SSNP118 - Validation of the elements of joint and interface in 2D plane and 3D

Summarized:

Validation of the elements of joint and interface. Comparison between the results and the analytical solution.

Joint : $2D$ plane (mesh QUAD4) and $3D$ (mesh HEXA8 or PENTA6) with the cohesive constitutive laws: CZM_LIN_REG and CZM_EXP_REG and a control by elastic prediction PRED_ELAS.

Interface : $2D$ plane (mesh QUAD8) and $3D$ (mesh HEXA20 or PENTA15) with the cohesive constitutive laws: CZM_OUV_MIX, CZM_TAC_MIX, CZM_FAT_MIX and CZM_TRA_MIX as well as control by elastic prediction PRED_ELAS for the two first.

Formulation XFEM : $2D$ plane with the cohesive constitutive law: CZM_TAC_MIX,

Modelization A : PLAN_JOINT with CZM_EXP_REG
Modelization B : 3D_JOINT nets HEXA8 with CZM_EXP_REG
Modelization C : 3D_JOINT nets PENTA6 with CZM_EXP_REG

Modelization D : PLAN_JOINT with CZM_LIN_REG
Modelization E : 3D_JOINT nets HEXA8 with CZM_LIN_REG
Modelization F : 3D_JOINT nets PENTA6 with CZM_LIN_REG

Modelization G : PLAN_INTERFACE_S with CZM_OUV_MIX and CZM_TAC_MIX
Modelization H : 3D_INTERFACE_S, mesh HEXA20 with CZM_OUV_MIX and CZM_TAC_MIX
Modelization I : 3D_INTERFACE_S, mesh PENTA15 with CZM_OUV_MIX and CZM_TAC_MIX

Modelization J : PLAN_INTERFACE_S with CZM_FAT_MIX
Modelization K : 3D_INTERFACE_S, mesh HEXA20 with CZM_FAT_MIX
Modelization L : 3D_INTERFACE_S, mesh PENTA15 with CZM_FAT_MIX

Modelization M : PLAN_INTERFACE_S with CZM_TRA_MIX
Modelization N : 3D_INTERFACE_S, mesh HEXA20 with CZM_TRA_MIX
Modelization O : 3D_INTERFACE_S, mesh PENTA15 with CZM_TRA_MIX

Modelization P : formulation XFEM , mesh QUAD8 with CZM_TAC_MIX

1 Problem of reference

1.1 Geometry

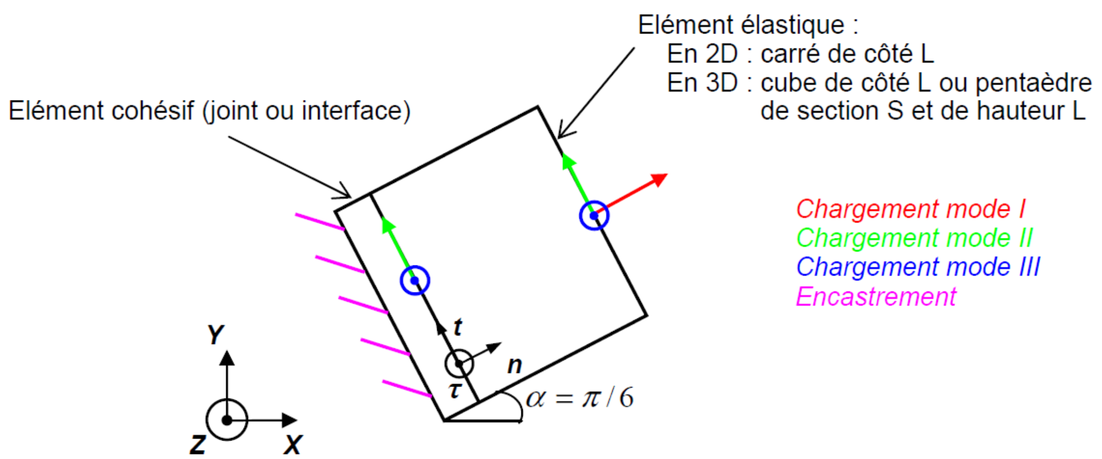

Figure 1 : Representation of the system of two elements in the plane (X, Y) . One chooses $L=1\,mm$.

1.1.1 Geometry: case X-FEM

In the modelizations in formulation `XFEM`, it has there no more in the model of cohesive element of joint or interface, but the cohesive model is defined on the interface using command `DEFI_CONTACT`, as one would do it for a model of contact. Consequently, the square is with a grid with some elements and line of discontinuity is introduced in the middle of the square, in a way nonin conformity: it cuts elements here elastic.

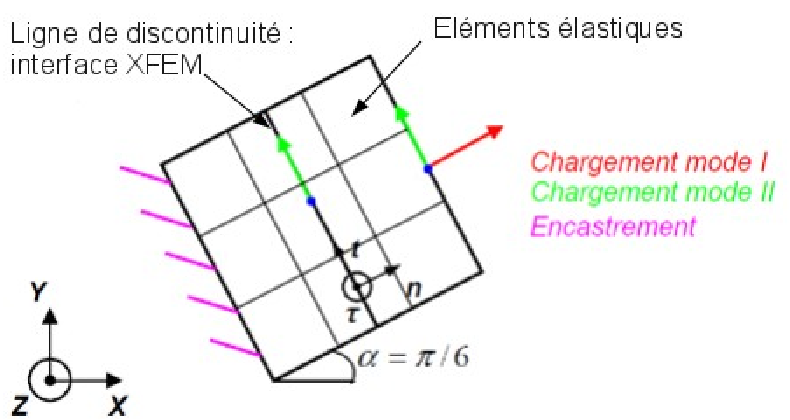

Figure 2 : Modelization X-FEM in the plane (X, Y) . One chooses $L=1\,mm$.

1.2 Properties of the material

1.2.1 cohesive Models

1.2.1.1 Cubic Material

RUPT_FRAG *:* elastic
Modulus Young: $E=0.5\,MPa$ (except for the modelizations J, K and L where one takes $E=100\,MPa$, this choice is purely practical)
Poisson's ratio $\nu=0$

Element of joint : models CZM_EXP_REG, CZM_LIN_REG
Element of interface : models CZM_OUV_MIX, CZM_TAC_MIX, CZM_FAT_MIX

Density of critical energy of surface:	$G_c=0.9\,N/mm$	(key word: GC)
forced critical:	$\sigma_c=1.1\,MPa$	(key word: SIGM_C)

Element of joint:

penalization of the dependancy	PENA_ADHERENCE = $10^{-3}\,mm$	(key word: PENA_ADHERENCE)
(small parameter of regularization of energy in 0, to see [R7.02.11])		
penalization of the contact	PENA_CONTACT = 1 (default value)	(key word: PENA_CONTACT)

Element of interface:

Penalization of Lagrangian	PENA_LAGR= 100 (value by default)	(key word: PENA_LAGR)
Stiffness of sliding	RIGI_GLIS= 10 (default value)	(key word: RIGI_GLIS)

NB: The data materials do not have of course authority to represent a material in particular. They are only intended for numerical tests of validation.

1.2.1.2 Cubic material

RUPT_DUCT *:* elastic
Modulus Young: $E=10^6\,MPa$ (this choice is purely practical)
Poisson's ratio $\nu=0$

Element of interface : model CZM_TRA_MIX

Density of critical energy of surface:	$G_c=0.9\,N/mm$	(key word: GC)
forced critical:	$\sigma_c=9\,MPa$	(key word: SIGM_C)
extrinsic Coefficient of form	0.0625	(key word: COEF_EXTR)
Coefficient of plastic form plate	0.3125	(key word: COEF_PLAS)
Penalization of Lagrangian	PENA_LAGR= 100 (default value)	(key word: PENA_LAGR)
Stiffness of sliding	RIGI_GLIS= 10 (default value)	(key word: RIGI_GLIS)

NB: The data materials do not have of course authority to represent a material in particular. They are only intended for numerical tests of validation.

1.3 Boundary conditions and loadings

Fixed support : Imposed displacements are null on the face of the cohesive element opposed to the elastic element.

In mode I : An imposed displacement $\boldsymbol{U}$ is applied to the face of the elastic element opposed to the joint (see figure 1).

DX = 2.16506351 DY = 1.250 DZ = 0

In mode II : Imposed displacement $\boldsymbol{U}$ is applied on all the nodes of the voluminal element.

DX = -1.250 DY = 2.16506350946110 DZ = 0

In mode III : Imposed displacement $\boldsymbol{U}$ is applied on all the nodes of the voluminal element.

DX = 0.0 DY = 0.0 DZ = 2.5

For models CZM_OUV_MIX, CZM_TAC_MIX, one uses the same standardized vectors with 1.

For fatigue model CZM_FAT_MIX (in mode I only) one uses the same vectors standardized with $0{,}094$. This value corresponds to the amplitude of the loading because this one is multiplied by a cyclic function, null into zero, which is worth 1 to odd times and 0 at even times.

For ductile model CZM_TRA_MIX (in mode I only) one uses the same standardized vectors with 1. One applies a cyclic loading to test all the states of the model but also a monotonic loading. One carries out the tests with the first loading.

1.3.1 Loading: case X-FEM

Fixed support : Imposed displacements are null on the left face of the square.

In mode I : An imposed displacement $\boldsymbol{U}$ is applied to the straight lines face of the square (see figure 2).

DX = 2.16506351 DY = 1.250 DZ = 0

2 Reference solution

2.1 general Case

In this part, one detail the analytical solution in pure I mode in its form $3D$. For computations $2D$ plane, the solution is identical, the component of the jump and the following vector forced τ do not intervene, and it is enough to replace surface S by the length L in the solution.
For the loadings in mode of shears, the elastic element does not play a part. One carries out only one test on the tangential constitutive law. For the cohesive models one imposes a jump of displacement and one checks the cohesive stress obtained.

2.2 In pure I mode

One presents the analytical solution of the total response of the system written in the local coordinate system $(\boldsymbol{n}, \boldsymbol{t}, \boldsymbol{\tau})$. One applies a loading colinéaire to the norm: $\boldsymbol{U}=U\,\boldsymbol{n}$, the cohesive element opens in pure I mode shear stresses and as well as the tangential jumps remain null. One thus brings back oneself to a scalar problem. One notes $\sigma=\boldsymbol{n}.\boldsymbol{\sigma}.\boldsymbol{n}$ the single non-zero component of the tensor of the stress of the elastic element in the local coordinate system. One presents the solution of the total response for the cohesive models:

- **CZM_EXP_REG**

the cohesive behavior model is given by (see Doc. [R7.02.11]):

$$\vec{\sigma}=\begin{pmatrix}\sigma_n\\ \sigma_t\\ \sigma_\tau\end{pmatrix}=\begin{pmatrix}\sigma_c \cdot e^{-\frac{\sigma_c}{G_c}\cdot\delta_n}\\ 0\\ 0\end{pmatrix}$$

with δ_n the jump of normal displacement. The elastic model of the voluminal element gives:

$$\sigma=E\,\varepsilon=F/S$$

where ε is the elastic strain and where F is the force corresponding to the displacement imposed on surface S. In the case of figure where the stress threshold in the cohesive element is not reached, the solution is elastic, the total response is linear, it is expressed in the following way:

$$U(F)=\frac{FL}{SE}$$

When the threshold of fracture is reached, the jump in the cohesive element is not null any more, the response is not linear any more. The equilibrium of the system is given by:

$$\sigma=\sigma_n$$

Moreover, in this simple case of loading, imposed displacement is equal to the sum of the jump of displacement and displacement related to the strain ε of the elastic element:

$$U=\delta_n+L\,\varepsilon$$

One from of deduced the relation between the force and imposed displacement:

$$U(F)=-\frac{G_c}{\sigma_c}\log\left(\frac{F}{S\sigma_c}\right)+\frac{FL}{SE}$$

Note: according to the material characteristics one can not have a back return of the total response which one collects with the control of the loading.

- **CZM_LIN_REG, CZM_OUV_MIX, CZM_TAC_MIX, CZM_FAT_MIX**

the cohesive behavior model is given by:

$$\vec{\sigma}=\begin{pmatrix}\sigma_n\\ \sigma_t\\ \sigma_\tau\end{pmatrix}=\begin{pmatrix}\sigma_c\left(1-\delta_n\frac{\sigma_c}{2G_c}\right)\\ 0\\ 0\end{pmatrix}$$

The same reasoning is adopted as with the exponential model, the analytical solution of the total response is expressed in the following way:

$$\boxed{U(F)=\frac{F}{S}\left(\frac{L}{E}-\frac{2G_c}{\sigma_c^2}\right)+2\frac{G_c}{\sigma_c}}$$

Note: for model CZM_FAT_MIX the preceding total response is valid only if chargemement is monotonous. In the pluspart of the cases this one is cyclic since this model is intended for fatigue. One proposes to refer to documentation [R7.02.11] cohesive models for more information.

2.3 In mode II and III pure

One tests only the constitutive law (see Doc. [R7.02.11] and [R7.02.13]):

- **CZM_EXP_REG**

$\boxed{\sigma_T=\sigma_c.e^{-\frac{\sigma_c}{G_c}.\delta_T}}$ T indicating respectively t in mode II and τ mode III

- **CZM_LIN_REG, CZM_OUV_MIX, CZM_TAC_MIX**

$\boxed{\sigma_T=\sigma_c\left(1-\delta_T\frac{\sigma_c}{2G_c}\right)}$, T indicating respectively t in mode II and τ Modelization III

3 mode A

Validation of the joint $2D$ with cohesive model CZM_EXP_REG

3.1 Characteristics of the modelization

Modelization in plane strains D_PLAN for the elastic element.
Modelization plane for the element of joint (key word PLAN_JOINT).

3.2 Characteristics of the mesh

Many nodes: 6
the elastic element is a QUAD4.
The element of joint is a QUAD4 degenerated (confused nodes).

3.3 Results of the modelization A

the control of the loading is tested in mode I. Indeed, one places figure in the case of where the total response has a back return (see internal note H-T64-2007-03420-FR for more details on this point).

Quantity I

mode tested	Reference	Tolerance ($\%$)
DX on Node 2	2.16506D-08	0.10
SIXX	4.49911D-02	0.10
SIGN	1.56379D-01	0.10
SITX	0.D+00	0.10

Quantity II

Mode tested	Reference	Tolerance ($\%$)
SIGN	0.D+00	0.10
SITX	1.56379D-01	0.10

4 Modelization B

Validation of joint 3D HEXA8 with cohesive model CZM_EXP_REG

4.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_JOINT for the element of joint

4.2 Characteristics of the mesh

Many nodes: 12
the elastic element is a HEXA8.
The element of joint is a degenerated HEXA8 (confused nodes).

4.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.

Quantity I

mode tested	Reference	Tolerance (%)
DX on Node 2	2.16506D-08	0.10
SIXX	4.49911D-02	0.10
SIGN	1.56379D-01	0.10
SITX	0.D+00	0.10
SITY	0.D+00	

Quantity II

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	1.56379D-01	0.10
SITY	0.D+00	0.10

Quantity III

Mode tested	Reference	Tolerance (%)
SIG N	0.D+00	0.10
SITX	0.D+00	0.10
SITY	1.56379D-01	0.10

5 Modelization C

Validation of joint 3D PENTA6 with cohesive model CZM_EXP_REG

5.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_JOINT for the element of joint

5.2 Characteristics of the mesh

Many nodes: 9
the elastic element is a PENTA6.
The element of joint is a degenerated PENTA6 (confused nodes).

5.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.

Quantity I

mode tested	Reference	Tolerance (%)
DX on Node 2	2.16506D-08	0.10
SIXX	4.49911D-02	0.10
SIGN	1.56379D-01	0.10
SITX	0.D+00	0.10
SITY	0.D+00	0.10

Quantity II

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	1.56379D-01	0.10
SITY	0.D+00	0.10

Quantity III

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	0.D+00	0.10
SITY	1.56379D-01	0.10

6 Modelization D

Validation of the joint 2D with cohesive model CZM_LIN_REG

6.1 Characteristics of the modelization

Modelization in plane strains D_PLAN for the elastic element.
Modelization plane for the element of joint (key word PLAN_JOINT).

6.2 Characteristics of the mesh

Many nodes: 6
the elastic element is a QUAD4.
The element of joint is a QUAD4 degenerated (confused nodes).

6.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.

Quantity I

mode tested	Reference	Tolerance (%)
DX on Node 2	2.16506D-08	0.10
SIXX	9.27629539D-02	0.10
SIGN	5.4887555D-01	0.10
SITX	0.D+00	0.10

Quantity II

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	4.3314872D-01	0.10

7 Modelization E

Validation of joint 3D HEXA8 with cohesive model CZM_LIN_REG

7.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_JOINT for the element of joint

7.2 Characteristics of the mesh

Many nodes: 12
the elastic element is a HEXA8.
The element of joint is a degenerated HEXA8 (confused nodes).

7.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.

Quantity I

mode tested	Reference	Tolerance (%)
DX on Node 2	2.16506D-08	0.10
SIXX	9.27629539D-02	0.10
SIGN	5.4887555D-01	0.10
SITX	0.D+00	0.10
SITY	0.D+00	0.10

Quantity II

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	4.3314616D-01	0.10
SITY	0.D+00	0.10

Quantity III

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	0.D+00	0.10
SITY	2.931186D-01	0.10

8 Modelization F

Validation of joint 3D PENTA6 with cohesive model CZM_LIN_REG

8.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_JOINT for the element of joint

8.2 Characteristics of the mesh

Many nodes: 9
the elastic element is a PENTA6.
The element of joint is a degenerated PENTA6 (confused nodes).

8.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.

Quantity I

mode tested	Reference	Tolerance (%)
DX on Node 2	2.16506D-08	0.10
SIXX	9.27629539D-02	0.10
SIGN	5.4887555D-01	0.10
SITX	0.D+00	0.10
SITY	0.D+00	0.10

Quantity II

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	4.3314616D-01	0.10
SITY	0.D+00	0.10

Quantity III

Mode tested	Reference	Tolerance (%)
SIGN	0.D+00	0.10
SITX	0.D+00	0.10
SITY	2.931186D-01	0.10

9 Modelization G

Validation of the element of interface HEXA8 with cohesive models CZM_OUV_MIX and CZM_TAC_MIX in mode of opening.

9.1 Characteristics of the modelization

Modelization D_PLAN for the elastic element.
Modelization PLAN_INTERFACE_S for the element of interface

9.2 Characteristics of the mesh

Many nodes: 12
the elastic element is a HEXA8.
The element of interface is a degenerated HEXA8 (confused nodes).

9.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.
The results are identical in mode I for the two models, we present only those obtained with CZM_OUV_MIX :

Quantity I

mode tested	Reference	Tolerance (%)
DX on Node 2	2.16506D-08	0.10
SIXX	7.37899D-01	0.10
SIGN	3.47849D-01	0.10
SITX	0.D+00	0.10
V1	2.6729D-01	0.10
V4	7.00003D-01	0.10

10 Modelization H

Validation of the element of interface HEXA20 with cohesive models CZM_OUV_MIX and CZM_TAC_MIX in mode of opening.

10.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_INTERFACE_S for the element of interface

10.2 Characteristics of the mesh

Many nodes: 32
the elastic element is a HEXA20.
The element of interface is a HEXA20 degenerated (confused nodes).

10.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.
The results are identical in mode I for the two models, we present only those obtained with CZM_OUV_MIX :

Quantity I

mode tested	Reference	Tolerance ($\%$)
DX on Node 2	2.16506D-08	0.10
SIXX	7.37899D-01	0.10
SIGN	3.47849D-01	0.10
SITX	0.D+00	0.10
V1	2.6729D-01	0.10
V4	7.00003D-01	0.10

11 Modelization I

Validation of the element of interface PENTA15 with cohesive models CZM_OUV_MIX and CZM_TAC_MIX in mode of opening.

11.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_INTERFACE_S for the element of interface

11.2 Characteristics of the mesh

Many nodes: 24
the elastic element is a PENTA15.
The element of interface is a degenerated PENTA15 (confused nodes).

11.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.
The results are identical in mode I for the two models, we present only those obtained with CZM_OUV_MIX :

Quantity I

mode tested	Reference	Tolerance (%)
DX on Node 2	2.16506D-08	0.10
SIXX	7.37899D-01	0.10
SIGN	3.47849D-01	0.10
SITX	0.D+00	0.10
V1	2.6729D-01	0.10
V4	7.00003D-01	0.10

12 Modelization J

Validation of the element of interface HEXA8 with the cohesive model for fatigue CZM_FAT_MIX in mode of opening. The loading here is cyclic (see 5) in teeth of saw. Odd times are the tops and the urgent pars correspond to the hollows.

12.1 Characteristics of the modelization

Modelization D_PLAN for the elastic element.
Modelization PLAN_INTERFACE_S for the element of interface

12.2 Characteristics of the mesh

Many nodes: 12
the elastic element is a HEXA8.
The element of interface is a degenerated HEXA8 (confused nodes).

12.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.

Quantity tested	Reference	Tolerance (%)
SIXX inst. 3	6.05826	0.10
SIGN (SIEF_ELGA) inst. 9	1.45221	0.10
SIGN (DEPL) inst. 9	1.45221	0.10
SITX (SIEF_ELGA) inst. 7.0.0		0.10
V1 inst. 3	2.04959E-02	0.10
V4 inst. 3	1.94457E-01	0.10

Note:
-The SIXX is tested on the elastic voluminal element, the other tests are carried out on the element of interface.
-One tests the normal stress on a point of gauss: SIGN (SIEF_ELGA) as well as the multiplier of Lagrange on a medium node: SIGN (DEPL).

13 Modelization K

Validation of the element of interface HEXA20 with the cohesive model for fatigue CZM_FAT_MIX in mode of opening. The loading here is cyclic (see 5) in teeth of saw. Odd times are the tops and the urgent pars correspond to the hollows.

13.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_INTERFACE_S for the element of interface

13.2 Characteristics of the mesh

Many nodes: 32
the elastic element is a HEXA20.
The element of interface is a HEXA20 degenerated (confused nodes).

13.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.
The quantities tested and the results are identical to those carried out in 2D (see modelization J paragraph 12.3).

Quantity tested	Reference	Tolerance (%)
SIXX inst. 3	6.05826	0.10
SIGN (SIEF_ELGA) inst. 9	1.45221	0.10
SIGN (DEPL) inst. 9	1.45221	0.10
SITX (SIEF_ELGA) inst. 7.0.0		0.10
V1 inst. 3	2.04959E-02	0.10
V4 inst. 3	1.94457E-01	0.10

14 Modelization L

Validation of the element of interface PENTA15 with the cohesive model for fatigue CZM_FAT_MIX in mode of opening. The loading here is cyclic (see 5) in teeth of saw. Odd times are the tops and the urgent pars correspond to the hollows.

14.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_INTERFACE_S for the element of interface

14.2 Characteristics of the mesh

Many nodes: 24
the elastic element is a PENTA15.
The element of interface is a degenerated PENTA15 (confused nodes).

14.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization.
The quantities tested and the results are identical to those carried out in $2D$ (see modelization J paragraph 12.3).

Quantity tested	Reference	Tolerance (%)
SIXX inst. 3	6.05826	0.10
SIGN (SIEF_ELGA) inst. 9	1.45221	0.10
SIGN (DEPL) inst. 9	1.45221	0.10
SITX (SIEF_ELGA) inst. 7.0.0		0.10
V1 inst. 3	2.04959E-02	0.10
V4 inst. 3	1.94457E-01	0.10

15 Modelization M

Validation of the element of interface HEXA8 with the cohesive model for fatigue CZM_TRA_MIX in mode of opening. The loading here is cyclic to traverse all the states of the model.

15.1 Characteristics of the modelization

Modelization D_PLAN for the elastic element.
Modelization PLAN_INTERFACE_S for the element of interface

15.2 Characteristics of the mesh

Many nodes: 12
the elastic element is a HEXA8.
The element of interface is a degenerated HEXA8 (confused nodes).

15.3 Quantities tested and Quantity

results tested	Reference	Tolerance (%)
total Response F inst 9.6	1.03932	0.10
total Response U inst 9.6	0.06235	0.10
SIGN (SIEF_ELGA) inst. 9	9	0.10
SIGN (DEPL) inst. 9	9	0.10
SITX inst. 9.6.0.0		0.10
V1 inst. 2.5 (contact)	0.01	0.10
V4 inst. 2.5 (contact)	0	0.10
V1 inst. 5.4 (plate)	0.017991	0.10
V4 inst. 5.4 (plate)	0.079910	0.10
V1 inst. 7.4 (discharge)	0.029991	0.10
V4 inst. 7.4 (discharge)	0.199910	0.10
V1 inst. 12.6 (endo)	0.108662	0.10
V4 inst. 12.6 (endo)	0.869312	0.10
V1 inst. 23 (fracture)	0.16	0.10
V4 inst. 23 (fracture)	1	0.10

One tests the normal stress on a point of gauss: SIGN (SIEF_ELGA) as well as the multiplier of Lagrange on a medium node: SIGN (DEPL).

16 Modelization N

Validation of the element of interface HEXA20 with the cohesive model for fatigue CZM_TRA_MIX in mode of opening. The loading here is cyclic to traverse all the states of the model.

16.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_INTERFACE_S for the element of interface

16.2 Characteristics of the mesh

Many nodes: 32
the elastic element is a HEXA20.
The element of interface is a HEXA20 degenerated (confused nodes).

16.3 Quantities tested and results

the quantities tested and the results are identical to those carried out in $2D$ (see modelization M).

Quantity tested	Reference	Tolerance (%)
SIGN (SIEF_ELGA) inst. 9	9	0.10
SIGN (DEPL) inst. 9	9	0.10
SITY inst. 9.6.0.0		0.10
V1 inst. 2.5 (contact)	0.01	0.10
V4 inst. 2.5 (contact)	0	0.10
V1 inst. 5.4 (plate)	0.017991	0.10
V4 inst. 5.4 (plate)	0.079910	0.10
V1 inst. 7.4 (discharge)	0.029991	0.10
V4 inst. 7.4 (discharge)	0.199910	0.10
V1 inst. 12.6 (endo)	0.108662	0.10
V4 inst. 12.6 (endo)	0.869312	0.10
V1 inst. 23 (fracture)	0.16	0.10
V4 inst. 23 (fracture)	1	0.10

One tests the normal stress on a point of gauss: SIGN (SIEF_ELGA) as well as the multiplier of Lagrange on a medium node: SIGN (DEPL).
Unlike $2D$, one tests SITY rather than SITX

17 Modelization O

Validation of the element of interface PENTA15 with the cohesive model for fatigue CZM_TRA_MIX in mode of opening. The loading here is cyclic to traverse all the states of the model.

17.1 Characteristics of the modelization

Modelization 3D for the elastic element.
Modelization 3D_INTERFACE_S for the element of interface

17.2 Characteristics of the mesh

Many nodes: 24
the elastic element is a PENTA15.
The element of interface is a degenerated PENTA15 (confused nodes).

17.3 Quantities tested and results

the quantities tested and the results are identical to those carried out in $2D$ (see modelization M).

Quantity tested	Reference	Tolerance ($\%$)
SIGN (SIEF_ELGA) inst. 9	9	0.10
SIGN (DEPL) inst. 9	9	0.10
SITY inst. 9.6.0.0		0.10
V1 inst. 2.5 (contact)	0.01	0.10
V4 inst. 2.5 (contact)	0	0.10
V1 inst. 5.4 (plate)	0.017991	0.10
V4 inst. 5.4 (plate)	0.079910	0.10
V1 inst. 7.4 (discharge)	0.029991	0.10
V4 inst. 7.4 (discharge)	0.199910	0.10
V1 inst. 12.6 (endo)	0.108662	0.10
V4 inst. 12.6 (endo)	0.869312	0.10
V1 inst. 23 (fracture)	0.16	0.10
V4 inst. 23 (fracture)	1	0.10

One tests the normal stress on a point of gauss: SIGN (SIEF_ELGA) as well as the multiplier of Lagrange on a medium node: SIGN (DEPL).
Unlike $2D$ one tests SITY rather than SITX.

18 Modelization P

Validation of the implementation of model CZM_TAC_MIX in X-FEM formulation. The mode of opening is tested. This modelization is an adaptation with X-FEM of the modelization G.

18.1 Characteristics of the modelization

line of discontinuity is modelled by an interface X-FEM, which is introduced into the model by the operator DEFI_FISS_XFEM, with TYPE_DISCONTINUITE=' INTERFACE'. This line the block crosses right through. It is at a distance $0{,}4$ from left edge and crosses the elements (see fig.2). It is said that the interface is nonin conformity.
The elements of contact are introduced by discretization CONTACT=' P2P1' into operator MODI_MODELE_XFEM.
The cohesive model is then defined in operator DEFI_CONTACT, by key word ALGO_CONT=' CZM' and RELATION=' CZM_TAC_MIX'.
The surface elements are of type D_PLAN.

18.2 Characteristics of the mesh

the square is discretized at a rate of 4 elements per side. Consequently:
Many elements, of type HEXA8: 16
Number of nodes: 65.

18.3 Quantities tested and results

the remark on control evoked for the modelization A is also true for this modelization. Not having more elements of interface to be strictly accurate in the model, one replaces the tests on SIGN and SIGTX by tests on the multipliers of contact X-FEM LAGS_C and LAGS_F1 respectively.

Quantity I

mode tested	Reference	Tolerance ($\%$)
ETA_PILO	8.29181D-01	0.10
DX out of node 2	2.16506D-08	0.10
SIXX out of mesh 32	7.37899D-01	0.10
LAGS_C out of node 9	3.47849D-01	0.10
LAGS_F1 out of node 9	0.D+00	0.10

19 Summary of the results

the numerical results are in agreement with the analytical solution. These tests make it possible to validate the elements of joint, the elements of interface in $2D$ and $3D$, in the various modes of opening and XFEM $2D$ in opening.