FORMA30 - Hollow roll thermo-elastic

Abstract:

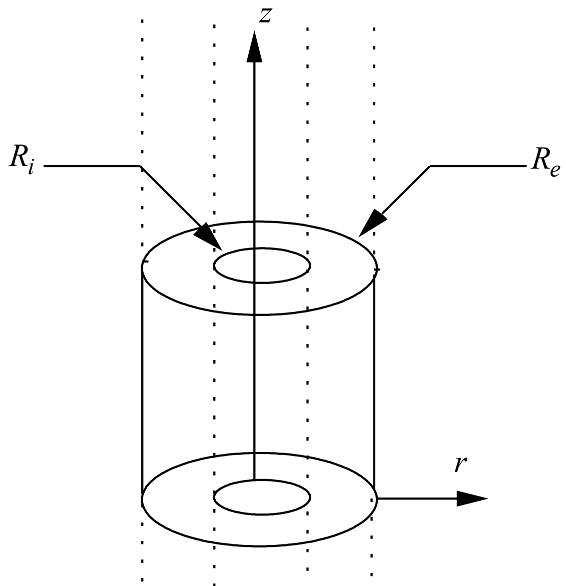
This test into $2D$ axisymmetric quasi-static makes it possible to illustrate on a simple case the relative questions with the thermoelastoplastic modelizations:

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

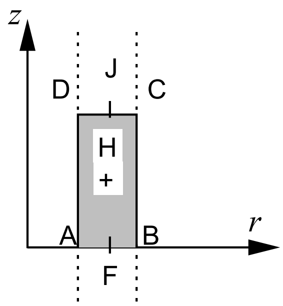
1 Problem of reference

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 the materials

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

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

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

1.3 Boundary conditions and loadings of thermal computation

the cylinder is subjected on its internal edge to an exchange with a fluid which passes brutally from $100\,°C$ to $0\,°C$:

null flux on edges AB BC, CD

edge AD, condition of convective exchange, with:

$H=100\,W/mm^2/°C$

$Text=100\,°C$ 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 computation

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

2 Thermoelastic reference solution

2.1 Solution

the reference solution is numerical. It is obtained with *Code_Aster* for a fine mesh (20 elements in the thickness). The TP is carried out with a very coarse mesh (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 computation, effects of going beyond maximum, instability of the explicit diagram and the contribution of the diagonalization of the thermal mass matrix,
for mechanical computation, stresses due to the incompatibility of the thermal strains, even if the cylinder is free, then incrémentaux aspects of computation with `STAT_NON_LINE`.

The values tested are:

Time (s)	Temperature max ($Tmax$) of $°C$	Many nodes reached by $Tmax$ and numbers of the nodes	Temperature min ($Tmin$) of $°C$	Many nodes
0.100		63 nodes	100	63.0,1.100
		1 the node is outside the field of definition with a right profile of the EXCLU type node: $N26$	69,5309	1 the node is outside the field of definition with a right profile of the EXCLU type node: $N62$
4.100		1 the node is outside the field of definition with a right profile of the EXCLU type node: $N1$	8,5.182	1 the node is outside the field of definition with a right profile of the EXCLU type node: $N62$
10.100		1 the node is outside the field of definition with a right profile of the EXCLU type node: $N2$	5,56755	1 the node is outside the field of definition with a right profile of the EXCLU type node: $N62$
100	95,1712	1 the node is outside the field of definition with a right profile of the EXCLU type node: $N3$	1,81091	1 the node is outside the field of definition with a right profile of the

EXCLU type node: $N62$

The values maximum and minimum of the stresses $SIYY$ to times $t=0\text{s}$ and $t=11\text{s}$

Urgent Case not

attached (s)	**Maximum stress $SIYY$ max**	**Number of meshes reached by $SIYY$ max and number of meshes**	**Forced minimal $SIYY$ the min**	**Number of meshes reached by $SIYY$ min and number from meshes**
the 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 $T=0°C$),

Time (s)	**Maximum stress $SIYY$ max**	**Number of meshes reached by $SIYY$ max and number of meshes**	**Forced minimal $SIYY$ the min**	**Number of meshes reached by $SIYY$ min and number from meshes**
the 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 $T=100°C$),

Time (s)	Maximum stress $SIYY$ max	Number of meshes reached by $SIYY$ max and number of meshes	Forced minimal $SIYY$ the min	Number of meshes reached by $SIYY$ min and number from meshes
the 11	138,5	1 mesh: $M21$	– 502,563	1 mesh: $M2$

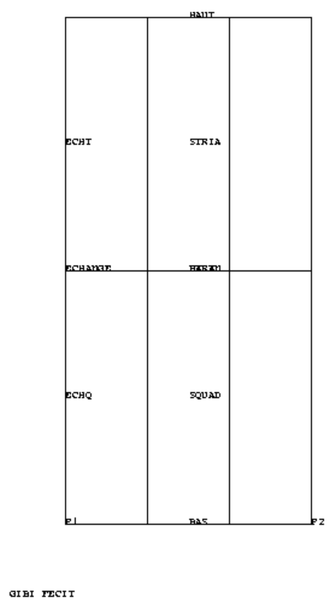
2.2 Bibliographical reference

Documentation of validation [V7.01.100].

3 Modelization A

3.1 Characteristic of the modelization

The modelization A corresponds to the statement of the TP. It comprises only the first thermal computation (without diagonalization of the thermal mass). The mesh comprises 3 meshes `QUAD4` in the thickness (mesh GIBI).



3.2 Characteristics of the mesh

the 6 meshes

useful edges for the boundary conditions are defined by the mesh groups:

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

3.3 Quantities tested and results

Temperature	time	Identification	Reference	*Aster*	% difference
maximum	4	temp max	126.314	126.314	0

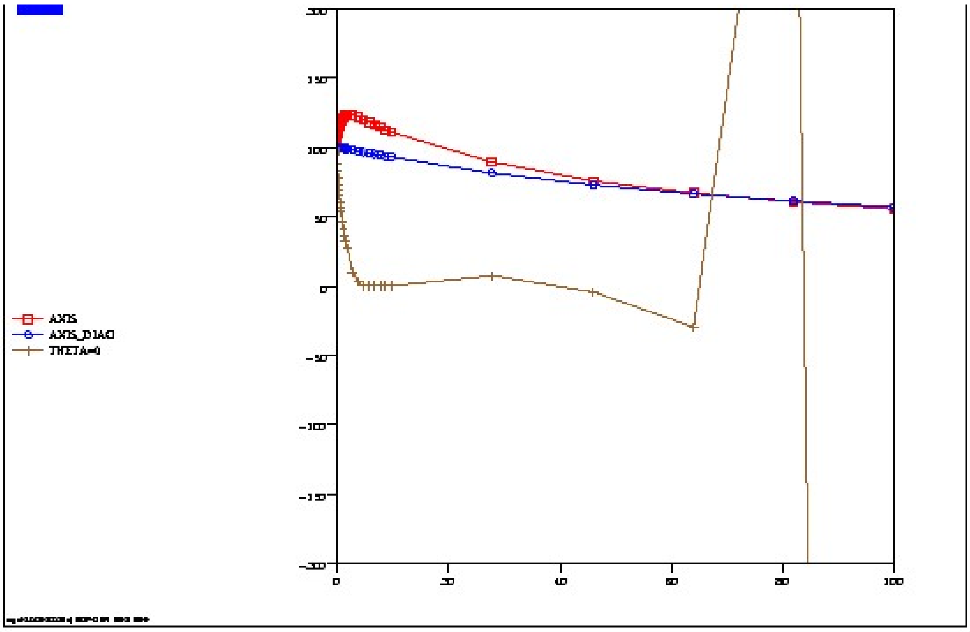
Note: :

This modelization comprises only one test of non regression. It is the starting point of the TP, intended to improve the modelization (cf modelization 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 Modelization B

4.1 Characteristic of the modelization

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



Appear 5.1-a

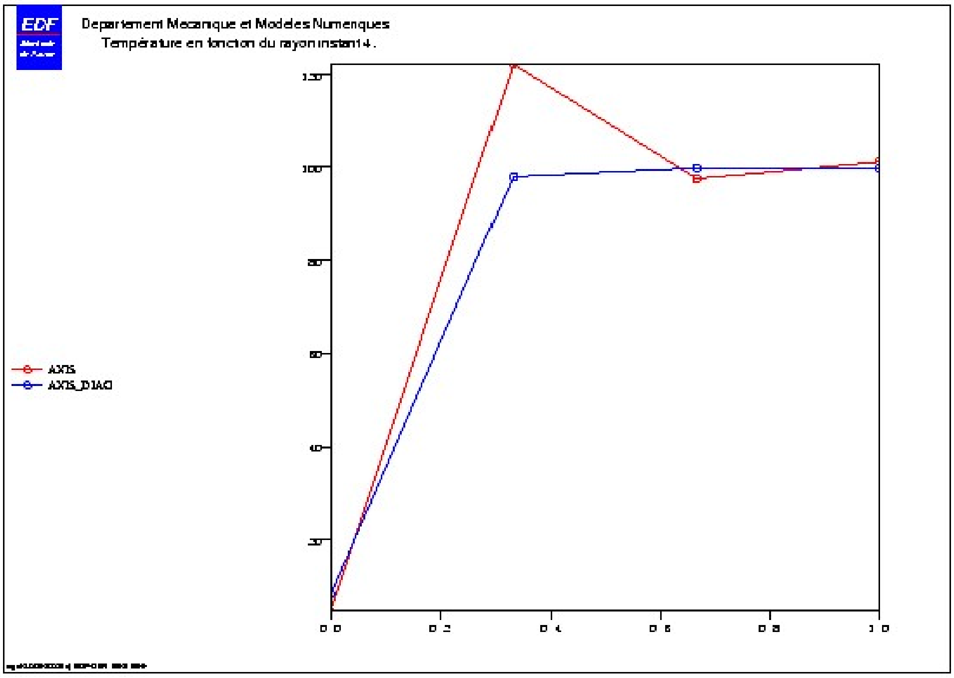


Figure 5.1-b

4.1.1 Thermal computation

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

- one can increase time step, which is not always compatible with the good apprehension of the speed of the transient (as in this case),
- or to refine the mesh, which is a good solution, but expensive in time computation,
- one can finally use the diagonalization of the thermal mass matrixes, i.e. here modelization `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 an explicit diagram ($THETA=0$), one sees time step appearing a clear instability for the large ones (curve with marker system on the figure [Figure 5.1-a] above).

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

4.1.2 Thermo-elastic computation in free thermal expansion

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

For mechanical computation, it will be enough to calculate at times $t=0\text{s}$, and $t=11\text{s}$ for example.

The stresses at time $t=0\text{s}$ are null, because the field of temperature is uniform ($T=200°C$) and remains compatible. On the other hand the strains obtained are not null since the reference temperature is equal to $200°C$.

A $t=11\text{s}$, or any other positive mechanical time, one sees appearing stresses known as of compatibility thermals. Indeed, the field of temperature is not uniform any more but varies according to r . This produced of the incompatible strains, which thus generate stresses, even for a cylinder not attached. This situation occurs even for a linear field of temperature compared to the radius. On the other hand (cf exposed) a field of temperature linear compared to the total coordinates does not produce a stress for a not attached structure.

4.1.3 Thermo-elastic computation with fastening

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

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

4.1.4 Thermoplastic computation with fastening

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

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

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

4.1.5 Thermoplastic computation with fastening and addition of initial conditions

One modifies the list of times: one adds one preliminary time $t=-1\text{s}$ for example. In this time, one defines a field of uniform temperature, equal to the reference temperature. One uses for this purpose commands CREA_CHAMP , then CREA_RESU to enrich the data structure thermal results with this uniform field. One carries out then mechanical computation, by providing the list of times: $t=-1\text{s}$ $t=0\text{s}$, and $t=11\text{s}$
It is noted whereas time $t=0\text{s}$ is well calculated, and that the stresses are identical to the case calculated with MECA_STATIQUE .

4.2 Characteristics of the mesh

Even mesh that for modelization A.

4.3 Grandeurs tested and values

Modelization AXIS_DIAG

Temperature	**time**	**Identification**	**Reference**	***Aster***	**% difference**
maximum	4	temp max	100.100		0

5 Summary of the results

This test is relating to training thermoplasticity. It shows the utility of the choice of modelization DIAG (diagonalized thermal mass matrix) for thermal computations, and famous in incremental thermomechanics (command STAT_NON_LINE) how to take into account the initial state correctly.