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

Abstract:

This test is resulting from the validation independent of version 3 in fracture mechanics.

It is about a two-dimensional test in static (plane strains) which relates to the computation of a crack parallel with the interface between two materials, for a nontrivial geometry in limited field.

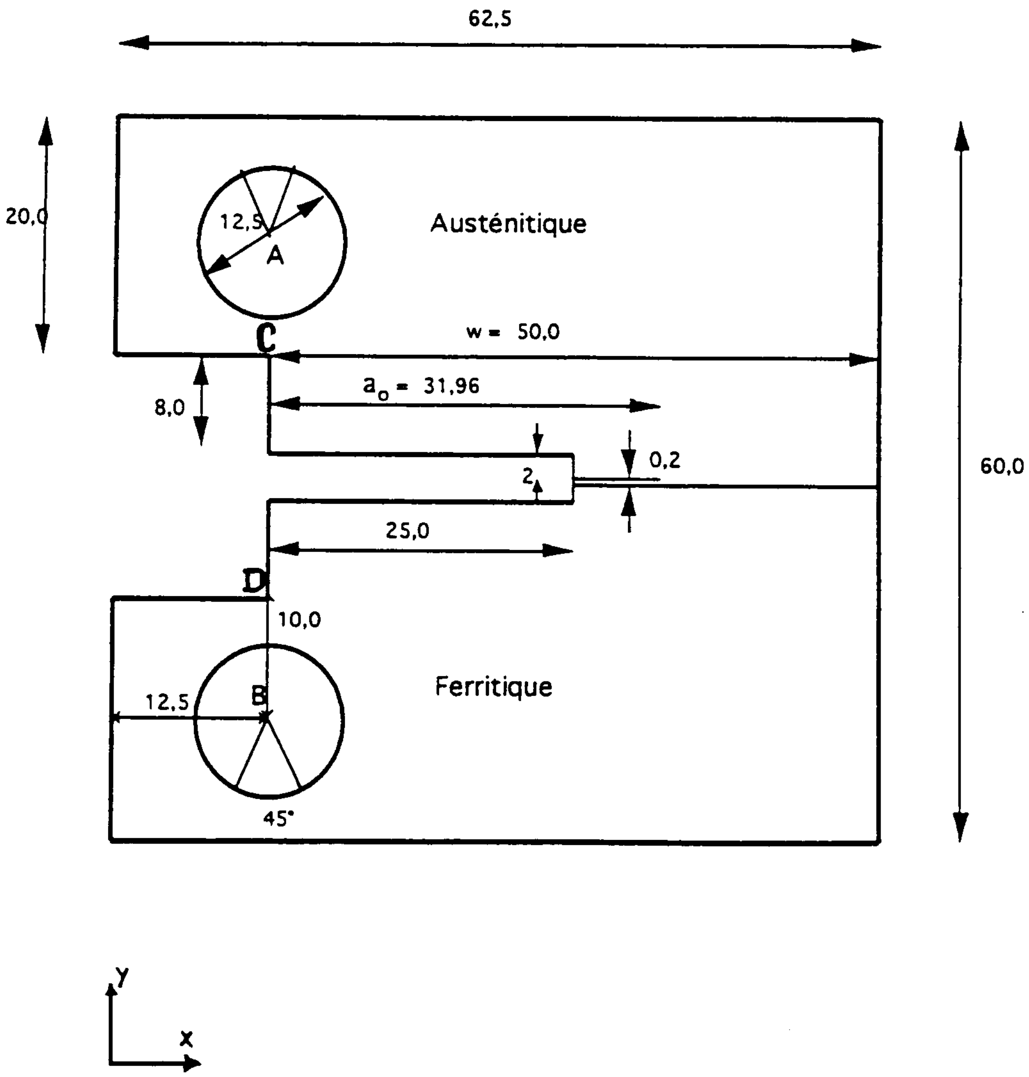
The structure has an elastoplastic behavior of Von Mises with isotropic hardening. Computations are carried out in nonlinear elasticity.

The purpose of this case test is the study of the sensitivity of G to the choice of contours.

It understands two plane $2D$ modelizations in which one studies the influence of an imposed incremental displacement. The first modelization 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 the materials

Material n° 1: elastoplastic austenitic steel

of type von Mises to isotropic hardening
Poisson's ratio, Young $E_1=2.10^5\,MPa$ Modulus $\nu_1=0{,}3$
Yield stress $\sigma_{y1}=310\,MPa$
uniaxial Curve of tension:

$\sigma(MPa)$	0.310.600			700
ε	0	0,155	40.100	

Material n° 2: elastoplastic ferritic

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

$\sigma(MPa)$	0.442.600			650
ε	0	0,221	40.100	

Material n° 3: quasi indeformable pins

linear Elastic isotropic
Poisson's ratio Boundary conditions, $E_3=6.10^{10}\,MPa$ Young Modulus $\nu_3=0{,}3$

1.3 and loading

being given the dissymmetry of the 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:

$0\le UY\le 1\,mm$ 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 works 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 area 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 computation 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 crack calculated by finite elements.

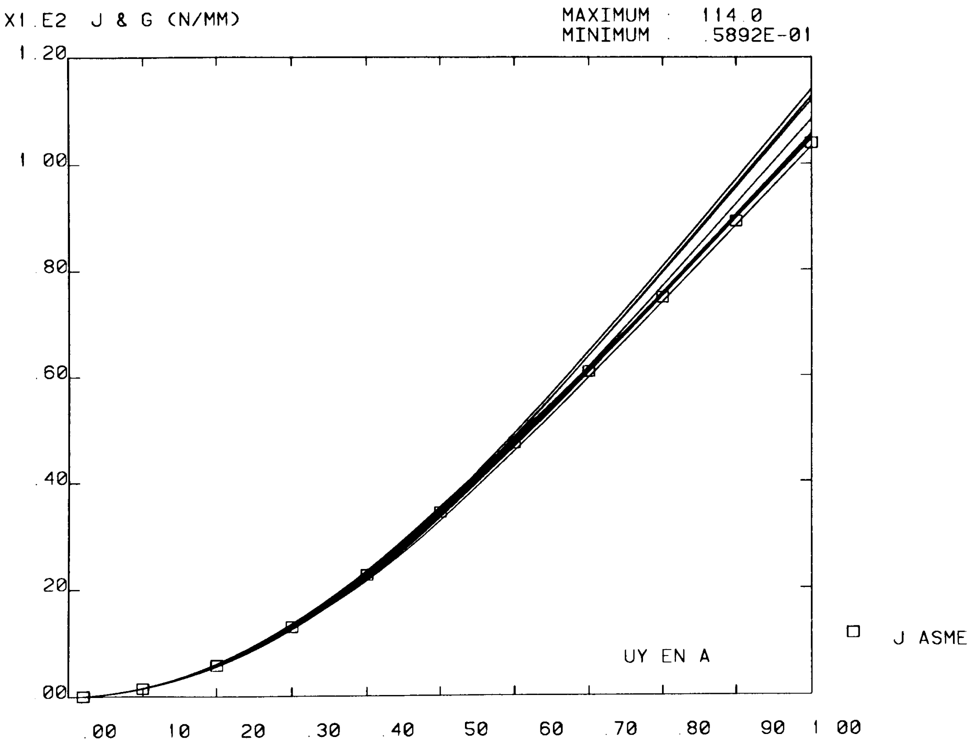


Fig.11 G et J_{ASTM} en fonction du déplacement imposé et suivant les 13 couronnes du vecteur θ

Rate of refund of energy G according to displacement in A

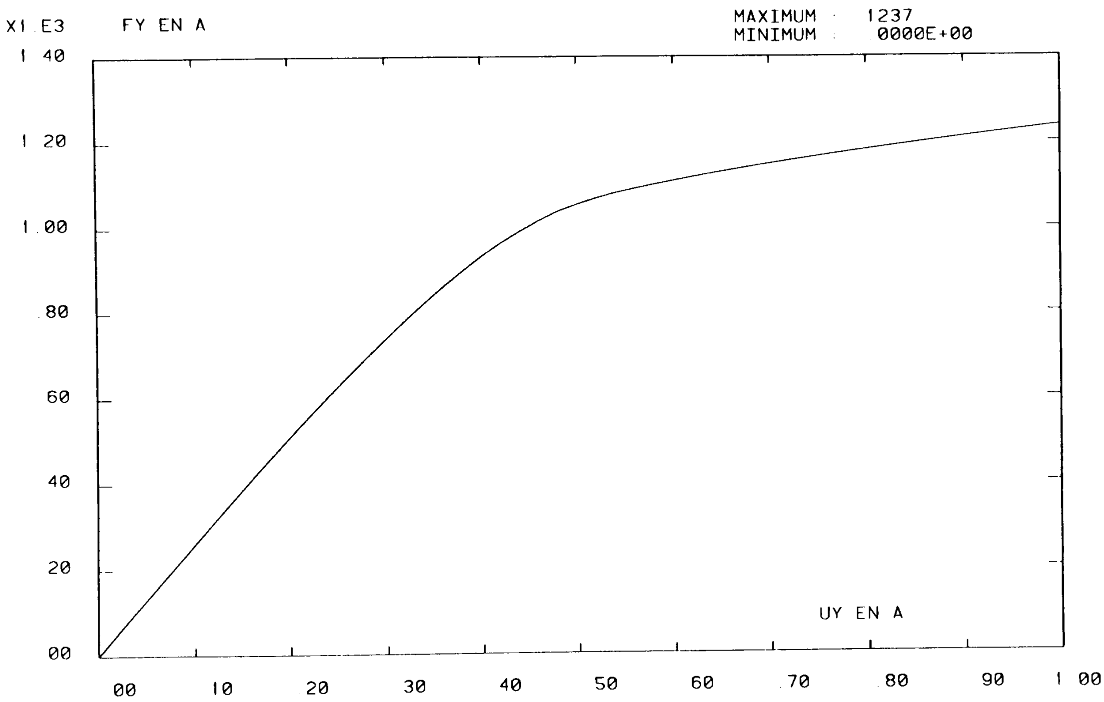


Fig.7 Fy au point A en fonction de Uy au point A

response Curve force-displacement to the point A

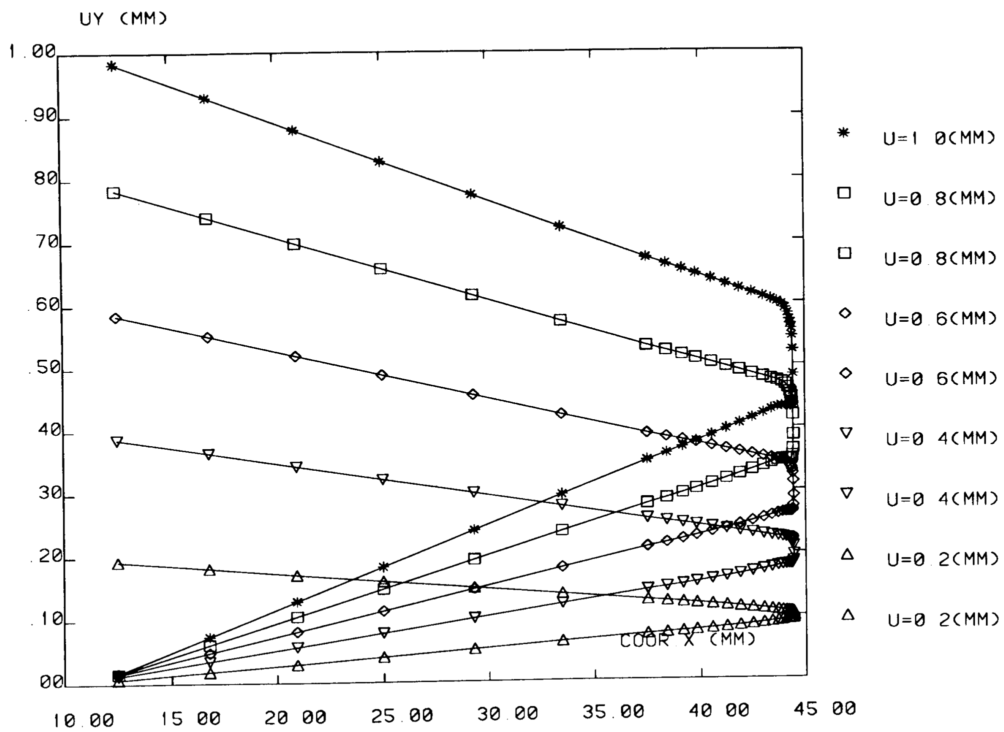


Fig.10 Déplacements des deux lèvres de la fissure au cours du chargement

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 the two materials

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

The computation Castem 2000 was carried out on the same mesh as the modelization 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 computation of a bimetallic test-tube CT with a crack close to the interface. Report French atomic energy agency DMT/94-132

3 Modelization A

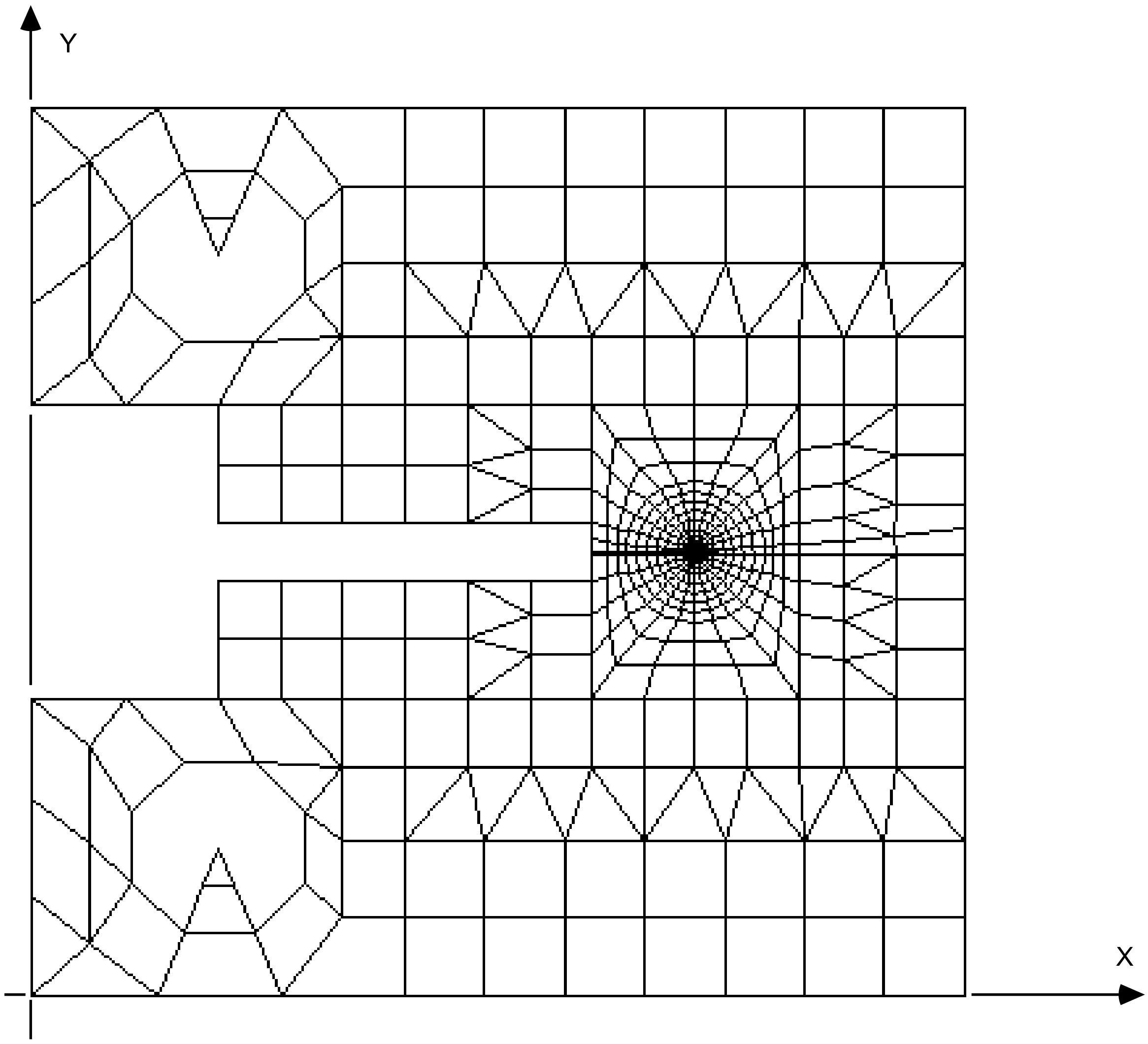
3.1 Characteristic of the modelization

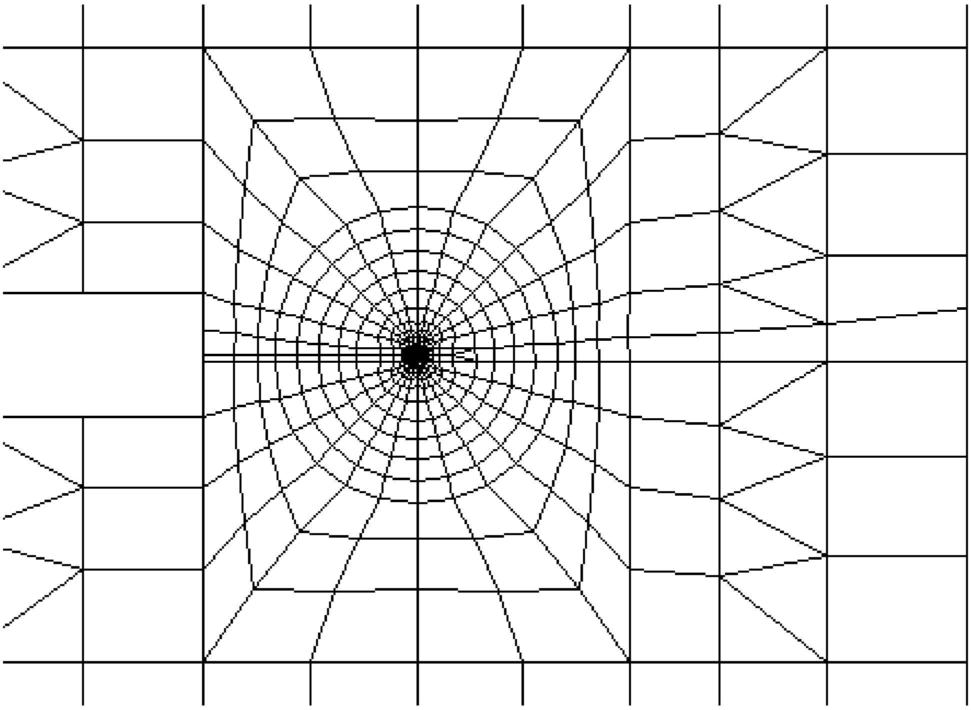
the totality of the test-tube is with a grid in quadrangular with 4 nodes or triangular elements with 3 nodes.

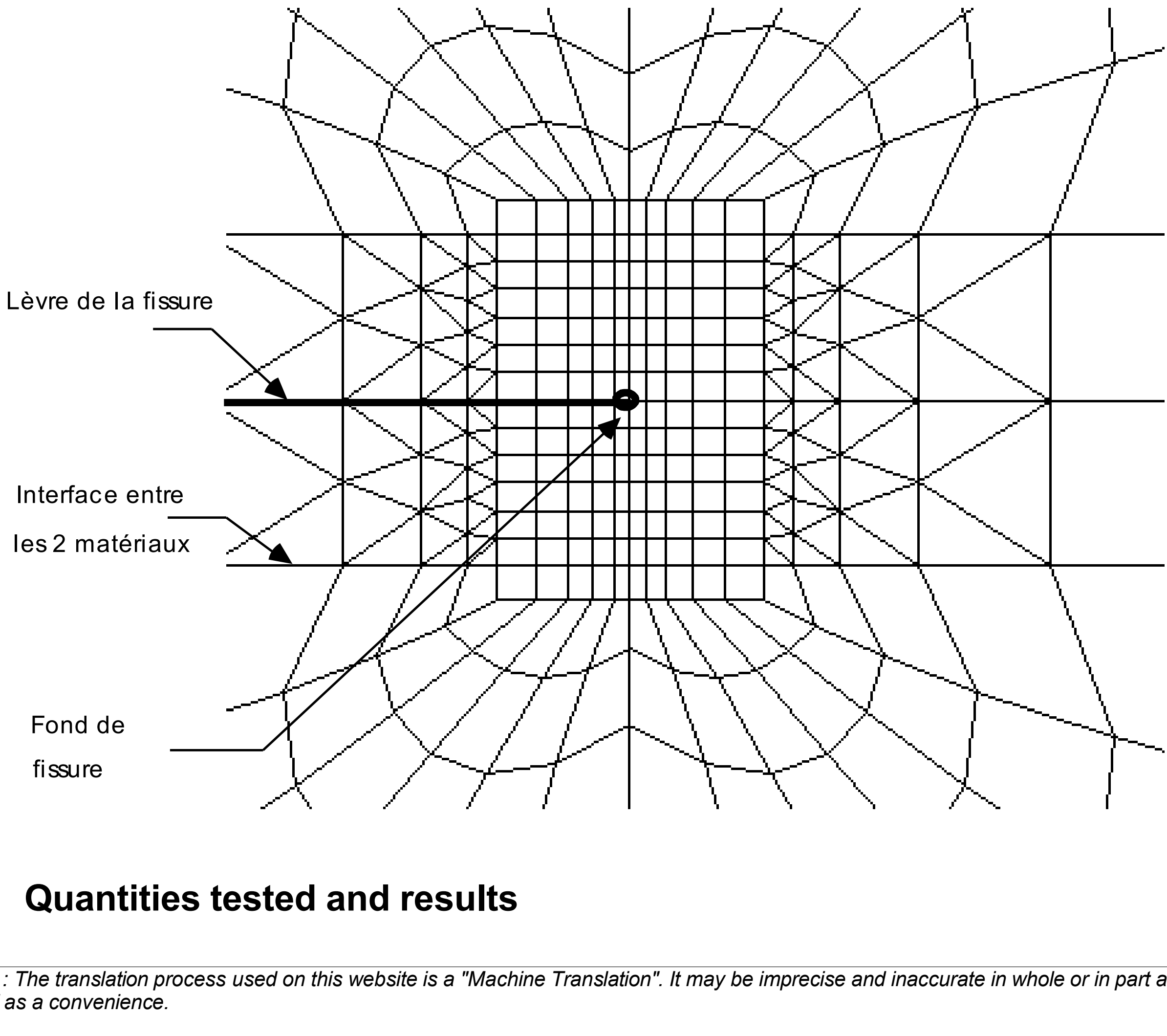
It comprises 799 nodes, 624 quadrangles, 185 triangles and 261 segments.

3.2 Characteristics of the mesh

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







3.3 Quantities tested and results

rate of energy restitution G is calculated by the method $THETA$ for 5 following contours:

- 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) Contour n°0 UY=0,2 mm	5,8.6,0.3,1		
G (N/mm) Contour n°0 UY=0,4 mm	22,6	23,2	2,8
G (N/mm) Contour n°0 UY=0,6 mm	47,2	48,2	2,0
G (N/mm) Contour n°0 UY=0,8 mm	74,7	75,0	0,5
G (N/mm) Contour n°0 UY=1,0 mm	103,7	102,8	-0,8
G (N/mm) Contour n°1 UY=0,2 mm	5,8	6,10	4,6
G (N/mm) Contour n°1 UY=0,4 mm	22,6	23,2	2,8
G (N/mm) Contour n°1 UY=0,6 mm	47,2	47,3	0,1
G (N/mm) Contour n°1 UY=0,8 mm	74,7	73,1	~2,2
G (N/mm) Contour n°1 UY=1,0 mm	103,7	99,8	~3,8
G (N/mm) Contour n°2 UY=0,2 mm	5,8.6,1.4,3		
G (N/mm) Contour n°2 UY=0,4 mm	22,6	23,3	3,2
G (N/mm) Contour n°2 UY=0,6 mm	47,2	48,0	1,6
G (N/mm) Contour n°2 UY=0,8 mm	74,7	74,9	0,3
G (N/mm) Contour n°2 UY=1,0 mm	103,7	103,1	~0,3

Identification	**Reference J ASTM**	***Aster***	**% difference**
G (N/mm) Contour n°3 UY=0,2 mm	5,8.6,1.4,4		
G (N/mm) Contour n°3 UY=0,4 mm	22,6	23,3	3,3
G (N/mm) Contour n°3 UY=0,6 mm	47,2	48,2	1,9
G (N/mm) Contour n°3 UY=0,8 mm	74,7	75,5	1,0
G (N/mm) Contour n°3 UY=1,0 mm	103,7	104,2	0,4
G (N/mm) Contour n°4 UY=0,2 mm	5,8.6,1.4,5		
G (N/mm) Contour n°4 UY=0,4 mm	22,6	23,4	3,4
G (N/mm) Contour n°4 UY=0,6 mm	47,2	48,2	2,1
G (N/mm) Contour n°4 UY=0,8 mm	74,7	75,5	1,1
G (N/mm) Contour n°4 UY=1,0 mm	103,7	104,4	0,7

Stability of G with the choice of contours

Identification	**Crowns 2**	**Contour 3**	**G Crowns**	**% 4 maximum change**
(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 computation of G is lower than 5%. For contours 3 to 5, the variation decreases according to displacement to reach a value quasi null.

Stability on contours 2,3 and 4 is very good, the difference between contours is always lower than $0,5\ \%$.

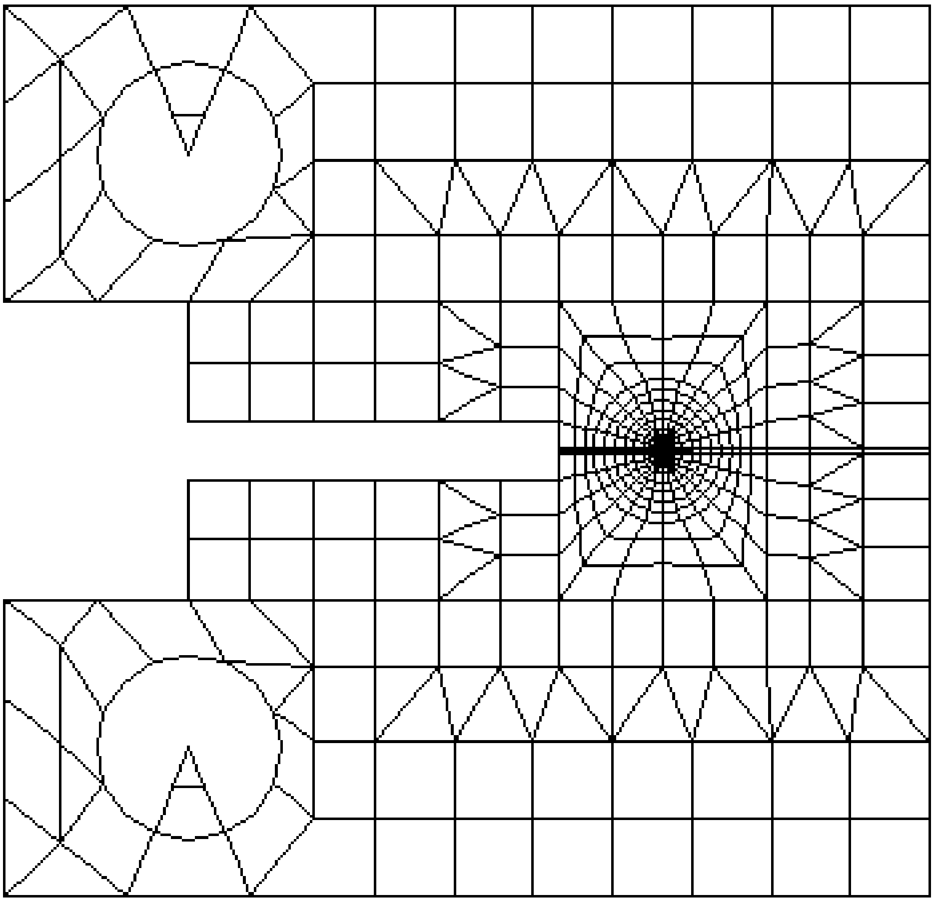
4 Modelization B

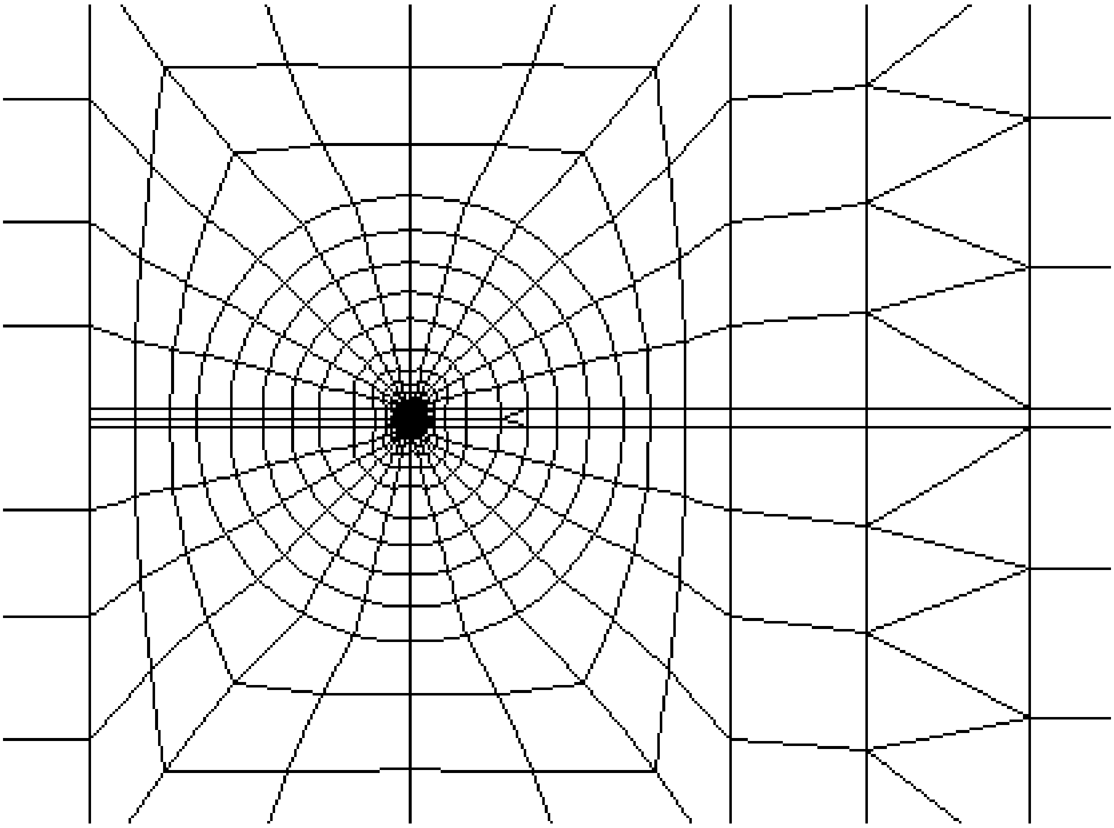
4.1 Characteristic of the modelization

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 mesh





4.3 Quantities tested and results

rate of energy restitution G is calculated by the method $THETA$ for 5 following contours:

- 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) Contour n°0 UY=0,2 mm	5,8.6,2.6,9		
G (N/mm) Contour n°0 UY=0,4 mm	22,6	23,1	2,1
G (N/mm) Contour n°0 UY=0,6 mm	47,2	47,2	~0,2
G (N/mm) Contour n°0 UY=0,8 mm	74,7	72,8	~2,5
G (N/mm) Contour n°0 UY=1,0 mm	103,7	98,2	~4,3
G (N/mm) Contour n°1 UY=0,2 mm	5,8.5,3		~8,7
G (N/mm) Contour n°1 UY=0,4 mm	22,6	20,7	~8,3
G (N/mm) Contour n°1 UY=0,6 mm	47,2	43,8	~7,3
G (N/mm) Contour n°1 UY=0,8 mm	74,7	68,6	~8,2
G (N/mm) Contour n°1 UY=1,0 mm	103,7	94,2	~9,2

G (N/mm) Contour n°2 UY=0,2 mm	5,8.5,4		˜ 7,4
G (N/mm) Contour n°2 UY=0,4 mm	22,6	21,1	˜ 6,8
G (N/mm) Contour n°2 UY=0,6 mm	47,2	44,2	˜ 6,4
G (N/mm) Contour n°2 UY=0,8 mm	74,7	69,1	˜ 7,5
G (N/mm) Contour n°2 UY=1,0 mm	103,7	94,7	˜ 8,8

Identification	Reference J ASTM	*Aster*	% difference
G (N/mm) Contour n°3 UY=0,2 mm	5,8.5,3		˜ 9,5
G (N/mm) Contour n°3 UY=0,4 mm	22,6	20,2	˜ 10,6
G (N/mm) Contour n°3 UY=0,6 mm	47,2	42,6	˜ 9,8
G (N/mm) Contour n°3 UY=0,8 mm	74,7	67,2	˜ 10,1
G (N/mm) Contour n°3 UY=1,0 mm	103,7	92,6	˜ 10,7
G (N/mm) Contour n°4 UY=0,2 mm	5,8.5,4		˜ 7,9
G (N/mm) Contour n°4 UY=0,4 mm	22,6	20,8	˜ 8,0
G (N/mm) Contour n°4 UY=0,6 mm	47,2	43,7	˜ 7,5
G (N/mm) Contour n°4 UY=0,8 mm	74,7	68,4	˜ 8,4
G (N/mm) Contour n°4 UY=1,0 mm	103,7	93,8	˜ 9,5

Stability of G with the choice of contours

Identification	Crowns 2	Contour 3	Crowns 4	% G maximum change
(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 all contours. Stability between contours is satisfactory.

5 Summary of the results

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

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

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

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