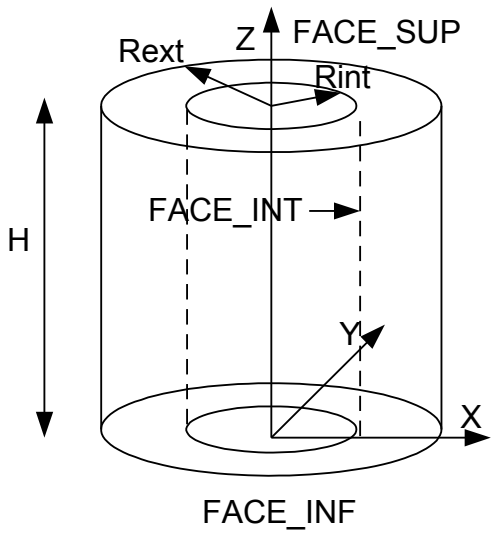
HSNV134 – Model META_LEMA_ANI : tube under pressure and constant temperature

Abstract:

This test constitutes a numerical validation of the model of behavior META_LEMA_ANI mechanics with effect of the metallurgical transformations developed for the material of the sheath of the fuel pins, Zircaloy. It is about a tube subjected to an internal pressure, with taking into account of the basic effect and with a uniform and constant temperature in time (thus only one involved phase). One cancels one of the coefficients material of the model in order to obtain viscosity of Norton the model. One can then compare the solution obtained with the software ZMAT, which comprises the same model exactly.

1Problem of reference

1.1Geometry



Appears 1.1-a: Geometry of the problem of reference

It acts of a cylinder height $H=20\text{mm}$, interior radius $Rint=4.118\text{mm}$ and external radius $Rext=4.746\text{mm}$.

1.2Material properties

The materials' properties are described by the following parameters:

Thermal properties:

$\rho C_p=2000000\,J.m^{-3}.°C^{-1}$
$\lambda=9999.9\,W.m^{-1}.°C^{-1}$

Metallurgical properties:

$TDEQ=809\,°C$
$K=1.135.10^{-2}$
$N=2.187$
$T1C=831\,°C$
$T2C=0.°C$
$QSR_K=14614$
$AC=1.58.10^{-4}$
$M=4.7$
$T1R=949{,}1\,°C$
$T2R=0.°C$
$AR=-5.725$
$BR=0.05$

Thermoelastic mechanical properties:

Young's modulus: $E=80\,000\ MPa$

Poisson's ratio: $NU=0.35$

Coefficient of thermal expansion identical for the phases heat and cold $F_{ALPHA}=8.\mathrm{E}-6\,°C^{-1}$ and $C_{ALPHA}=8.\mathrm{E}-6\,°C^{-1}$

• **Mechanical properties of model META_LEMA_ANI :**

Parameters related to viscosity

-Phase α formulates

```
pure = 2.39
F1_M = 0.
F1_N = 4.39
F1_Q = 19922.8
```

-Mixture $\alpha+\beta$

```
formulates = 0.22
F2_M = 0.77 E-4
F2_N = 2.96
F2_Q = 21023.7
```

-Phase β pure

```
C_A = 9.36
C_M = 0.99 E-4
C_N = 6.11
C_Q = 6219
```

Coefficient of the matrix of anisotropy in the plane (r,θ,z) .

-Phase α

```
F_MRR_RR = 0.4414
F_MTT_TT = 0.714
F_MZZ_ZZ = 1
F_MRT_RT = 0.75
F_MRZ_RZ = 0.75
F_MTZ_TZ = 0.75
```

-Phase β

```
C_MRR_RR = 1
C_MTT_TT = 1
C_MZZ_ZZ = 1
C_MRT_RT = 0.75
C_MRZ_RZ = 0.75
C_MTZ_TZ = 0.75
```

1.3Boundary conditions and loadings

Left thermal: the temperature is imposed on all the cylinder on $700\,°C$ throughout all mechanical loading of 0 on $100\mathrm{s}$.

Mechanical part:

The lower part of the cylinder (FACE_INF) is blocked in following displacement z : $UZ(x,y,0)=0$

All the upper part of the cylinder (FACE_SUP) has a displacement according to z uniform.

One imposes a pressure on the interior face of the tube (FACE_INT):

Time (s)	Pressure (MPa)
0	0.
1.1.7.5.100	

.	9.5

One takes account of the basic effect on the upper part of the tube (FACE_SUP):

Time (s)	Pressure (MPa)
0	0.
1.1.100	$-7.5\times coef$
.	$-9.5\times coef$

With $coef=(Rint\times Rint)/[(Rext\times Rext)-(Rint\times Rint)]$

1.4Initial conditions

Initially, the temperature is of $700\,°C$ and it tube is made up of 100% of cold phase α, that is to say:

$V1=1.0$
$V2=0.0$
$V3=20.$
$V4=0.$

$V1$: proportion of the cold phase α
$V2$: proportion of the cold phase α , mixed with the phase β
$V3$: temperatures with the nodes
$V4$: time corresponding to end or the initial temperature of the transformation to the equilibrium

2Reference solution

the results of reference are got with the software ZMAT which comprises the equivalent model with the file material .33 following:

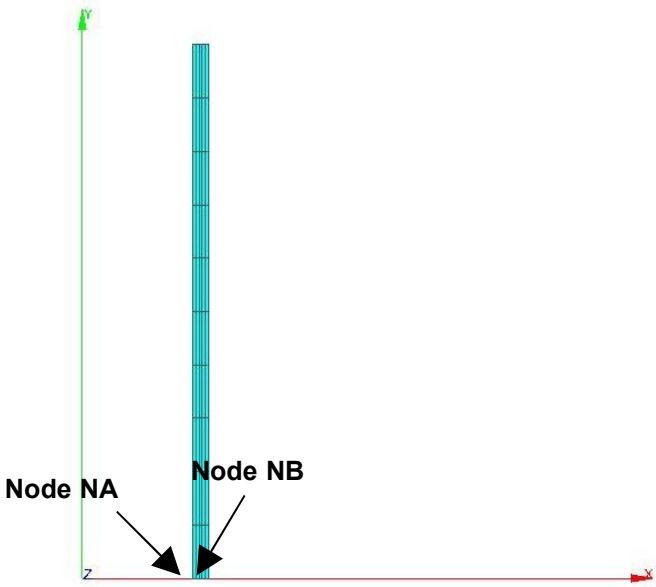
```
*** material
*integration theta_method_a 1. 1.e-12 100

*** behavior gen_evp
** elasticity
Young 80000.
fish 0.35
** potential gen_evp ev
*flow norton
K 253.5497
N 4.39
*criterion anisotropic orthotropic
c11 0.294267      c22 0.6666667      c33 0.476
c44 0.5               c55  0.5                  c66 0.5
c12 -0.242467    c23  -0.4242        c31 -0.0518
*isotropic constant
R0 0.
*** return
```

3Modelization A

3.1Characteristic of the modelization

The modelization used in the benchmark is the following one:

Elements 2D "AXIS" (QUA8)



Appears 3.1-a: Geometry and mesh of the modelization

Cutting: 5 meshes QUAD8 according to the axis of x
the 10 meshes QUAD8 according to the axis of y

3.2the Characteristics of the mesh

Many nodes: 181
Number of meshes and types: 50 QUAD8, 30 SEG3.
The node is outside the field of definition with a right profile of the EXCLU type node: $NA \quad X = Rint$ $Y = 0$.
The node is outside the field of definition with a right profile of the EXCLU type node: $NB \quad X = Rext$ $Y = 0$.

3.3Characteristics of the loading

Boundary conditions:

```
FACE_IMPO =_F (GROUP_MA=' FACE_INF', DNOR=0)
LIAISON_UNIF =_F (GROUP_MA=' FACE_SUP', DDL=' DY')
```

Loading:

```
PRES_REP=_F (GROUP_MA=' FACE_INT' PRES=1.),
```

```
_F (GROUP_MA=' FACE_SUP' PRES=-coeff.),
```

with $coef = (Rint \times Rint) / [(Rext \times Rext) - (Rint \times Rint)]$

3.4Quantities tested and results

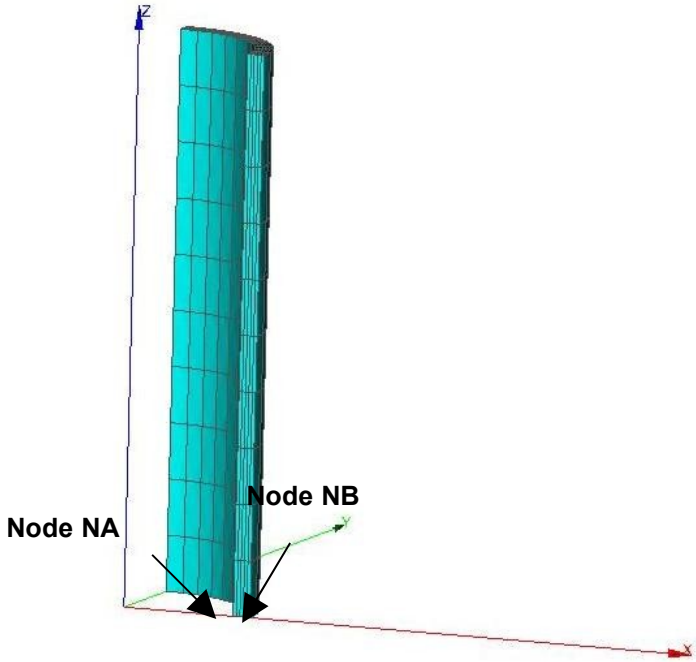
Identification	Quantity	Reference
t=100s NA	SIXX	-9.442
t=100s NA	SIZZ	60.226
t=100s NA	SIYY	26.795
t=100s NA	EPXX	-9.49597E-03
t=100s NA	EPZZ	1.35633E-02
t=100s NA	EPYY	-3.7769E-03
t=100s NB	SIXX	3.28215E-02
t=100s NB	SIZZ	64.199
t=100s NB	SIYY	30.771
t=100s NB	EPXX	-6.58609E-03
t=100s NB	EPZZ	1.07189E-02
t=100s NB	EPYY	-3.7769E-03

4Modelization B

4.1Characteristic of the modelization

The modelization used in the case test is the following one:

Elements 3D (HEXA20)



Appears 5.1-a: Geometry and mesh of the modelization

Cutting: 5 meshes HEXA20 according to the axis r (cylindrical coordinate system)
10 meshes HEXA20 according to the axis θ (cylindrical coordinate system)
10 meshes HEXA20 according to the axis z

4.2Characteristics of the mesh

Many nodes: 2651
Number of meshes and types: 500 HEXA20, 400 QUAD8, 100 SEG3.
The node is outside the field of definition with a right profile of the EXCLU type node: $NA \quad X = Rint$ $Y = 0$.
The node is outside the field of definition with a right profile of the EXCLU type node: $NB \quad X = Rext$ $Y = 0$.

4.3Characteristics of the loading

Boundary conditions:

```
FACE_IMPO =_F (GROUP_MA=' FACE_INF', DNOR=0)
           _F (GROUP_MA=' FACE_X0', DX=0)
           _F (GROUP_MA=' FACE_Y0', DY=0)
```

```
LIAISON_UNIF =_F (GROUP_MA=' FACE_SUP', DDL=' DZ')
```

Loading:

```
PRES_REP=_F (GROUP_MA=' FACE_INT' PRES=1.),
          _F (GROUP_MA=' FACE_SUP' PRES=-coeff.),
```

with $coef = (Rint \times Rint) / [(Rext \times Rext) - (Rint \times Rint)]$

4.4Quantities tested and results

Identification	Quantity	Reference
t=100s NA	SIXX	-9.4420
t=100s NA	SIZZ	60.226
t=100s NA	SIYY	26.795
t=100s NA	EPXX	-9.49597E-03
t=100s NA	EPZZ	1.35633E-02
t=100s NA	EPYY	-3.7769E-03
t=100s NB	SIXX	3.28215E-02
t=100s NB	SIZZ	64.199
t=100s NB	SIYY	30.771
t=100s NB	EPXX	-6.58609E-03
t=100s NB	EPZZ	1.07189E-02
t=100s NB	EPYY	-3.7769E-03

4.5Comments

the values tested in 3D are those calculated in the cylindrical coordinate system.

5Conclusion

the values of reference are those obtained with ZMAT. The results got with *Code_Aster* are in very good agreement with ZMAT.