# HSNV134 – Model META_LEMA_ANI : tube under pressure and constant temperature

**Summary:**

This test constitutes a digital validation of the model of behavior META_LEMA_ANI mechanics with effect of the metallurgical transformations developed for 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 at a uniform and constant temperature in time (thus only one involved phase). One cancels one of the coefficients material of the law in order to obtain the model of viscosity of Norton. One can then compare the solution obtained with the software ZMAT, which comprises the same law exactly.

# 1Problem of reference

## 1.1Geometry

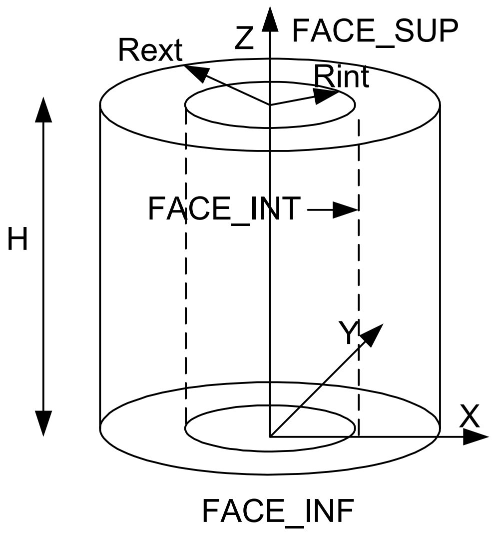


**Figure 1.1-a: Geometry of the problem of reference**

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

## 1.2Material properties

The properties materials 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 modulus: $E=80\,000\,MPa$

Poisson's ratio: $NU=0.35$

Identical for the phases heat and cold dilation coefficient $F_{ALPHA}=8.\mathrm{E}-6\,°C^{-1}$ and $C_{ALPHA}=8.\mathrm{E}-6\,°C^{-1}$

• **Mechanical properties of the law META_LEMA_ANI :**

Parameters related to viscosity

-Phase $\alpha$ pure

```
F1_A = 2.39
F1_M = 0.
F1_N = 4.39
F1_Q = 19922.8
```

-Mixture $\alpha+\beta$

```
F2_A = 0.22
F2_M = 0.77 E-4
F2_N = 2.96
F2_Q = 21023.7
```

-Phase $\beta$ 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 plan $(r,\theta,z)$.

-Phase $\alpha$

```
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 $\beta$

```
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

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

**Mechanical part:**

The lower part of the cylinder ( $\mathrm{FACE\_INF}$ ) is blocked in following displacement $z$ : $UZ(x,y,0)=0$

All the upper part of the cylinder ( $\mathrm{FACE\_SUP}$ ) has a following displacement $z$ uniform.

One imposes a pressure on the interior face of the tube ( $\mathrm{FACE\_INT}$ ):

| 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 | $-7.5 \times coef$ |
| 100. | $-9.5 \times coef$ |

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 $\alpha$ , that is to say:

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

*$V1$ : proportion of the cold phase $\alpha$*
*$V2$ : proportion of the cold phase $\alpha$ , mixed with the phase $\beta$*
*$V3$ : temperatures with the nodes*
*$V4$ : time corresponding to or end the initial temperature of the transformation with balance*

# 2Reference solution

The results of reference are got with the software ZMAT which comprises the equivalent law 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
```

# 3Modeling A

## 3.1Characteristics of modeling

The modeling used in the CAS-test is the following one:

**Elements 2D 'AXIS' (QUA8)**

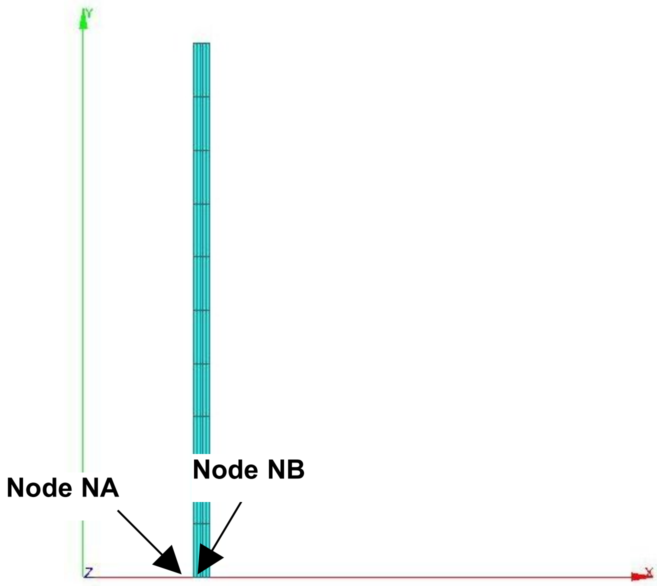


**Figure 3.1-a: Geometry and grid of modeling**

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

## 3.2Characteristics of the grid

Many nodes: 181
Many meshs and types: 50 QUAD8, 30 SEG3.
Node $NA$ : $X=Rint$ , $Y=0$ .
Node $NB$ : $X=Rext$ , $Y=0$ .

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

## 3.4Sizes tested and results

| Identification | Size | 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 |

# 4Modeling B

## 4.1Characteristics of modeling

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

**Elements 3D (HEXA20)**

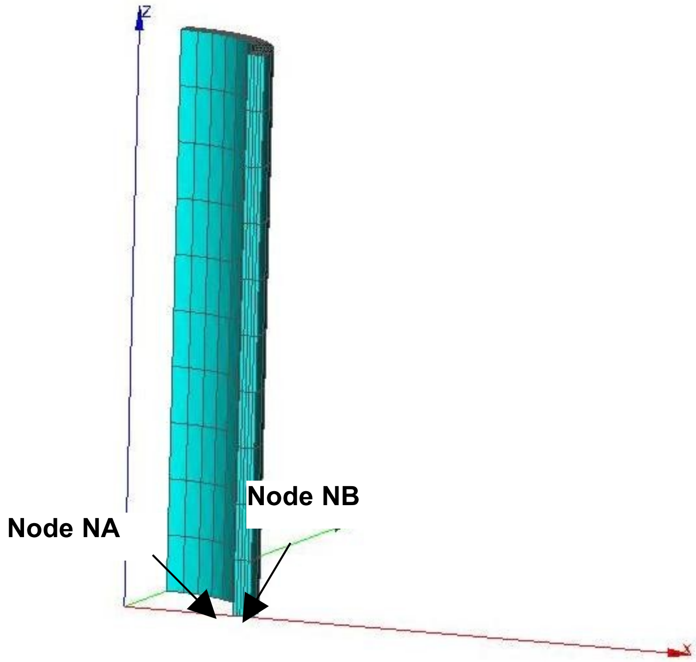


**Figure 5.1-a: Geometry and grid of modeling**

Cutting: 5 meshs HEXA20 according to the axis $r$ (cylindrical reference mark)
10 meshs HEXA20 according to the axis $\theta$ (cylindrical reference mark)
10 meshs HEXA20 according to the axis $z$

## 4.2Characteristics of the grid

Many nodes: 2651
Many meshs and types: 500 HEXA20, 400 QUAD8, 100 SEG3.
Node $NA$ : $X=Rint$ , $Y=0$ .
Node $NB$ : $X=Rext$ , $Y=0$ .

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

## 4.4Sizes tested and results

| Identification | Size | 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 reference mark.

# 5Conclusion

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