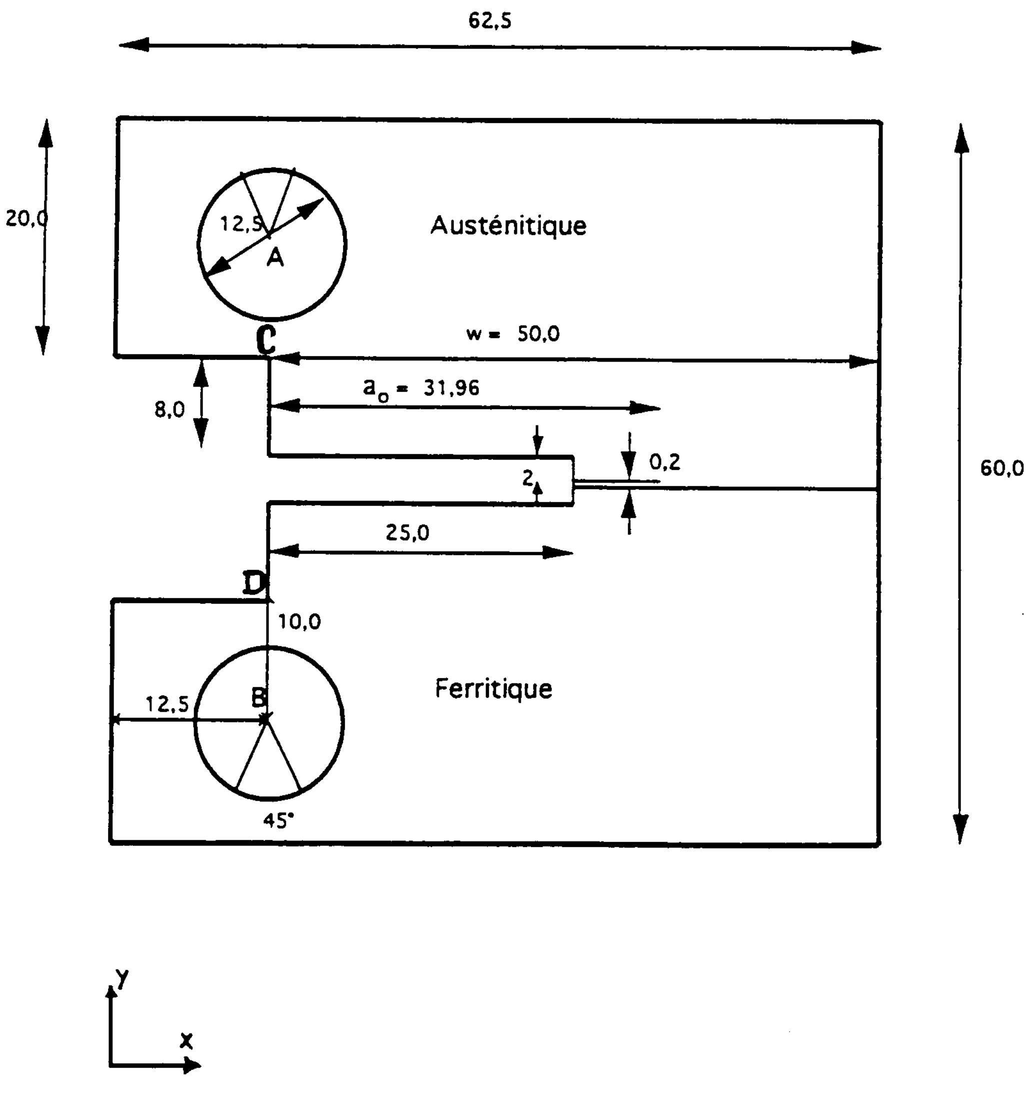
The structure has an elastoplastic behavior of Von Mises with isotropic work hardening. Calculations are carried out in nonlinear elasticity.

The objective of this case test is the study of the sensitivity of G with the choice of the crowns.

It understands two modelings $2D$ plane in which one studies the influence of an imposed incremental displacement. The first modeling uses linear elements, the other of the quadratic elements.

1 Problem of reference

1.1 Geometry



All the dimensions are expressed in mm . The crack is with $0{,}2\,mm$ interface, in the upper part of the test-tube.

1.2 Properties of materials

Material n° 1: austenitic steel

Elastoplastic of type von Mises to isotropic work hardening
Young modulus $E_1=2.10^5 MPa$, Poisson's ratio $\nu_1=0,3$
Yield stress $\sigma_{y1}=310 MPa$
Uniaxial traction diagram:

$\sigma(MPa)$	0	310	600	700
ε	0	0.155	40	100

Material n° 2: ferritic steel

Elastoplastic of type von Mises to isotropic work hardening
Young modulus $E_2=2.10^5 MPa$, Poisson's ratio $\nu_2=0,3$
Yield stress $\sigma_{y2}=442 MPa$

$\sigma(MPa)$	0	442	600	650
ε	0	0.221	40	100

Material n° 3: quasi indeformable pins

Isotropic linear rubber band
Young modulus $E_3=6.10^{10} MPa$, Poisson's ratio $\nu_3=0,3$

1.3 Boundary conditions and loading

Being given the dissymmetry of materials, the totality of the test-tube is modelled.

Blockings:

$UX=UY=0$ at the point B (center of the lower pin)
$UX=0$ at the point A (center of the higher pin)

Loading by imposed displacement:

$0\leq UY\leq 1\ mm$ at the point A , by equal increments of $0,02\ mm$

The loading is thus monotonous growing.

2 Reference solution

2.1 Method of calculating used for the reference solution

The reference solution used is an semi-empirical formula resulting from work of ASTM [bib1].

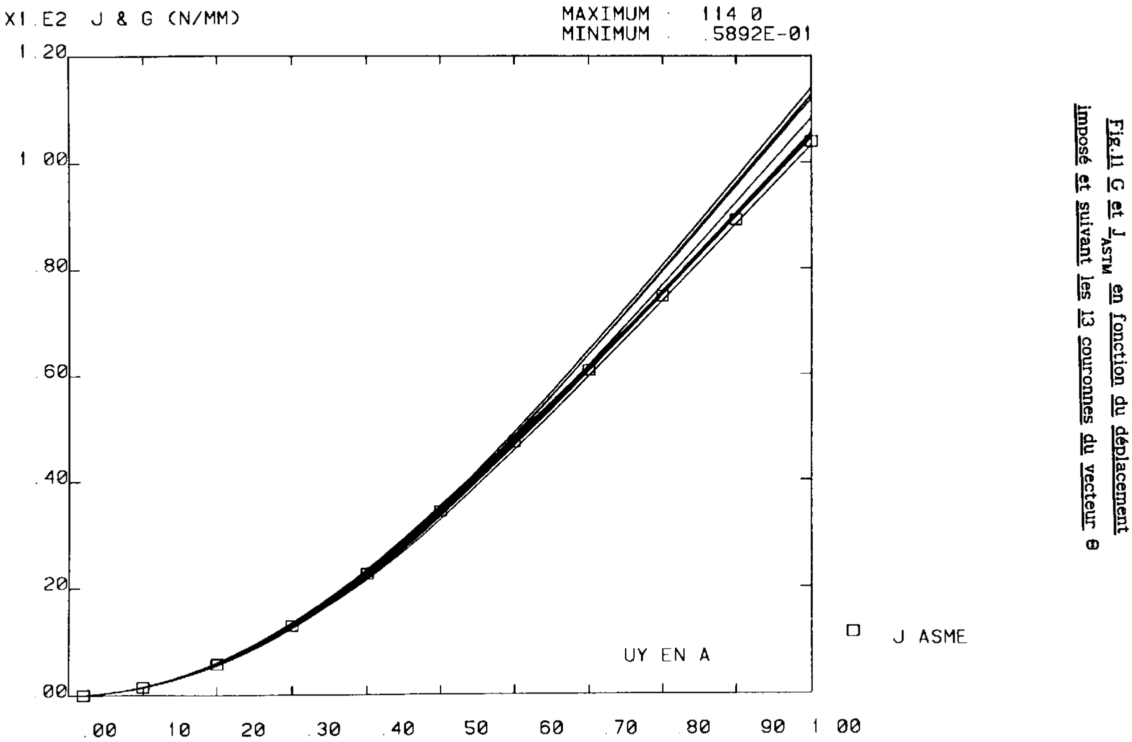
2.2 Results of reference

The formula of ASTM for the integral of Rice J is the following one:

$$J_{ASTM}=(2+0{,}522*b_0/w)*A/b_0\ ,$$

where $b_0=w-a_0$ is the initial length of the ligament and where A is the surface under curved load-displacement at the point A , i.e. the work of the load applied.

The integral J_{ASTM} is compared on the figure below with the rate of refund of energy G resulting from a calculation by finite elements with CASTEM2000 and the method theta [bib2]. One also plots the response curve force-displacement and the opening of the lips of the crack calculated by finite elements.



Rate of refund of energy G according to displacement in A

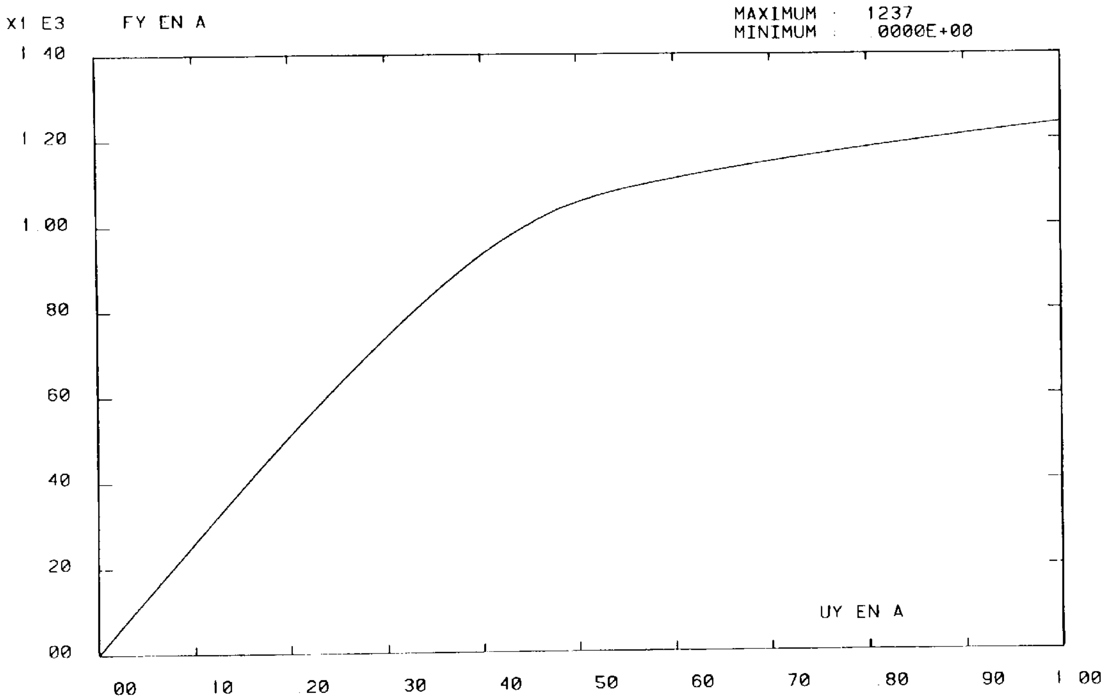


Fig.7 Fy au point A en fonction de Uy au point A

Response curve force-displacement to the point A

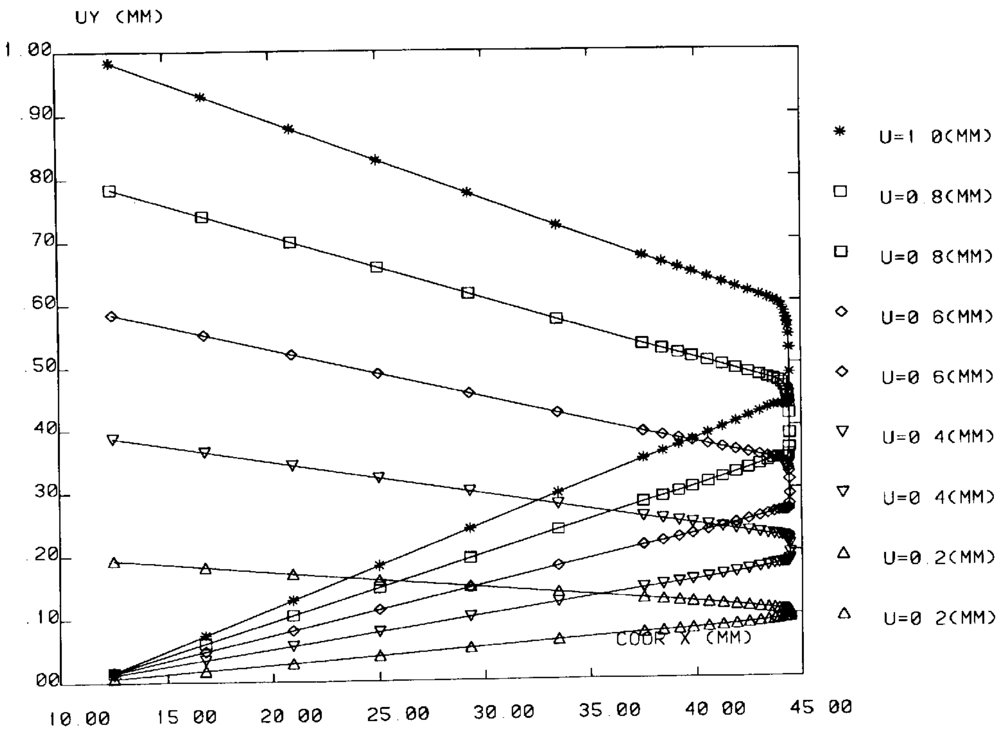


Fig.10 Déplacements des deux lèvres de la fissure au cours du chargement

Vertical displacement of the two lips of the crack

2.3 Uncertainty on the solution

It should be noted that the reference solution is not an exact solution and that it does not apply, in general, in the case of bi--materials. It is however exploitable for this study because the crack is not located at the interface of two materials

The maximum change between results CASTEM2000 and the formula of ASTM is of approximately 9% for the first crown (nearest to the crack) and the maximum loading. This variation decreases when one takes crowns further away from the bottom of crack.

Calculation Castem 2000 was carried out on the same grid as modeling A of this case test.

2.4 Bibliographical references

1) American Society for Testing and Materials. Annual Book Standard of ASTM, flight 3.01, Section 3, Metals Test Methods and Analytical Procedures, E813 article, page 711.1990.

2) X.Z. SUO and J. BROCHARD: Elastoplastic calculation of a bimetallic test-tube CT with a crack close to the interface. Report ECA DMT/94-132

3 Modeling A

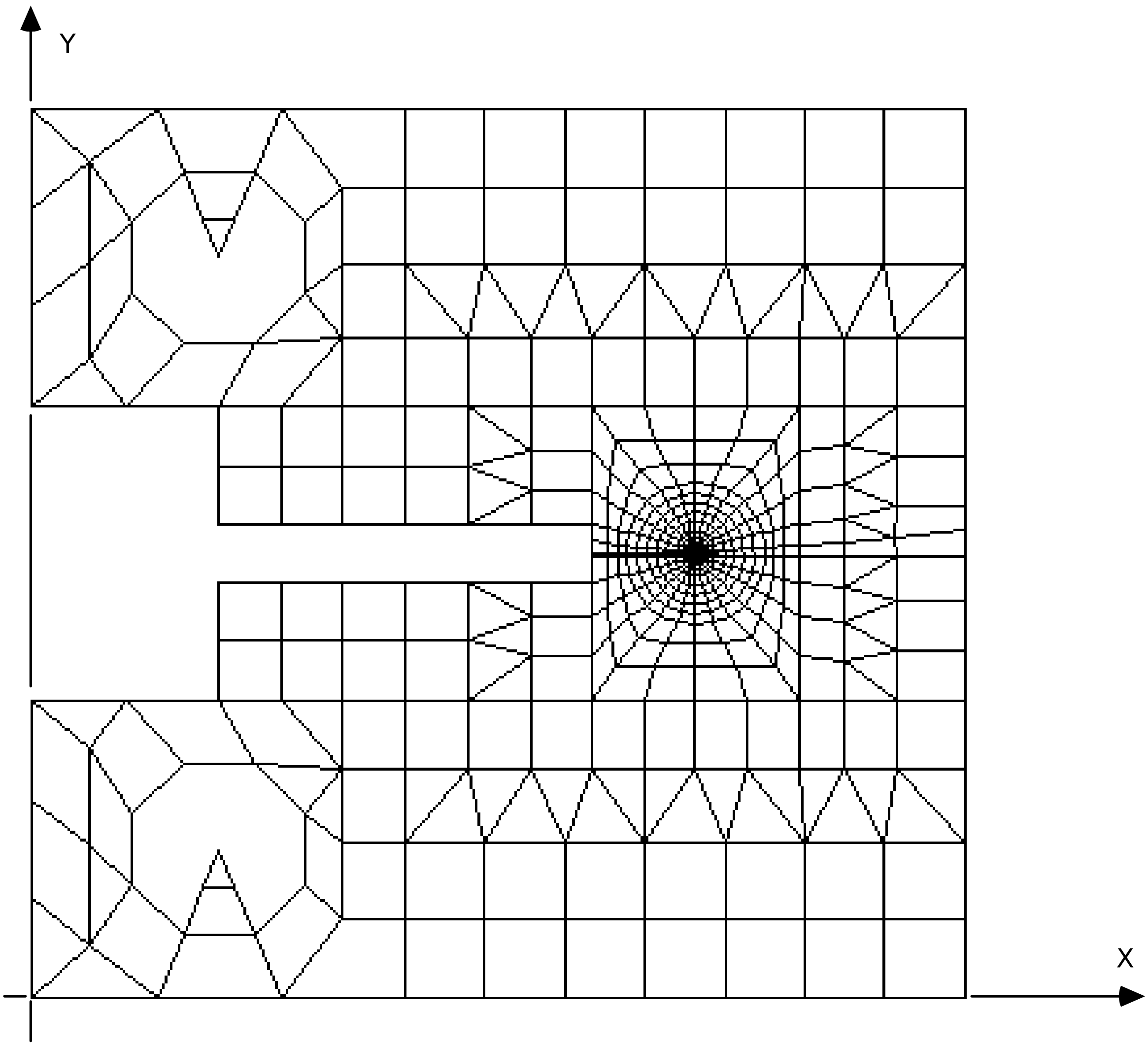
3.1 Characteristics of modeling

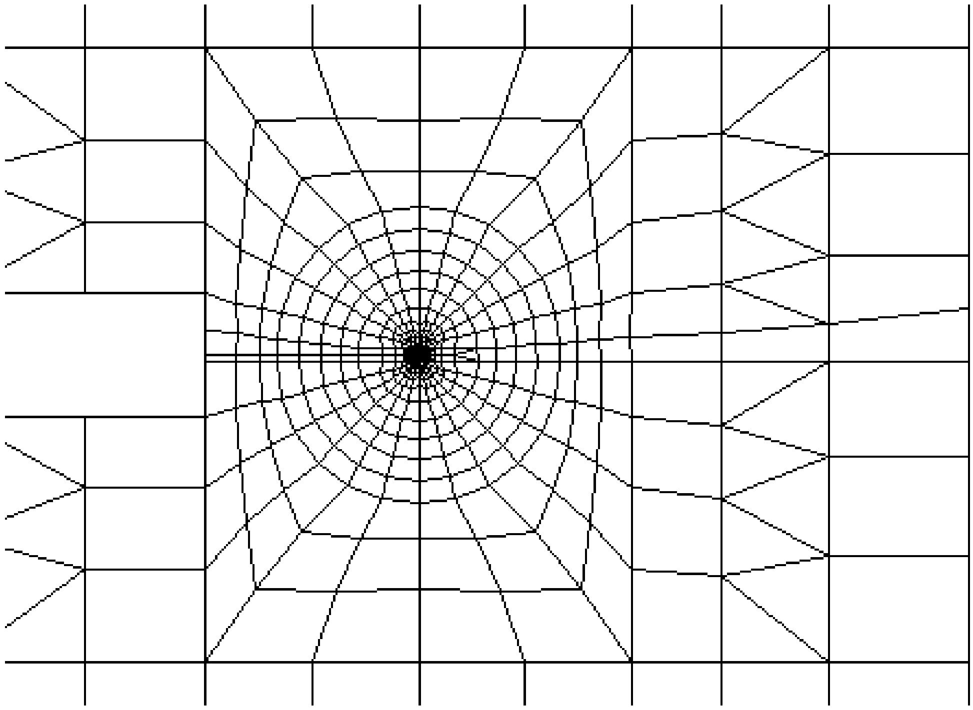
The totality of the test-tube is with a grid in quadrangular with 4 nodes or triangular elements with 3 nodes.

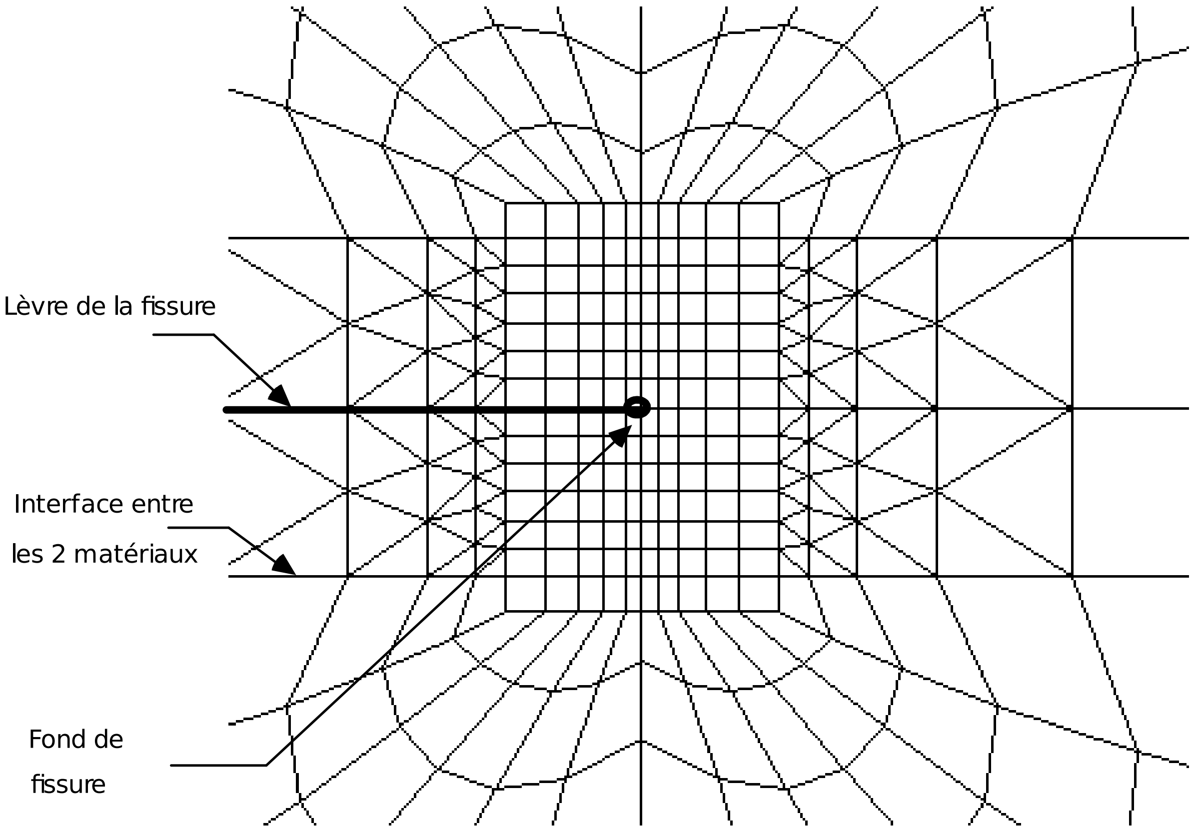
It comprises 799 nodes, 624 quadrangles, 185 triangles and 261 segments.

3.2 Characteristics of the grid

Very small elements ($0{,}02\,mm$) to the forefront of the crack.
The first crown is located in only one material, the 4 other crowns cross the interface between two materials.







3.3 Sizes tested and results

The rate of refund of energy G is calculated by the method $THETA$ for the 5 following crowns:

- Crown 0: $R_{inf}=0{,}02\,mm$ $R_{\sup}=0{,}18\,mm$
- Crown 1: $R_{inf}=0{,}2\,mm$ $R_{\sup}=1\,mm$
- Crown 2: $R_{inf}=1\,mm$ $R_{\sup}=2\,mm$
- Crown 3: $R_{inf}=2\,mm$ $R_{\sup}=3\,mm$
- Crown 4: $R_{inf}=3\,mm$ $R_{\sup}=5\,mm$

Values tested

Identification	**Reference J ASTM**	***Aster***	**% difference**
G (N/mm) Crown n°0 UY=0,2 mm	5.8	6.0	3.1
G (N/mm) Crown n°0 UY=0,4 mm	22.6	23.2	2.8
G (N/mm) Crown n°0 UY=0,6 mm	47.2	48.2	2.0
G (N/mm) Crown n°0 UY=0,8 mm	74.7	75.0	0.5
G (N/mm) Crown n°0 UY=1,0 mm	103.7	102.8	-0.8
G (N/mm) Crown n°1 UY=0,2 mm	5.8	6.10	4.6
G (N/mm) Crown n°1 UY=0,4 mm	22.6	23.2	2.8
G (N/mm) Crown n°1 UY=0,6 mm	47.2	47.3	0.1
G (N/mm) Crown n°1 UY=0,8 mm	74.7	73.1	-2.2
G (N/mm) Crown n°1 UY=1,0 mm	103.7	99.8	-3.8
G (N/mm) Crown n°2 UY=0,2 mm	5.8	6.1	4.3
G (N/mm) Crown n°2 UY=0,4 mm	22.6	23.3	3.2
G (N/mm) Crown n°2 UY=0,6 mm	47.2	48.0	1.6
G (N/mm) Crown n°2 UY=0,8 mm	74.7	74.9	0.3
G (N/mm) Crown n°2 UY=1,0 mm	103.7	103.1	-0.3

Identification	**Reference J ASTM**	***Aster***	**% difference**
G (N/mm) Crown n°3 UY=0,2 mm	5.8	6.1	4.4
G (N/mm) Crown n°3 UY=0,4 mm	22.6	23.3	3.3
G (N/mm) Crown n°3 UY=0,6 mm	47.2	48.2	1.9
G (N/mm) Crown n°3 UY=0,8 mm	74.7	75.5	1.0
G (N/mm) Crown n°3 UY=1,0 mm	103.7	104.2	0.4
G (N/mm) Crown n°4 UY=0,2 mm	5.8	6.1	4.5
G (N/mm) Crown n°4 UY=0,4 mm	22.6	23.4	3.4
G (N/mm) Crown n°4 UY=0,6 mm	47.2	48.2	2.1
G (N/mm) Crown n°4 UY=0,8 mm	74.7	75.5	1.1
G (N/mm) Crown n°4 UY=1,0 mm	103.7	104.4	0.7

Stability of G with the choice of the crowns

Identification	**Crown 2**	**Crown 3**	**Crown 4**	**% maximum change**
G (N/mm) UY=0,2 mm	6.1	6.1	6.1	0.2

G (N/mm) UY=0,4 mm	23.3	23.3	23.4	0.1
G (N/mm) UY=0,6 mm	48.0	48.2	48.2	0.4
G (N/mm) UY=0,8 mm	74.9	75.5	75.5	0.5
G (N/mm) UY=1,0 mm	103.1	104.2	104.4	0.4

3.4 Remarks

In all the cases, the absolute value of the variation on the calculation of G is lower than 5%. For crowns 3 to 5, the variation decreases according to displacement to reach a quasi worthless value.

Stability on crowns 2.3 and 4 is very good, the difference between crowns is always lower than $0,5\ \%$.

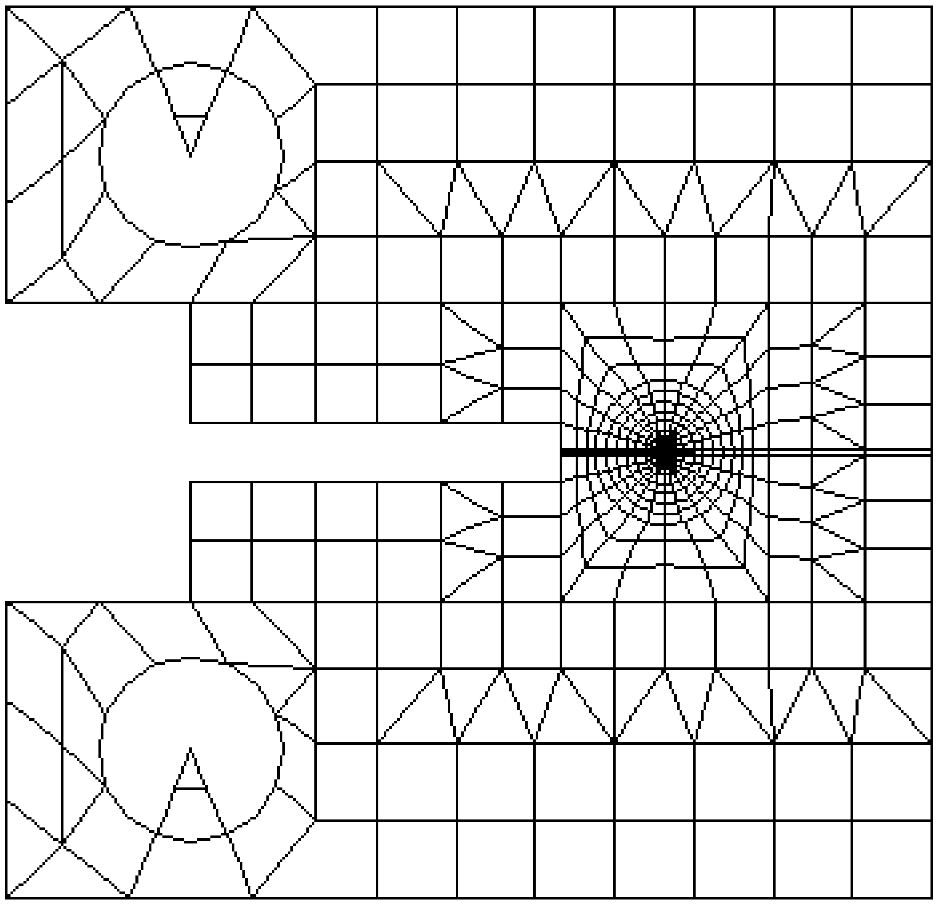
4 Modeling B

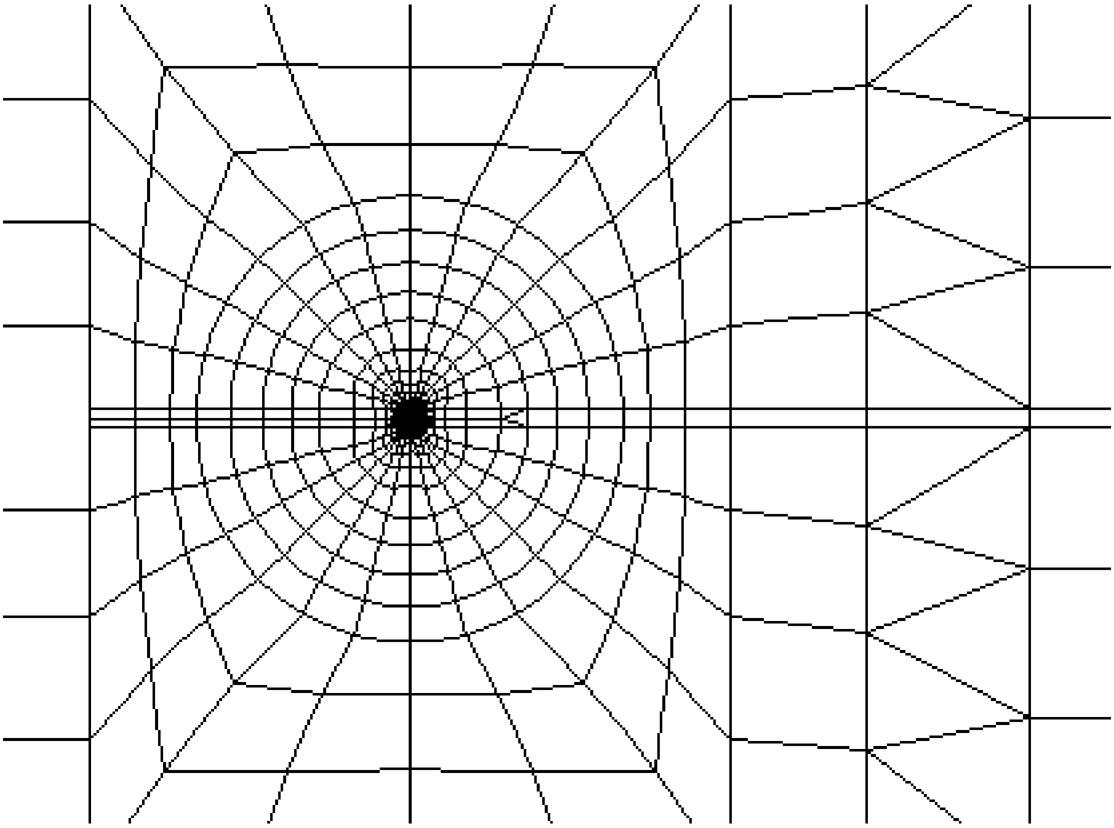
4.1 Characteristics of modeling

The totality of the test-tube is with a grid in quadrangular with 8 nodes or triangular elements with 6 nodes.

It comprises 2416 nodes, 625 quadrangles, 185 triangles and 264 segments.

4.2 Characteristics of the grid





4.3 Sizes tested and results

The rate of refund of energy G is calculated by the method $THETA$ for the 5 following crowns:

- Crown 0: $R_{inf}=0{,}02\,mm$ $R_{\sup}=0{,}18\,mm$
- Crown 1: $R_{inf}=0{,}2\,mm$ $R_{\sup}=1\,mm$
- Crown 2: $R_{inf}=1\,mm$ $R_{\sup}=2\,mm$
- Crown 3: $R_{inf}=2\,mm$ $R_{\sup}=3\,mm$
- Crown 4: $R_{inf}=3\,mm$ $R_{\sup}=5\,mm$

Identification	Reference J_{ASTM}	*Aster*	% difference
G (N/mm) Crown n°0 UY=0,2 mm	5.8	6.2	6.9
G (N/mm) Crown n°0 UY=0,4 mm	22.6	23.1	2.1
G (N/mm) Crown n°0 UY=0,6 mm	47.2	47.2	~0.2
G (N/mm) Crown n°0 UY=0,8 mm	74.7	72.8	~2.5
G (N/mm) Crown n°0 UY=1,0 mm	103.7	98.2	~4.3
G (N/mm) Crown n°1 UY=0,2 mm	5.8	5.3	~8.7
G (N/mm) Crown n°1 UY=0,4 mm	22.6	20.7	~8.3
G (N/mm) Crown n°1 UY=0,6 mm	47.2	43.8	~7.3
G (N/mm) Crown n°1 UY=0,8 mm	74.7	68.6	~8.2
G (N/mm) Crown n°1 UY=1,0 mm	103.7	94.2	~9.2

G (N/mm) Crown n°2 UY=0,2 mm	5.8	5.4	~7.4
G (N/mm) Crown n°2 UY=0,4 mm	22.6	21.1	~6.8
G (N/mm) Crown n°2 UY=0,6 mm	47.2	44.2	~6.4
G (N/mm) Crown n°2 UY=0,8 mm	74.7	69.1	~7.5
G (N/mm) Crown n°2 UY=1,0 mm	103.7	94.7	~8.8

Identification	**Reference J ASTM**	***Aster***	**% difference**
G (N/mm) Crown n°3 UY=0,2 mm	5.8	5.3	~9.5
G (N/mm) Crown n°3 UY=0,4 mm	22.6	20.2	~10.6
G (N/mm) Crown n°3 UY=0,6 mm	47.2	42.6	~9.8
G (N/mm) Crown n°3 UY=0,8 mm	74.7	67.2	~10.1
G (N/mm) Crown n°3 UY=1,0 mm	103.7	92.6	~10.7
G (N/mm) Crown n°4 UY=0,2 mm	5.8	5.4	~7.9
G (N/mm) Crown n°4 UY=0,4 mm	22.6	20.8	~8.0
G (N/mm) Crown n°4 UY=0,6 mm	47.2	43.7	~7.5
G (N/mm) Crown n°4 UY=0,8 mm	74.7	68.4	~8.4
G (N/mm) Crown n°4 UY=1,0 mm	103.7	93.8	~9.5

Stability of G with the choice of the crowns

Identification	**Crown 2**	**Crown 3**	**Crown 4**	**% maximum change**
G (N/mm) UY=0,2 mm	5.4	5.3	5.4	2.2
G (N/mm) UY=0,4 mm	21.1	20.2	20.8	4.2
G (N/mm) UY=0,6 mm	44.2	42.6	43.7	3.7
G (N/mm) UY=0,8 mm	69.1	67.2	68.4	2.8
G (N/mm) UY=1,0 mm	94.7	92.6	93.8	2.1

4.4 Remarks

The value of G model Aster is lower than that of the reference.

The variation is of approximately 10% for the whole of the crowns. Stability between the crowns is satisfactory.

5 Summary of the results

It is pointed out that reference solution is not an exact solution and that it does not apply, in general, in the case of bi--materials. In addition, calculations are carried out in nonlinear elasticity on a crack; in any rigour, it would be advisable to do the calculations in elastoplasticity on a notch.

Modeling A (degree 1) gives results in conformity with those of the reference.

Modeling B (degree 2) revealed a variation of approximately 8% on the value of G.

One can notice that the crowns far away from the crack provide results more precise and more stable than those close to the bottom of crack.