COMP010 – Thermomechanical validation of the elastoviscoplastic laws

Summary

This test makes it possible to validate the taking into account of the temperature variation in the elastoviscoplastic laws of behavior. These tests make it possible to check the two following points:

- Thermal dilation is well calculated (with taking into account of the variation of thermal dilation with the temperature)
- The variation of the coefficients material with the temperature is correct, in particular in the incremental resolution of the behavior,

The laws of behaviors validated are the following ones:

- Modeling A : this modeling makes it possible to validate the model GRAN_IRRA_LOG ,
- Modeling B : this modeling makes it possible to validate the model LEMAITRE,
- Modeling C : this modeling makes it possible to validate the model LEMA_SEUIL ,
- Modeling D : this modeling makes it possible to validate the model LEMAITRE_IRRA,
- Modeling E : this modeling makes it possible to validate the model VISC_IRRA_LOG,
- Modeling F : this modeling makes it possible to validate the model VISC_TAHERI,
- Modeling G : this modeling makes it possible to validate the model ROUSS_VISC,
- Modeling H : this modeling makes it possible to validate the model VISCOCHAB .
- Modeling I : this modeling makes it possible to validate the model META_LEMA_ANI .

1 Methodology

It is about a double simulation, the first in thermomechanics, the second in pure mechanics. The first will be validated in comparison with the second, by supposing of course that the behavior tested provides a correct solution in pure mechanics.

The first simulation (thermomechanical solution which one seeks to validate) consists in applying a temperature variation to a material point, with a worthless deformation imposed according to the axis x : $\varepsilon_{xx}=0$. The imposed temperature is increasing linearly according to time . The temperature varies $T_0=0°C$ with $T_{max}=500°C$. The transient is made up of NCAL pas. La temperature of reference is of $T_{ref}=0°C$.

The second simulation (which must be equivalent to the first) consists in applying to the same material point a deformation imposed according to x : $\varepsilon_{xx}=-\varepsilon^{th}=-\alpha(T)(T-T_{ref})$, in pure mechanics on NCAL moments of calculations thermomechanics. With each calculation i , the imposed loading is made up by the thermal deformation $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and internal variables of preceding mechanical calculation, the constraints being corrected variation of the Young modulus

Indeed, for any behavior (while supposing the additive decomposition of the deformations):

$$\sigma_{xx}=E(T)(\varepsilon_{xx}-\varepsilon^{th}-\varepsilon_{xx}^{p})$$

in the first case, $\sigma_{xx}=E(T)(0-\varepsilon^{th}-\varepsilon_{xx}^{p})$, and in the second: $\sigma_{xx}=E(T)(\varepsilon-\varepsilon_{xx}^{p})$.

It is thus enough, at every moment to apply, for mechanical calculation, $\varepsilon_{xx}=-\varepsilon^{th}=-\alpha(T)(T-T_{ref})$.

Moreover, to get the same results in both cases, it is necessary, with each step of time of the second simulation, to carry out pure mechanical calculation with coefficients whose values are interpolated according to the temperature at the current moment. This interpolation is carried out in the command file of the test, in a loop in time external with SIMU_POINT_MAT/STAT_NON_LINE .

2 Interpretation of the results

It is a question of checking with TEST_TABLE that at every moment got result of the mechanical transient thermo of the first simulation is identical to the result got with the second simulation.

The validation is done by the comparison between the computed fields with each step of the transient on the one hand and the result of a mechanical calculation on the other hand. The value of reference being the component of the field extracted to a given moment i the first thermomechanical simulation carried out on NCAL moments. The computed value is that obtained at the end of mechanical calculation $i+1$ loop on NCAL.

3 Modeling A

3.1 Law of behavior and parameters materials

The law of behavior tested 'GRAN_IRRA_LOG', is documented in documentation [R5.03.09]. It is a law of behavior of creep and growth under irradiation for the fuel assemblies, similar to the law 'VISC_IRRA_LOG' for the viscoplastic deformation, which integrates in more one deformation of growth under irradiation. The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The elastoplastic parameters are the following:

A, B, ω, Φ, Q, a, b and s

Values of the parameters used:

Parameters	$T=0°C$	$T=500°C$
$E(T)$	$1.E5\,MPa$	$0.8E5\,MPa$
$\nu(T)$	0.	0.
$\alpha(T)$	$1.E-5\,K^{-1}$	$2.E-5\,K^{-1}$
A	$1.28E-1$	$1.28E-1$
B	0.01159	0.01159
C	0.	0.
ω	0.3540	0.3540
Φ	1.	1.
Q	5000.	5000.
a	$-1.51E-16$	$-1.51E-16$
b	$1.542E-13$	$1.542E-13$
s	0.396	0.396

3.2 Sizes tested and results

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	VMIS (MPa)	AUTRE_ASTER	201.09766	0.10%
RESU_19	TRACE (MPa)	AUTRE_ASTER	-201.09766	0.10%
RESU_19	V1	AUTRE_ASTER	7.486279	0.10%

4 Modeling B

4.1 Law of behavior and parameters materials

The law of behavior tested 'LEMAITRE', is documented in documentation [R5.03.08]. It is about a non-linear viscoplastic law of LEMAITRE without threshold. The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The parameters elastoviscoplastic are the following:

$N(T)$, $1/K(T)$ and $1/M(T)$

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	$1.\mathrm{E}5\,MPa$	$2.\mathrm{E}5\,MPa$
$\nu(T)$	$0.$	$0.$
$\alpha(T)$	$2.E-5\,K^{-1}$	$2.E-5\,K^{-1}$
$N(T)$	10.8	8.0
$1/K(T)$	$6.9\mathrm{E}-4(MPa)^{-1}$	$4.0\mathrm{E}-4(MPa)^{-1}$
$1/M(T)$	0.102	0.05

4.2 Sizes tested and results

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	VMIS (MPa)	AUTRE_ASTER	1037.97825	0.10%
RESU_19	TRACE (MPa)	AUTRE_ASTER	-1037.97825	0.10%
RESU_19	V1	AUTRE_ASTER	4.410109E-3	0.10%

5 Modeling C

5.1 Law of behavior and parameters materials

The law of behavior tested 'LEMA_SEUIL', is documented in documentation [R5.03.08]. It is about a viscoplastic law with threshold under irradiation for the fuel assemblies. The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The parameters elastoviscoplastic are the following:

$A(T)$ and $S(T)$

Values of the parameters used:

Parameters	$T=0°C$	$T=500°C$
$E(T)$	$1.\text{E}5\,MPa$	$0.8\text{E}5\,MPa$
$\nu(T)$	$0.$	$0.$
$\alpha(T)$	$1.0\text{E}-4\,K^{-1}$	$2.0\text{E}-4\,K^{-1}$
$A(T)$	$1.0\text{E}-10$	$0.5\text{E}-10$
$S(T)$	$40.$	$20.$

5.2 Results

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	VMIS (MPa)	AUTRE_ASTER	499.998221	0.10%
RESU_19	TRACE (MPa)	AUTRE_ASTER	-499.998221	0.10%
RESU_19	V1	AUTRE_ASTER	3.557036E-8	0.10%
RESU_19	V2	AUTRE_ASTER	10.421848	0.10%

6 Modeling D

6.1 Simulation 1

It is about a thermomechanical test with a worthless deformation imposed according to the axis x. The test is carried out on a material point with the order SIMU_POINT_MAT. The temperature varies $T_0=20°C$ with $T_{max}=500°C$. The transient is made up of NCAL not.
The temperature of reference is of $T_{Ref}=20°C$.

6.2 Simulation 2

It is a question of carrying out a loop on NCAL mechanical calculations. With each calculation i, the imposed loading is made up by the thermal deformation $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and internal variables of preceding mechanical calculation.

6.3 Law of behavior and parameters materials

The law of behavior tested, 'LEMAITRE_IRRA ', is documented in documentation [R5.03.08]. It is about a law of behavior of creep and growth under irradiation for the fuel assemblies.

The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The parameters elastoviscoplastic are the following:

N, $1/M$, $1/K$, L, ϕ_0, β, Q/K, a, b, and S

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	$2.E5\,MPa$	$1.E5\,MPa$
$\nu(T)$	0.0	0.0
$\alpha(T)$	$1.0E-5\,K^{-1}$	$2.0E-5\,K^{-1}$
$1/K$	$1.E-6\,MPa^{-1}$	$1.E-6\,MPa^{-1}$
$1/M$	0.207060772	0.207060772
N	2.3364	2.3364
L	0.	0.
ϕ_0	4.240281E+21	4.240281E+21
β	1.2	1.2
Q/K	3321.093	3321.093
a	−1.51E−16	−1.51E−16
b	1.542E−13	1.542E−13
S	0.396	0.396

6.4 Results

The validation is done by the comparison between the computed fields with each step of the transient on the one hand and the result of a mechanical calculation on the other hand.

The order used is TEST_TABLE who tests the value of reference compared to the computed value.

The value of reference being the component of the field extracted to a given moment i the first thermomechanical simulation carried out on NCAL moments. The computed value is that obtained at the end of mechanical calculation $i+1$ loop on NCAL.

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	VMIS (Pa)	AUTRE_ASTER	1000.	0.10%
RESU_19	TRACE (Pa)	AUTRE_ASTER	-1000.	0.10%

7 Modeling E

7.1 Simulation 1

It is about a thermomechanical test with a worthless deformation imposed according to the axis x. The test is carried out on a material point with the order `SIMU_POINT_MAT`. The temperature varies $T_0=0°C$ with $T_{max}=500°C$. The transient is made up of `NCAL` not.
The temperature of reference is of $T_{Ref}=0°C$.

7.2 Simulation 2

It is a question of carrying out a loop on `NCAL` mechanical calculations. With each calculation i, the imposed loading is made up by the thermal deformation $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and internal variables of preceding mechanical calculation.

7.3 Law of behavior and parameters materials

The law of behavior tested `'VISC_IRRA_LOG'`, is documented in documentation [R5.03.09]. Law of axial creep under irradiation of the fuel assemblies. It makes it possible to model primary education and secondary creep, parameterized by the neutron fluence.

The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The parameters elastoviscoplastic are the following:

A, B, ϕ, ω and Q

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	$195000.Mpa$	$180000.Mpa$
$\nu(T)$	$0.$	$0.$
$\alpha(T)$	$10^{-5}K^{-1}$	$2.\times10^{-5}K^{-1}$
A	0.128	0.128
B	0.01159	0.01159
ϕ	10^{-4}	10^{-4}
ω	0.3540	0.3540
Q	$5000.$	$5000.$

7.4 Results

The validation is done by the comparison between the computed fields with each step of the transient on the one hand and the result of a mechanical calculation on the other hand.

The order used is TEST_TABLE who tests the value of reference compared to the computed value. The value of reference being the component of the field extracted to a given moment i the first thermomechanical simulation carried out on NCAL moments. The computed value is that obtained at the end of mechanical calculation $i+1$ loop on NCAL.

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	VMIS (MPa)	AUTRE_ASTER	1799.49858	0.10%
RESU_19	TRACE (MPa)	AUTRE_ASTER	-1799.49858	0.10%
RESU_19	V1	AUTRE_ASTER	2.78565E-6	0.10%

8 Modeling F

8.1 Simulation 1

It is about a thermomechanical test with a worthless deformation imposed according to the axis x. The test is carried out on a material point with the order SIMU_POINT_MAT. The temperature varies $T_0=20°C$ with $T_{max}=500°C$. The transient is made up of NCAL not.
The temperature of reference is of $T_{Ref}=20°C$.

8.2 Simulation 2

It is a question of carrying out a loop on NCAL mechanical calculations. With each calculation i, the imposed loading is made up by the thermal deformation $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and internal variables of preceding mechanical calculation.

8.3 Law of behavior and parameters materials

The law of behavior tested 'VISC_TAHERI', is documented in documentation [R5.03.05]. It is about a law of behavior (visco) - plastic modelling the material answer under cyclic plastic loading, and in particular making it possible to represent the effects of ratchet.

The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The viscoplastic parameters are the following:

S, C_∞, C_1, b, m, A, α and R_0

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	$200\,000.\,MPa$	$180\,000.\,MPa$
$\nu(T)$	0.	0.
$\alpha(T)$	$1.0E-5\,K^{-1}$	$2.0E-5\,K^{-1}$
S	450.	400.
C_∞	0.065	0.06
C_1	−0.012	−0.01
b	30.	20.
m	0.1	0.15
A	312.	200.
α	0.3	0.25
R_0	72.	50.

8.4 Results

The validation is done by the comparison between the computed fields with each step of the transient on the one hand and the result of a mechanical calculation on the other hand.

The order used is TEST_TABLE who tests the value of reference compared to the computed value. The value of reference being the component of the field extracted to a given moment i the first thermomechanical simulation carried out on NCAL moments. The computed value is that obtained at the end of mechanical calculation $i+1$ loop on NCAL.

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	VMIS (MPa)	AUTRE_ASTER	117.329035	0.10%
RESU_19	TRACE (MPa)	AUTRE_ASTER	-117.329035	0.10%
RESU_19	V1	AUTRE_ASTER	8.948172E-3	0.10%
RESU_19	V2	AUTRE_ASTER	117.329035	0.10%
RESU_19	V9	AUTRE_ASTER	3.0	0.10%

9 Modeling G

9.1 Simulation 1

It is about a thermomechanical test with a worthless deformation imposed according to the axis x. The test is carried out on a material point with the order SIMU_POINT_MAT. The temperature varies $T_0 = T_{ref} = 20°C$ with $T_{max} = 800°C$. The transient is made up of NCAL=30 not.

9.2 Simulation 2

It is a question of carrying out a loop on NCAL mechanical calculations. With each calculation i, the imposed loading is made up by the thermal deformation $\varepsilon_{xx} = -\varepsilon_{th} = -\alpha(T)(T_i - T_{Ref})$. The initial loading is made up by the strains, stresses and internal variables of preceding mechanical calculation.

9.3 Law of behavior and parameters materials

The law of behavior tested 'ROUSS_VISC', is documented in documentation [R5.03.07]. It is about a law behavior elastoviscoplastic of Rousselier to model the ductile rupture.
parameters of the behavior are the following:

Parameters	$T=20°C$	$T=800°C$
$E(T)$	$210000.\ MPa$	$100000.\ MPa$
$\nu(T)$	0.	0.
$\alpha(T)$	$10^{-5} K^{-1}$	$2.\times 10^{-5} K^{-1}$
$\sigma_1(T)$	500.	450.
$\beta(T)$	1.	1.
$f_0(T)$	5.10^{-4}	3.10^{-4}
$D(T)$	1.5	2.5
$\sigma_0(T)$	800,	800,
$\varepsilon(T)$	1.10^{-2}	1.10^{-2}
m	2	2

as well as the traction diagrams:

$T=20°C$

ε	$\sigma(MPa)$
800/210000.	800
1.005	1600,

$T=800°C$

ε	$\sigma(MPa)$
600/100000.	600
1.005	1200

9.4 Results

The validation is done by the comparison between the computed fields with each step of the transient on the one hand and the result of a mechanical calculation on the other hand.

The order used is TEST_TABLE who tests the value of reference compared to the computed value.
The value of reference being the component of the field extracted to a given moment i the first thermomechanical simulation carried out on NCAL moments. The computed value is that obtained at the end of mechanical calculation $i+1$ loop on NCAL.

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_29	VMIS (MPa)	AUTRE_ASTER	709.6639	0.11%
RESU_29	TRACE (MPa)	AUTRE_ASTER	-709.6639	0.11%
RESU_29	V1	AUTRE_ASTER	8.5046E-3	0.11%
RESU_29	V2	AUTRE_ASTER	4.9887E-4	0.11%
RESU_29	V3	AUTRE_ASTER	0.1229	0.11%
RESU_29	V5	AUTRE_ASTER	1	0.11%

10 Modeling H

10.1 Simulation 1

It is about a thermomechanical test with a worthless deformation imposed according to the axis x. The test is carried out on a material point with the order SIMU_POINT_MAT. The temperature varies $T_0=20°C$ with $T_{max}=200°C$. The transient is made up of $NCAL=100$ not.
The temperature of reference is of $T_{Ref}=20°C$.

10.2 Simulation 2

It is a question of carrying out a loop on NCAL mechanical calculations. With each calculation i, the imposed loading is made up by the thermal deformation $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and internal variables of preceding mechanical calculation.

10.3 Law of behavior and parameters materials

The law of behavior tested 'VISCOCHAB', is documented in documentation [R5.03.12]. It is about a elastoviscoplastic law of behavior of J.L.Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the tensorial variables of recall, an effect of memory of greatest work hardening, and effects of restoration.

The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The parameters elastoviscoplastic are them following:

$K(T)$, $\alpha_K(T)$, $\alpha_R(T)$, $K_0(T)$, $N(T)$, $\alpha(T)$, $B(T)$, $M_R(T)$, $G_R(T)$, $MU(T)$, $Q_0(T)$, $Q_M(T)$, $QR_0(T)$, $ETA(T)$, $C1(T)$, $M_1(T)$, $D1(T)$, $G_{X1}(T)$ $G1_0(T)$, $C2(T)$, $M_2(T)$, $d2(T)$, $G\_X2(T)$, $G2\_0(T)$, and $a_\infty(T)$

Values of the parameters used:

Parameters	$T=20°C$	$T=200°C$
$E(T)$	$150000.\ MPa$	$100000.\ MPa$
$\nu(T)$	0.	0.
$\alpha(T)$	$10^{-5}K^{-1}$	$2.\times10^{-5}K^{-1}$
$K(T)$	25.	40.
$\alpha_K(T)$	1.	1.
$\alpha_R(T)$	0.5	0.8
$K_0(T)$	60	80
$N(T)$	30	15
$\alpha(T)$	0.	0.
$B(T)$	15.	15.

Parameters	$T=20°C$	$T=200°C$
$M_R(T)$	2.	2.
$G_R(T)$	2.5×10^{-7}	1.5×10^{-7}
$MU(T)$	22	16
$Q_0(T)$	40	45
$Q_M(T)$	500	400
$QR_0(T)$	150	250
$ETA(T)$	0.06	0.03
$C1(T)$	1600	1600
$M_1(T)$	3	5
$D1(T)$	0.36×10^{-3}	0.42×10^{-3}
$G_{X1}(T)$	2.5×10^{-13}	1.5×10^{-13}
$G1_0(T)$	40	60
$C2(T)$	55000	55000
$M_2(T)$	5	3.5
$d2(T)$	0.05	0.06
$G\_X2(T)$	$0,8\times10^{-12}$	1.5×10^{-12}
$G2\_0(T)$	1500	1000
$a_\infty(T)$	0.41	0.56

10.4 Results

The validation is done by the comparison between the computed fields with each step of the transient on the one hand and the result of a mechanical calculation on the other hand.

The order used is TEST_TABLE who tests the value of reference compared to the computed value. The value of reference being the component of the field extracted to a given moment i the first thermomechanical simulation carried out on NCAL moments. The computed value is that obtained at the end of mechanical calculation $i+1$ loop on NCAL.

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	VMIS (MPa)	AUTRE_ASTER	146.87158	0.0%
RESU_19	TRACE (MPa)	AUTRE_ASTER	-146.87143	0.10%
RESU_19	V1	AUTRE_ASTER	-2.14218	0.10%
RESU_19	V2	AUTRE_ASTER	1.0719	0.10%
RESU_19	V3	AUTRE_ASTER	1.0719	0.10%

11 Modeling I

11.1 Simulation 1

It is about a thermomechanical test with a worthless deformation imposed according to the axis x. The test is carried out on an element HEXA8 with the order STAT_NON_LINE. The temperature varies $T_0=700°C$ with $T_{max}=1000°C$. The transient is made up of NCAL not.
The temperature of reference is of $T_{Ref}=700°C$.

11.2 Simulation 2

It is a question of carrying out a loop on NCAL mechanical calculations. With each calculation i, the imposed loading is made up by the thermal deformation $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and internal variables of preceding mechanical calculation.

11.3 Law of behavior and parameters materials

The law of behavior tested, 'META_LEMA_ANI ', is documented in documentation [R4.04.05]. It is about a law of behaviour of creep of the sheath of the fuel pin with taking into account of the metallurgical transformations.
The two metallurgical phases are supposed here to have isotropic mechanical properties.

The elastic parameters are the following:

$E(T)$, $\nu(T)$ and $\alpha(T)$

The parameters elastoviscoplastic are the following:

a_1, Q_1, n_1, m_1, a_2, Q_2, n_2, m_2, a_3, Q_3, n_3, m_3

Values of the parameters used:

Parameters	$T=700°C$	$T=1000°C$
$E(T)$	$80000.MPa$	$40000.MPa$
$\nu(T)$	0.35	0.35
$\alpha(T)$	$10^{-5}K^{-1}$	$2.\times 10^{-5}K^{-1}$

Parameters elastoviscoplastic cities above are independent of the temperature: only the phase shifts modify the properties of material:

	$i=1$: phase α	$i=2$: phase $\alpha\beta$	$i=3$: phase β
a_i	$2.39MPa$	$0.22MPa$	$9.36MPa$
Q_i	$19922.8K$	$21023.7K$	$6219K$
n_i	4.39	2.96	6.11
m_i	$0.$	0.000077	0.000099

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11.4 Results

The validation is done by the comparison between the computed fields with each step of the transient on the one hand and the result of a mechanical calculation on the other hand.

The order used is TEST_TABLE who tests the value of reference compared to the computed value.

The value of reference being the component of the field extracted to a given moment i the first thermomechanical simulation carried out on NCAL moments. The computed value is that obtained at the end of mechanical calculation $i+1$ loop on NCAL.

Result with the sequence number i	Name of the parameter tested	Type of reference	Value of reference	tolerance
RESU_19	SIYY (MPa)	AUTRE_ASTER	-11,815 97	0.10%
RESU_19	V1	AUTRE_ASTER	0.0057046	0.10%

12 Synthesis

This test makes it possible to validate the taking into account of the temperature variation in the élasto-viscoplastic laws of behavior. These tests make it possible to check the two following points:

- Thermal dilation is well calculated (with taking into account of the variation of thermal dilation with the temperature)
- The variation of the coefficients material with the temperature is correct, in particular in the incremental resolution of the behavior,

For all the laws of behaviors tested in present modelings, these two criteria are well checked, because calculations differences between thermomechanical calculation and pure mechanical calculation with interpolation is numerically worthless.