COMP009 – Thermomechanical *validation of the modelization BARS*

Summarized

This test makes it possible to validate the taking into account of the variation in temperature in the constitutive laws available with the modelization BARS. These tests make it possible to check the following points:

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

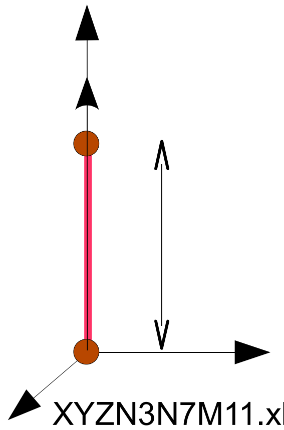
the validated constitutive laws are the following ones:

- Modelization A : this modelization makes it possible to validate ELAS , Modelization
- the model B : this modelization makes it possible to validate VMIS_ISOT_LINE , Modelization
- the model C : this modelization makes it possible to validate VMIS_ISOT_TRAC , Modelization
- the model D : this modelization makes it possible to validate VMIS_CINE_LINE , Modelization
- the model F : this modelization makes it possible to validate the model PINTO_MENEGOTTO,

1 Methodology

mesh used is composed of only one mesh SEG2, on which one affects a modelization of the type BARS. The ends of the bar are clamped, no axial strain is not possible.

Nodes N3 and N7 : $DX=DY=DZ=0.$
Section: $A=1.$



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 (solution which one seeks to validate) consists in applying a variation in temperature to the element BARS , by blocking for example displacements along the local x axis: $\varepsilon_{xx}=0$. The imposed temperature is increasing linearly according to time.

The second simulation (which must be equivalent to the first) consists in applying to the element a strain imposed according to the direction x : $\varepsilon_{xx}=-\varepsilon^{th}=-\alpha(T)(T-T_{ref})$, in pure mechanics. Indeed, for any behavior (while supposing the additive decomposition of the strains) one a:

$\sigma_{xx}=E(T)(\varepsilon_{xx}-\varepsilon^{th}-\varepsilon^{p}_{xx})$ with for normal force $N=A\sigma_{xx}$

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

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

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

2 Interpretation of the results

It acts to check with TEST_TABLE that result at every moment obtained mechanical transient thermo of the first simulation identical to is result obtained with the second simulation.

3 Modelization A

3.1 Characteristic of the modelization

3.1.1 Simulation 1

It acts of a thermomechanical test with a strain imposed null according to the local x axis. The test is carried out on an element of BAR with command STAT_NON_LINE. The temperature varies from $T_0=20$ with $T_{max}=500°C$. The transient consists of NCAL not.
The reference temperature is of $T_{ref}=20°C$.

3.1.2 Simulation 2

It acts to carry out a loop on NCAL mechanical computations. A each computation i, the imposed loading is made up by the thermal strain $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses (normal force) and local variables of preceding mechanical computation.

3.2 Properties of the material

the constitutive law tested is "ELAS". This model is elastic.

The elastic parameters are the following:

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

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	200000. MPa	100000. MPa
$\nu(T)$	0.	0.
$\alpha(T)$	1.E−5 K^{-1}	2.E−5 K^{-1}

3.3 Quantities tested and results

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

The command used is TEST_TABLE which tests the value of reference compared to the computed value.

The value of reference being the component of the field extracted to a time given i the first mechanical simulation thermo carried out on urgent NCAL. The computed value is that obtained at the end of the mechanical computation $i+1$ of the loop on the NCAL.

Result at the sequence number i	Name of the parameter tested	Standard of reference	Value of reference	tolerance
RESU_i	NOM_PARA		VALE_REF	TOLE

RESU_4	N	NON_REGRESSION	-960.	0.1%

4 Modelization B

4.1 Characteristic of the modelization

4.1.1 Simulation 1

It acts of a thermomechanical test with a strain imposed null according to the axis x. The test is carried out on an element of BAR with command STAT_NON_LINE. The temperature varies from $T_0=20°C$ with $T_{max}=500°C$. The material arrives at plasticization. The transient consists of NCAL not. The reference temperature is of $T_{ref}=20°C$.

4.1.2 Simulation 2

It acts to carry out a loop on NCAL mechanical computations. A each computation i, the imposed loading is made up by the thermal strain $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and local variables of preceding mechanical computation.

4.2 Properties of the material

the constitutive law tested is "VMIS_ISOT_LINE" documented in Doc. [R5.03.09]. This model is with symmetric linear isotropic hardening.

The elastic parameters are the following:

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

elastoplastic parameters are the following:

$\sigma_y(T)$, $E_T(T)$

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	200000. MPa	100000. MPa
$\nu(T)$	0.	0.
$\alpha(T)$	10^{-5} K^{-1}	$2.\times10^{-5}$ K^{-1}
$\sigma_y(T)$	100. MPa	50. MPa
$E_T(T)$	10000. MPa	5000. MPa

4.3 Quantities tested and results

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

The command used is TEST_TABLE which tests the value of reference compared to the computed value.

The value of reference being the component of the field extracted to a time given i the first mechanical simulation thermo carried out on urgent NCAL. The computed value is that obtained at the end of the mechanical computation $i+1$ of the loop on the NCAL.

Result at the sequence number i	Name of the parameter tested	Standard of reference	Value of reference	Tolerance
RESU_i	NOM_PARA		VALE_REF	TOLE
RESU_19	N	NON_REGRESSION	-95.5	0.1%
RESU_19	V1	NON_REGRESSION	8.645E-03	0.1%

5 Modelization C

5.1 Characteristic of the modelization

5.1.1 Simulation 1

It acts of a thermomechanical test with a strain imposed null according to the axis x. The test is carried out on an element of BAR with command STAT_NON_LINE. The temperature varies from $T_0=20°C$ with $T_{max}=500°C$. The material arrives at plasticization. The transient consists of NCAL not. The reference temperature is of $T_{ref}=20°C$.

5.1.2 Simulation 2

It acts to carry out a loop on NCAL mechanical computations. A each computation i, the imposed loading is made up by the thermal strain $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and local variables of preceding mechanical computation.

5.2 Properties of the material

the constitutive law tested is "VMIS_ISOT_TRAC" documented in Doc. [R5.03.09]. This model is with nonlinear isotropic hardening.

The elastic parameters are the following:

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

elastoplastic parameters are the following:

$\sigma(\varepsilon, T)$

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	200000. MPa	100000. MPa
$\nu(T)$	0.	0.
$\alpha(T)$	1.E−5 K^{-1}	2.E−5 K^{-1}

Parameter	Temperature	$\varepsilon=0.005$	$\varepsilon=1.005$
$\sigma(\varepsilon, T)$	$20°C$	1000. MPa	3000. MPa
	$500°C$	800. MPa	2000. MPa

5.3 Quantities tested and results

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

The command used is TEST_TABLE which tests the value of reference compared to the computed value.

The value of reference being the component of the field extracted to a time given i the first mechanical simulation thermo carried out on urgent NCAL. The computed value is that obtained at the end of the mechanical computation $i+1$ of the loop on the NCAL.

Result at the sequence number i	Name of the parameter tested	Standard of reference	Value of reference	Tolerance
RESU_i	NOM_PARA		VALE_REF	TOLE
RESU_19	N	NON_REGRESSION	-801.926	0.1%
RESU_19	V1	NON_REGRESSION	1.5807E-3	0.1%

6 Modelization D

6.1 Characteristic of the modelization

6.1.1 Simulation 1

It acts of a thermomechanical test with a strain imposed null according to the axis x. The test is carried out on an element of BAR with command STAT_NON_LINE. The temperature varies from $T_0=20°C$ with $T_{max}=100°C$. The material arrives at plasticization. The transient consists of NCAL not. The reference temperature is of $T_{ref}=20°C$.

6.1.2 Simulation 2

It acts to carry out a loop on NCAL mechanical computations. A each computation i, the imposed loading is made up by the thermal strain $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and local variables of preceding mechanical computation.

6.2 Properties of the material

the constitutive law tested is "VMIS_CINE_LINE" documented in Doc. [R5.03.09]. This model is with symmetric linear kinematic hardening.

The elastic parameters are the following:

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

elastoplastic parameters are the following:

$\sigma_y(T)$, $E_T(T)$

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	2.E11 Pa	1.E11 Pa
$\nu(T)$	0.	0.
$\alpha(T)$	1.E−5 K^{-1}	2.E−5 K^{-1}
$\sigma_y(T)$	2.E8 Pa	1.E8 Pa
$E_T(T)$	2.E9 Pa	1.E9 Pa

6.3 Quantities tested and results

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

The command used is TEST_TABLE which tests the value of reference compared to the computed value.

The value of reference being the component of the field extracted to a time given i the first mechanical simulation thermo carried out on urgent NCAL. The computed value is that obtained at the end of the mechanical computation $i+1$ of the loop on the NCAL.

Result at the sequence number i	Name of the parameter tested	Standard of reference	Value of reference	Tolerance
RESU_i	NOM_PARA		VALE_REF	TOLE
RESU_19	N	NON_REGRESSION	-1.086E8	0.1%
RESU_19	V1	NON_REGRESSION	-8.6E6	

7 Modelization F

7.1 Characteristic of the modelization

7.1.1 Simulation 1

It acts of a thermomechanical test with a strain imposed null according to the axis x. The test is carried out on an element of BAR with command STAT_NON_LINE. The temperature varies from $T_0=20°C$ with $T_{max}=100°C$. The material arrives at plasticization. The transient consists of NCAL not. The reference temperature is of $T_{ref}=20°C$.

7.1.2 Simulation 2

It acts to carry out a loop on NCAL mechanical computations. A each computation i, the imposed loading is made up by the thermal strain $\varepsilon_{xx}=-\varepsilon_{th}=-\alpha(T)(T_i-T_{Ref})$. The initial loading is made up by the strains, stresses and local variables of preceding mechanical computation.

7.2 Properties of the material

the constitutive law tested is "PINTO_MENEGOTTO" documented in Doc. [R5.03.09]. This model is isothermal uniaxial elastoplastic modelling the response of steel reinforcements in the reinforced concrete under cyclic loading.

The elastic parameters are the following:

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

elastoplastic parameters are the following:

σ_y^0 ε_u σ_u ε_h b $R0$ $a1$ $a2$ L/D $a6$ c, a

Values of the parameters used:

Parameters	$T=20°C$	$T=500°C$
$E(T)$	2.1 $E11$ Pa	1.E11 Pa
$\nu(T)$	0.	0.
$\alpha(T)$	1.E−5 K^{-1}	2.E−5 K^{-1}

Parameters	
σ_y^0	2.E8 Pa
ε_u	3.E−2
σ_u	2.58E8 Pa
ε_h	0.0023
b	0.01
$R0$	20.

Parameters	
$a1$	18.5
$a2$	0.15
L/D	4.9
$a6$	620.
c	0.5
a	0.008

7.3 Quantities tested and results

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

The command used is `TEST_TABLE` which tests the value of reference compared to the computed value.

The value of reference being the component of the field extracted to a time given i the first mechanical simulation thermo carried out on `urgent` NCAL. The computed value is that obtained at the end of the mechanical computation $i+1$ of the loop on `the NCAL`.

Result at the sequence number i	Name of the parameter tested	Standard of reference	Value of reference	Tolerance
RESU_i	NOM_PARA		VALE_REF	TOLE
RESU_19	N	NON_REGRESSION	-2.58E8	0.1%
RESU_19	V4	NON_REGRESSION	-9.6E-2	
RESU_19	V5	NON_REGRESSION	-7.08E-3	

8 Summary of the results

For each studied constitutive law, the results of the mechanical transient thermo of the first simulation are compared with those obtained with the second simulation in pure mechanics. The results are concordant, which show the good taking into account of thermal thermal expansion by these constitutive laws, as well as the good dependence of materials parameters with the temperature.