

## COMP009 – Vthermomechanical alidation of modeling BARS

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### Summary

This test makes it possible to validate the taking into account of the temperature variation in the laws of behavior available with modeling `BAR`. These tests make it possible to check the 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,

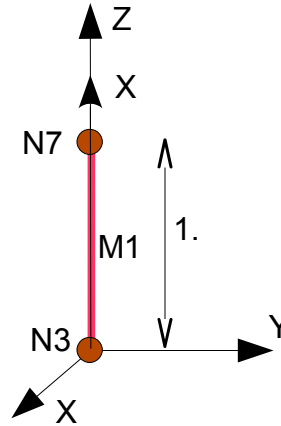
The laws of behaviors validated are the following ones:

- Modeling *A* : this modeling makes it possible to validate the model `ELAS`,
- Modeling *B* : this modeling makes it possible to validate the model `VMIS_ISOT_LINE`,
- Modeling *C* : this modeling makes it possible to validate the model `VMIS_ISOT_TRAC`,
- Modeling *D* : this modeling makes it possible to validate the model `VMIS_CINE_LINE`,
- Modeling *F* : this modeling makes it possible to validate the model `PINTO_MENEGOTTO`,

## 1 Methodology

The grid used is composed of only one nets `SEG2`, on which one affects a modeling of the type `BAR`. The ends of the bar are embedded, no axial deformation 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 temperature variation to the element `BAR`, by blocking for example displacements along the axis  $x$  room:  $\varepsilon_{xx} = 0$ . 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 deformation 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 deformations) one a:

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

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

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 `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.

## 3 Modeling A

### 3.1 Characteristics of modeling

#### 3.1.1 Simulation 1

It is about a thermomechanical test with a worthless deformation imposed according to the axis  $x$  room. The test is carried out on an element of `BAR` with the order `STAT_NON_LINE`. The temperature varies  $T_0=20$  with  $T_{max}=500^\circ C$ . The transient is made up of `NCAL` not.

The temperature of reference is of  $T_{ref}=20^\circ C$ .

#### 3.1.2 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 (normal effort) and internal variables of preceding mechanical calculation.

### 3.2 Properties of material

The law of behavior tested is 'ELAS'. This law is elastic.

The elastic parameters are the following:

$$E(T), \nu(T) \text{ and } \alpha(T)$$

Values of the parameters used:

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

### 3.3 Sizes 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 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 mechanical simulation thermo 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_i	NOM_PARA		VALE_REF	SHEET

RESU_4	NR	NON_REGRESSION	-960.	0.1%
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## 4 Modeling B

### 4.1 Characteristics of modeling

#### 4.1.1 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 of `BAR` with the order `STAT_NON_LINE`. The temperature varies  $T_0=20^\circ\text{C}$  with  $T_{max}=500^\circ\text{C}$ . The material arrives at plasticization. The transient is made up of `NCAL` pas. La temperature of reference is of  $T_{ref}=20^\circ\text{C}$ .

#### 4.1.2 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.

### 4.2 Properties of material

The law of behavior tested is 'VMIS\_ISOT\_LINE' documented in Doc. [R5.03.09]. This law is with symmetrical linear isotropic work hardening.

The elastic parameters are the following:

$$E(T), \nu(T) \text{ and } \alpha(T)$$

The elastoplastic parameters are the following:

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

Values of the parameters used:

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

## 4.3 Sizes 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 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 mechanical simulation thermo 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_ $i$	NOM_PARA		VALE_REF	SHEET
RESU_19	NR	NON_REGRESSION	-95.5	0.1%
RESU_19	V1	NON_REGRESSION	8.645E-03	0.1%

## 5 Modeling C

### 5.1 Characteristics of modeling

#### 5.1.1 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 of `BAR` with the order `STAT_NON_LINE`. The temperature varies  $T_0=20^\circ C$  with  $T_{max}=500^\circ C$ . The material arrives at plasticization. The transient is made up of `NCAL` pas. La temperature of reference is of  $T_{ref}=20^\circ C$ .

#### 5.1.2 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.

### 5.2 Properties of material

The law of behavior tested is 'VMIS\_ISOT\_TRAC' documented in Doc. [R5.03.09]. This law is with non-linear isotropic work hardening.

The elastic parameters are the following:

$$E(T), \nu(T) \text{ and } \alpha(T)$$

The elastoplastic parameters are the following:

$$\sigma(\varepsilon, T)$$

Values of the parameters used:

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

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

## 5.3 Sizes 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 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 mechanical simulation thermo 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_ $i$	NOM_PARA		VALE_REF	SHEET
RESU_19	NR	NON_REGRESSION	-801,926	0.1%
RESU_19	V1	NON_REGRESSION	1.5807E-3	0.1%



## 6 Modeling D

### 6.1 Characteristics of modeling

#### 6.1.1 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 of `BAR` with the order `STAT_NON_LINE`. The temperature varies  $T_0=20^\circ\text{C}$  with  $T_{max}=100^\circ\text{C}$ . The material arrives at plasticization. The transient is made up of `NCAL` pas. La temperature of reference is of  $T_{ref}=20^\circ\text{C}$ .

#### 6.1.2 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.

### 6.2 Properties of material

The law of behavior tested is 'VMIS\_CINE\_LINE' documented in Doc. [R5.03.09]. This law is with symmetrical linear kinematic work hardening.

The elastic parameters are the following:

$$E(T), \nu(T) \text{ and } \alpha(T)$$

Parameters elastoplastic are the following:

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

Values of the parameters used:

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

## 6.3 Sizes 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 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 mechanical simulation thermo 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_ $i$	NOM_PARA		VALE_REF	SHEET
RESU_19	NR	NON_REGRESSION	-1.086E8	0.1%
RESU_19	V1	NON_REGRESSION	-8.6E6	

## 7 Modeling F

### 7.1 Characteristics of modeling

#### 7.1.1 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 of `BAR` with the order `STAT_NON_LINE`. The temperature varies  $T_0=20^\circ\text{C}$  with  $T_{max}=100^\circ\text{C}$ . The material arrives at plasticization. The transient is made up of `NCAL` pas. La temperature of reference is of  $T_{ref}=20^\circ\text{C}$ .

#### 7.1.2 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.

### 7.2 Properties of material

The law of behavior tested is 'PINTO\_MENEGOTTO' documented in Doc. [R5.03.09]. This law is elastoplastic isotherm uniaxial modelling the answer of the steel reinforcements in the reinforced concrete under cyclic loading.

The elastic parameters are the following:

$$E(T), \nu(T) \text{ and } \alpha(T)$$

Parameters elastoplastic are the following:

$$\sigma_y^0, \varepsilon_u, \sigma_u, \varepsilon_h, b, R0, a1, a2, L/D, a6, c, a$$

Values of the parameters used:

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

Parameters	
$\sigma_y^0$	2.E8 Pa
$\varepsilon_u$	3.E-2
$\sigma_u$	2.58E8 Pa
$\varepsilon_h$	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 Sizes 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 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 mechanical simulation thermo 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_ $i$	NOM_PARA		VALE_REF	SHEET
RESU_19	NR	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

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For each studied law of behavior, 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 dilation by these laws of behavior, as well as the good dependence of the parameters materials at the temperature.