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.
1 Problem of reference

1.1 Geometry

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

1.2 Material properties

The properties materials are described by the following parameters:

**Thermal properties:**

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

**Metallurgical properties:**

- $T_{DEQ} = 809^\circ\text{C}$
- $K = 1.135.10^{-2}$
- $N = 2.187$
- $T1C = 831^\circ\text{C}$
- $T2C = 0.\text{o C}$
- $QSR_k = 14614$
- $AC = 1.58.10^{-4}$
- $M = 4.7$
- $T1R = 949.1^\circ\text{C}$
- $T2R = 0.\text{o C}$
- $AR = -5.725$
- $BR = 0.05$

**Thermoelastic mechanical properties:**

- Young modulus: $E = 80000 \text{MPa}$
Poisson's ratio: \( NU = 0.35 \)

Identical for the phases heat and cold dilation coefficient \( F_{ALPHA} = 8.0 \times 10^{-6} C^{-1} \) and \( C_{ALPHA} = 8.0 \times 10^{-6} C^{-1} \)

- **Mechanical properties of the law META_LEMAANI:**

  **Parameters related to viscosity**

  - **Phase \( \alpha \) pure**
    
    \[
    \begin{align*}
    F1_A &= 2.39 \\
    F1_M &= 0. \\
    F1_N &= 4.39 \\
    F1_Q &= 19922.8 \\
    \end{align*}
    \]

  - **Mixture \( \alpha + \beta \)**
    
    \[
    \begin{align*}
    F2_A &= 0.22 \\
    F2_M &= 0.77 \times 10^{-4} \\
    F2_N &= 2.96 \\
    F2_Q &= 21023.7 \\
    \end{align*}
    \]

  - **Phase \( \beta \) pure**
    
    \[
    \begin{align*}
    C_A &= 9.36 \\
    C_M &= 0.99 \times 10^{-4} \\
    C_N &= 6.11 \\
    C_Q &= 6219 \\
    \end{align*}
    \]

  **Coefficient of the matrix of anisotropy in the plan \((r, 0, z)\).**

  - **Phase \( \alpha \)**
    
    \[
    \begin{align*}
    F_{MRR_{RR}} &= 0.4414 \\
    F_{MTT_{TT}} &= 0.714 \\
    F_{MZZ_{ZZ}} &= 1 \\
    F_{MRT_{RT}} &= 0.75 \\
    F_{MRZ_{RZ}} &= 0.75 \\
    F_{MTZ_{TZ}} &= 0.75 \\
    \end{align*}
    \]

  - **Phase \( \beta \)**
    
    \[
    \begin{align*}
    C_{MRR_{RR}} &= 1 \\
    C_{MTT_{TT}} &= 1 \\
    C_{MZZ_{ZZ}} &= 1 \\
    C_{MRT_{RT}} &= 0.75 \\
    C_{MRZ_{RZ}} &= 0.75 \\
    C_{MTZ_{TZ}} &= 0.75 \\
    \end{align*}
    \]

1.3 **Boundary conditions and loadings**

**Thermal part:** the temperature is imposed on all the cylinder on \( 700^\circ C \) throughout all mechanical loading of \( 0 \) with \( 100s \).

**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 following displacement \( z \) uniform.

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

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.1</td>
<td>7.5</td>
</tr>
</tbody>
</table>
One takes account of the basic effect on the upper part of the tube (FACE_SUP):

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.</td>
</tr>
<tr>
<td>1.1</td>
<td>$-7.5 \times \text{coef}$</td>
</tr>
<tr>
<td>100.</td>
<td>$-9.5 \times \text{coef}$</td>
</tr>
</tbody>
</table>

With $\text{coef} = (R_{\text{int}} \times R_{\text{int}}) / [(R_{\text{ext}} \times R_{\text{ext}}) - (R_{\text{int}} \times R_{\text{int}})]$

1.4 Initial conditions

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

$V1 = 1.0$
$V2 = 0.0$
$V3 = 20.0$
$V4 = 0.0$

$V1$: 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

2 Reference solution

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

```plaintext
*** 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
*criteterion 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
```
3 Modeling A

3.1 Characteristics of modeling

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

Elements 2D ‘AXIS’ (QUA8)

![Geometry and grid of modeling](image)

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

Cutting:
- 5 meshes QUAD8 according to the axis of \( x \)
- 10 meshes QUAD8 according to the axis of \( y \)

3.2 Characteristics of the grid

Many nodes: 181
Many meshes and types: 50 QUAD8, 30 SEG3.

Node \( NA \): \( X = R_{\text{in}}, Y = 0 \).
Node \( NB \): \( X = R_{\text{ex}}, Y = 0 \).

3.3 Characteristics of the loading

Boundary conditions:

\[
\text{FACE}_\text{IMPO} = _F \ (\text{GROUP}_\text{MA} = \text{FACE}_\text{INF}, \ \text{DNOR}=0)
\]

\[
\text{LIAISON}_\text{UNIF} = _F \ (\text{GROUP}_\text{MA} = \text{FACE}_\text{SUP}, \ \text{DDL}=\text{DY})
\]

Loading:

\[
\text{PRES}_\text{REF} = _F \ (\text{GROUP}_\text{MA} = \text{FACE}_\text{INT}, \ \text{PRES}=1.),
\]

\[
_\text{F} \ (\text{GROUP}_\text{MA} = \text{FACE}_\text{SUP}, \ \text{PRES}=-\text{coeff}.),
\]

with \( \text{coef} = \frac{(R_{\text{in}} \times R_{\text{in}})(R_{\text{ex}} \times R_{\text{ex}}) - (R_{\text{in}} \times R_{\text{in}})}{(R_{\text{ex}} \times R_{\text{ex}})} \)
### 3.4 Sizes tested and results

<table>
<thead>
<tr>
<th>Identification</th>
<th>Size</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>t=100s NA</td>
<td>SIXX</td>
<td>-9.442</td>
</tr>
<tr>
<td>t=100s NA</td>
<td>SIZZ</td>
<td>60.226</td>
</tr>
<tr>
<td>t=100s NA</td>
<td>SIYY</td>
<td>26.795</td>
</tr>
<tr>
<td>t=100s NA</td>
<td>EPXX</td>
<td>-9.49597E-03</td>
</tr>
<tr>
<td>t=100s NA</td>
<td>EPZZ</td>
<td>1.35633E-02</td>
</tr>
<tr>
<td>t=100s NA</td>
<td>EPYY</td>
<td>-3.7769E-03</td>
</tr>
<tr>
<td>t=100s NB</td>
<td>SIXX</td>
<td>3.28215E-02</td>
</tr>
<tr>
<td>t=100s NB</td>
<td>SIZZ</td>
<td>64.199</td>
</tr>
<tr>
<td>t=100s NB</td>
<td>SIYY</td>
<td>30.771</td>
</tr>
<tr>
<td>t=100s NB</td>
<td>EPXX</td>
<td>-6.58609E-03</td>
</tr>
<tr>
<td>t=100s NB</td>
<td>EPZZ</td>
<td>1.07189E-02</td>
</tr>
<tr>
<td>t=100s NB</td>
<td>EPYY</td>
<td>-3.7769E-03</td>
</tr>
</tbody>
</table>
Modeling B

4.1 Characteristics 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 meshes HEXA20 according to the axis \( r \) (cylindrical reference mark)
- 10 meshes HEXA20 according to the axis \( \theta \) (cylindrical reference mark)
- 10 meshes HEXA20 according to the axis \( z \)

4.2 Characteristics of the grid

Many nodes: 2651
Many meshes and types: 500 HEXA20, 400 QUAD8, 100 SEG3.

Node \( NA: X = R_{int}, Y = 0 \).
Node \( NB: X = R_{ext}, Y = 0 \).

4.3 Characteristics 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:

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\[ \text{PRES REP } = \_F \text{ (GROUP MA } = \text{ 'FACE INT' PRES } = 1.),} \]
\[ \_F \text{ (GROUP MA } = \text{ 'FACE SUP' PRES } = \text{ -coeff.)}, \]

with \( \text{coef } = \frac{(R_{\text{int}} \times R_{\text{int}})}{\left[ (R_{\text{ext}} \times R_{\text{ext}}) - (R_{\text{int}} \times R_{\text{int}}) \right]} \]

### 4.4 Sizes tested and results

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<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>t=100s NA</td>
<td>SIXX</td>
<td>-9.4420</td>
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<tr>
<td>t=100s NA</td>
<td>SIZZ</td>
<td>60,226</td>
</tr>
<tr>
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<td>SIYY</td>
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</tr>
</tbody>
</table>

### 4.5 Comments

The values tested in 3D are those calculated in the cylindrical reference mark.

### 5 Conclusion

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

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