FORMA30 - Thermoelastic hollow roll

Summary:

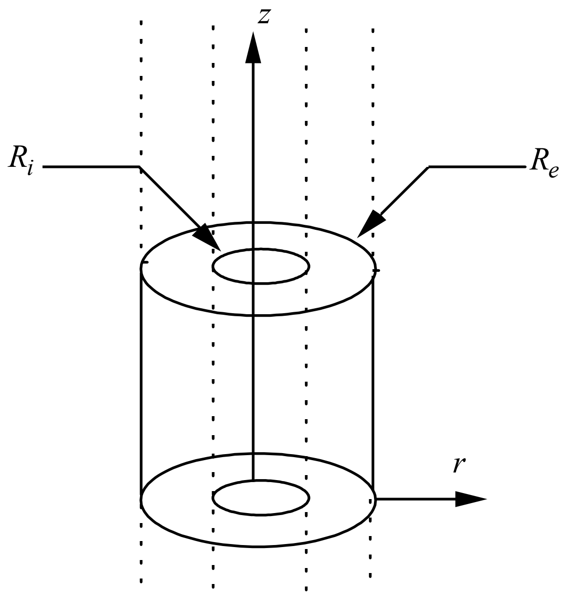
This test in $2D$ axisymmetric quasi-static allows to illustrate on a simple case the relative questions with thermoelastoplastic modelings:

- for thermal calculation, it highlights the effects of going beyond maximum, of instability of the explicit diagram and watch the contribution of the diagonalisation of the thermal matrix of mass,
- For mechanical calculation, it highlights the constraints due to the incompatibility of the thermal deformations, even if the cylinder is free, then the incrémentaux aspects of calculation with `STAT_NON_LINE`. One shows also the influence of the temperature of reference and the temperature of definition of the thermal dilation coefficient.

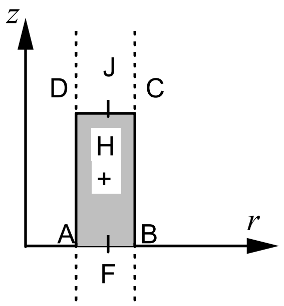
1 Problem of reference

1.1 Geometry

The studied structure is a slice of cylinder, modelled into axisymmetric, (cf HPLA100)



Rayon intérieur	R_i = 19.5 mm
Rayon extérieur	R_e = 20.5 mm
Point F	R = 20.0 mm
Epaisseur	h = 1.0 mm
Hauteur	L = 10.0 mm



1.2 Properties of materials

The material is homogeneous isotropic, thermoelastic linear. The mechanical coefficients are $E=2.10^5 M/mm^2$; $\nu=0.3$

The dilation coefficient is function of the temperature:
$\alpha=10^{-5} {}^{\circ}C^{-1}$ for $T=100{}^{\circ}C$, $\alpha=10^{-4} {}^{\circ}C^{-1}$ for $T=0{}^{\circ}C$

The temperature of reference is worth $0{}^{\circ}C$. The thermal coefficients are worth:
$\lambda=1\,W/mK$, $\rho C_p=1000\,MJ/m^3 K$

1.3 Boundary conditions and loadings of thermal calculation

The cylinder is subjected on its internal edge to an exchange with a fluid which passes brutally from $100{}^{\circ}C$ with $0{}^{\circ}C$:

- null flow on the edges AB , BC , CD
- on the edge AD , condition of convectif exchange, with:
  $H=100\,W/mm^2/{}^{\circ}C$

$Text=100°C$ with $t=0\text{s}$, then $0°C$ with $t=0.01\text{s}$, and then maintained constant.

1.4 Boundary conditions and loadings of mechanical calculation

Conditions of symmetry
Case not attached: following null displacement Oy along the side AB .
Attached case: following null displacement Oy along sides AB and CD .
Loading: thermal dilation.

2 Reference solution

2.1 Thermoelastic solution

The reference solution is digital. It is obtained with *Code_Aster* for a fine grid (20 elements in the thickness). The TP is carried out with a very coarse grid (3 elements in the thickness), one thus should not be astonished to get results rather far away from the reference solution.

Indeed, the goal of the TP is to show:

- for thermal calculation, effects of going beyond maximum, instability of the explicit diagram and the contribution of the diagonalisation of the thermal matrix of mass,
- for mechanical calculation, constraints due to the incompatibility of the thermal deformations, even if the cylinder is free, then incrémentaux aspects of calculation with `STAT_NON_LINE`.

The values tested are:

Moment (s)	Temperature max ($Tmax$) in $°C$	Many nodes reached by $Tmax$ and numbers of the nodes	Temperature min ($Tmin$) in $°C$	Many nodes
0	100	63 nodes	100	63
0.1	100	1 node: $N26$	69.5309	1 node: $N62$
4	100	1 node: $N1$	8,5.182	1 node: $N62$
10	100	1 node: $N2$	5.56755	1 node: $N62$
100	95.1712	1 node: $N3$	1.81091	1 node: $N62$

The values maximum and minimum of the constraints $SIYY$ at the moments $t=0\text{s}$ and $t=11\text{s}$

Case not attached

Moment (s)	Maximum constraint $SIYY$ max	Many meshs reached by $SIYY$ max and number of the meshs	Minimal constraint $SIYY$ min	Many meshs reached by $SIYY$ min and number of the meshs
11	364.875	1 mesh: $M21$	– 320.094	1 mesh: $M2$

Case attached with `MECA_STATIQUE` and `STAT_NON_LINE` with $TREF=0$ (and an initial state $T=0°C$),

Moment (s)	Maximum constraint $SIYY$ max	Many meshs reached by $SIYY$ max and number of the meshs	Minimal constraint $SIYY$ min	Many meshs reached by $SIYY$ min and number of the meshs
0	– 200	1 mesh: $M40$	– 200	1 mesh: $M1$
11	– 61.5003	1 mesh: $M1$	– 702.563	1 mesh: $M22$

Case attached with `MECA_STATIQUE` and `STAT_NON_LINE` with $TREF=100°C$ (and an initial state $T=100°C$),

Moment (s)	Maximum constraint $SIYY$ max	Many meshs reached by $SIYY$ max and number of the meshs	Minimal constraint $SIYY$ min	Many meshs reached by $SIYY$ min and number of the meshs
11	138.5	1 mesh: $M21$	– 502.563	1 mesh: $M2$

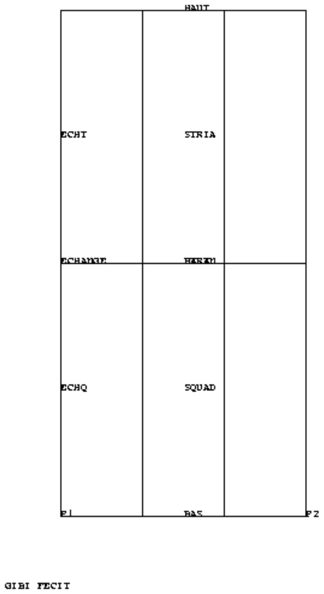
2.2 Bibliographical reference

Documentation of validation [V7.01.100].

3 Modeling A

3.1 Characteristics of modeling

Modeling A corresponds to the statement of the TP. It comprises only the first thermal calculation (without diagonalisation of the thermal mass). The grid comprises 3 meshs `QUAD4` in the thickness (grid GIBI).



3.2 Characteristics of the grid

6 meshs

The useful edges for the boundary conditions are defined by the groups of meshs:

- *ECHANGE* (left edge)
- *HAUT* (higher edge)
- *BAS* (lower edge)

3.3 Sizes tested and results

Temperature	moment	Identification	Reference	*Aster*	% difference
maximum	4	Temp max	126,314	126,314	0

Notice :

> *This modeling comprises only one test of nonregression. It is the starting point of the TP, intended to improve modeling (cf modeling B). On the change of the temperature in the middle of the cylinder according to time, and the distribution of temperature with* $t=4\mathrm{s}$ *. One notes (see curved reds, with square marker on the following figure), whom one exceeds the temperature of* $100°C$*, which is not physical. This characterizes nona respect of the principle of the maximum.*

4 Modeling B

4.1 Characteristics of modeling

This modeling corresponds to corrected TP. It implements all calculations suggested, by commenting on the got results.

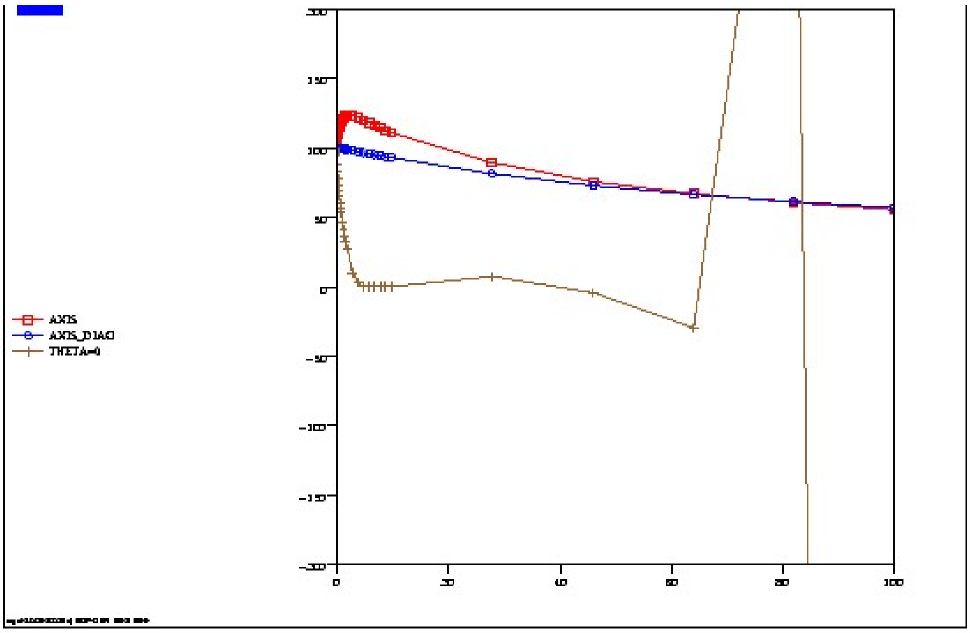


Figure 5.1-a

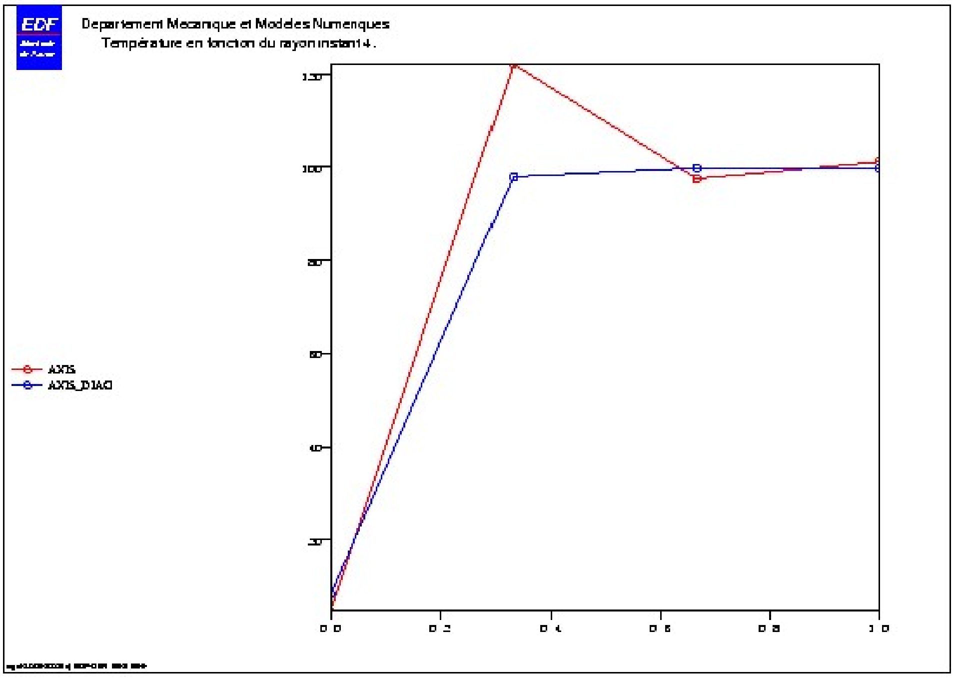


Figure 5.1-b

4.1.1 Thermal calculation

To improve the results of modeling A, therefore to mitigate these goings beyond the maximum temperature (cf [R3.06.07]), several solutions are possible:

- one can increase the step of time, which is not always compatible with the good apprehension of the speed of the transient (as in this case),
- or to refine the grid, which is a good solution, but expensive in time calculation,
- one can finally use the diagonalisation of the thermal matrices of mass, i.e. here modeling `AXIS_DIAG`. One then obtains the curves marked of circles on the figures [Figure 5.1-a] and [Figure 5.1-b] Ci above. The temperature remains always lower than $100°C$. It is the simplest solution.

If one seeks to use a diagram clarifies ($THETA=0$), one sees appearing a clear instability for great steps of time (curve with marker cross on the figure [Figure 5.1-a] above).

In conclusion, for thermal calculation, it is necessary to use one $THETA$ equal to or higher than 0.5, to have a stable diagram some is the step of time. Moreover it is necessary to use a step of time sufficiently small to apprehend the transient, but not too small to avoid the oscillations. If they appear, either the grid should be refined, or to use modeling `AXIS_DIAG`, (or `PLAN_DIAG`, or `3D_DIAG`).

4.1.2 Thermoelastic calculation in free dilation

One carries out calculation with `MECA_STATIQUE`, using for only loading thermal dilation. With the boundary conditions of the case not attached: following null displacement Oy along the side AB .

For mechanical calculation, it will be enough to calculate at the moments $t=0\mathrm{s}$, and $t=11\mathrm{s}$ for example.

Constraints at the moment $t=0\mathrm{s}$ are worthless, because the field of temperature is uniform ($T=200°C$) and remains compatible. On the other hand the deformations obtained are not worthless since the temperature of reference is equal to $200°C$.

With $t=11\mathrm{s}$, or any other positive mechanical moment, one sees appearing constraints known as of compatibility thermics. Indeed, the field of temperature is not uniform any more but varies according to r . This produced of the incompatible deformations, which thus generate constraints, even for a cylinder not attached. This situation occurs even for a linear field of temperature compared to the ray. On the other hand (cf exposed) a linear field of temperature compared to the total coordinates does not produce a constraint for a not attached structure.

4.1.3 Thermoelastic calculation with fastening

Calculation with `MECA_STATIQUE` case attached watch the contribution of fastening on the constraints ($SIYY$ in particular): at the moment $t=0\mathrm{s}$, the temperature of reference being equal to $0°C$, the uniform field of temperature causes a uniform state of stress $SIYY$ of $200\mathrm{MPa}$, and with $t=11\mathrm{s}$, the state of stresses is different from the case not attached.

This modeling is correct, but is limited to the linear behaviors.

4.1.4 Thermoplastic calculation with fastening

One seeks to carry out same calculation as previously, but this time with `STAT_NON_LINE` , with `COMPORTEMENT=_F (RELATION=' ELAS')` , not to complicate the problem (another behavior would lead to the same observations). The list of moments provided to `STAT_NON_LINE` is: $t=0\mathrm{s}$ and $t=11\mathrm{s}$.

Since an incremental calculation is done, moment 0 is regarded as initial moment. It is thus not calculated, and at the next moment ($t=11\mathrm{s}$), one calculates the solution due to the increase in load (thermal here) enters $0\mathrm{s}$ and $11\mathrm{s}$. It is noted whereas the solution obtained (displacements, constraints) is different from calculation with `MECA_STATIQUE` . It is logical and coherent with the definition of incremental calculation, but it is a trap for the use. To retain: implicitly, `STAT_NON_LINE` into incremental supposes that at the initial moment, the structure is not forced, not deformed. This imply that the field of temperature must be uniform and equal to the temperature of reference.

It is not the case here: with $t=0\mathrm{s}$, $TREF=0°C$, and $T=200°C$. By not calculating this thermal dilation, one supposes here that with $t=0\mathrm{s}$, there are no strain, and no stress.

4.1.5 Thermoplastic calculation with fastening and addition of initial conditions

One modifies the list of moments: one preliminary moment is added $t=-1\mathrm{s}$ for example. In this moment, one defines a field of uniform temperature, equal to the temperature of reference. One uses for this purpose the orders `CREA_CHAMP` , then `CREA_RESU` to enrich the structure of data thermics results with this uniform field. One carries out then mechanical calculation, by providing the list of moments: $t=-1\mathrm{s}$, $t=0\mathrm{s}$, and $t=11\mathrm{s}$
It is noted whereas the moment $t=0\mathrm{s}$ is well calculated, and that the constraints are identical to the case calculated with `MECA_STATIQUE` .

4.2 Characteristics of the grid

Even grid that for modeling A.

4.3 Sizes tested and values

Modeling `AXIS_DIAG`

Temperature	moment	Identification	Reference	*Aster*	% difference
maximum	4	Temp max	100	100	0

5 Summary of the results

This test is relating to the formation thermoplasticity. It shows the utility of the choice of modeling `DIAG` (thermal matrix of diagonalized mass) for thermal calculations, and famous in incremental thermomechanics (order `STAT_NON_LINE`) how to take into account the initial state correctly.