
HSNV125 - Element of volume in traction/shearing and temperature variables

Summary:

This test, suggested by the IPSI for the Phi2As day of March 30th, 2000 on the nonlinear behaviors makes it possible to validate the good taking into account of the variation of the coefficients with the temperature for three elastoplastic models of behavior (perfect plasticity, linear kinematic work hardening, and nonlinear kinematic work hardening) and a model élasto-visco-plastic in 3D, and to show the capacity of these models to highlight an effect of ratchet or accommodation.

The model is also tested `VMIS_CIN2_MEMO`, allowing to take into account the effect of memory maximum of work hardening, with parameters chosen to correspond to `VMIS_CIN2_CHAB`.

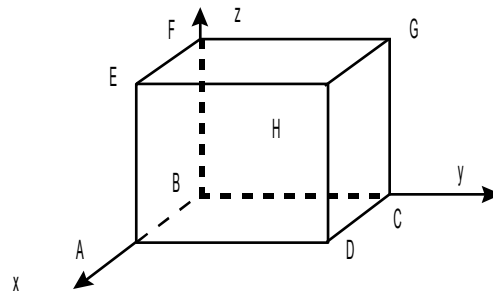
Five modelings make it possible to validate each one of these behaviors. Two additional modelings make it possible to test on the one hand the optimization of the step of time in thermal loading, and on the other hand the keyword `TEMP_DEF_ALPHA`.

The reference solutions are digital. They are obtained with the Zébulon™ code.

1 Problem of reference

1.1 Geometry

Element of volume materialized by a unit cube on side (1 mm):



1.2 Properties of materials

Young modulus: $E(T) = 2 \cdot 10^5 - 10^5 \left(\frac{T-100}{960} \right)^2$ (in MPa) T in °celcius

Poisson's ratio: $\nu = 0.3$,

Thermal dilation coefficient secant definite from $20^\circ C$:

$$\alpha(T) = 10^{-5} + 10^{-5} \left(\frac{T-100}{960} \right)^4 \quad (\text{in } ^\circ C^{-1})$$

The material is elastoplastic with various types of behavior:

C1 : Perfect plasticity:

$$\sigma_y(T) = 500 - 25 \left(\frac{T-100}{96} \right) \quad (\text{in MPa})$$

C2 : Linear kinematic work hardening: (uniaxial expression)

$$(\sigma - X)_{eq} = \sigma_y(T)$$

$$X = \frac{2}{3} C(T) \varepsilon^P$$

$$\sigma_y(T) = 100 \quad (\text{in MPa})$$

$$C(T) = 40000 - 3500 \left(\frac{T-100}{96} \right) \quad (\text{in MPa})$$

C3 : Nonlinear kinematic work hardening: (uniaxial expression)

$$\begin{aligned}(\sigma - X)_{eq} &= \sigma_y(T) \\ X &= \frac{2}{3} C(T) \alpha \\ \dot{\alpha} &= \dot{\varepsilon}^P - D(T) \alpha \dot{p} \\ \sigma_y(T) &= 100 \quad (\text{in MPa}) \\ C(T) &= 2 \cdot 10^6 - 192500 \left(\frac{T-100}{96} \right) \quad (\text{in MPa}) \\ D(T) &= 5000 - 450 \left(\frac{T-100}{96} \right)\end{aligned}$$

C4 : Viscoplasticity with nonlinear kinematic work hardening: (uniaxial expression)

$$\begin{aligned}(\sigma - X)_{eq} &= R(T, p) + \sigma_v(T) \\ X &= \frac{2}{3} C(T) \alpha \\ \dot{\alpha} &= \dot{\varepsilon}^P - D(T) \alpha \dot{p} \\ \dot{p} &= \left\langle \frac{(\sigma - X)_{eq} - R(T, p)}{K} \right\rangle^n \\ R(p, T) &= Q(t) (1 - e^{-b(t)p}) + \sigma_y(T) \\ \sigma_y(T) &= 200 \quad (\text{in MPa}), \quad Q(t) = -100, \quad b(t) = 20 \\ C(T) &= 1 \cdot 10^6 - 98500 \left(\frac{T-100}{96} \right) \\ K(T) &= 300 - 300 \left(\frac{T-700}{700} \right) \quad (\text{in MPa}) \\ n(T) &= 7 - \left(\frac{T-100}{160} \right) \\ D(T) &= 5000 - 5(T-100)\end{aligned}$$

1.3 Boundary conditions and loadings

Such that the stress and strain states are uniform in the element of volume:

- Not B blocked in x , y and z . Not A blocked in z , $Dx=0$ on the face $ADHE$
- Displacement imposed on the face $BCFG$: Dx

Tangential forces distributed F_c producing a state of constant shearing in cube SIXY:

- F_y on the faces $ADHE$ and $BCFG$
- F_x on the faces $DCHG$ and $ABEF$.

Uniform temperature $T(t)$ on the cube. The temperature of reference is worth $20^\circ C$.

Dx , F_c and T vary according to time in the following way:

moment $t(s)$	0	1	61	121	181	241	301	361	421	481
$F_c(t)$ (Mpa)	0	100	100	100	100	100	100	100	100	100
$Dx(t)$ (mm)	0	0	-0.02	0	-0.02	0	-0.02	0	-	0
									0.02	
$T(t)$ (°C)	1060	1060	100	1060	100	1060	100	1060	100	1060

2 Reference solution

2.1 Method of calculating used for the reference solution

Digital results got with the Zébulon™ code and suggested as reference solutions for the day ϕ^2 Ace [bib1].

2.2 Results of reference

Evolution of axial stress S_{IXX} , axial deformation EP_{XX} and of the shearing strain EP_{XY} (in an unspecified point of volume because the fields are homogeneous there) according to time for the last cycle.

Note:

Deformation EP_{XX} indicated in reference is the deformation as from moment 0. In Code_Aster, one carries out a preliminary calculation as from one moment when the temperature is equal to the temperature of reference. One thus adds the deformation corresponding (0.0208) to EP_{XX} .

perfect plasticity	Moment (S)	S _{IXX} (Mpa)	EP _{XX}	EP _{XX} early	EP _{XY}
	421	- 469.15	- 2 10 ⁻²	8 10 ⁻⁴	1.4658 10 ⁻²
local maximum of S _{IXX}	447.4	349.52			1.4832 10 ⁻²
	461.8	281			1.5527 10 ⁻²
	478.6	- 195.84			1.6161 10 ⁻²
end of the cycle	481	- 180.52	0	2.08 10 ⁻²	1.7483 10 ⁻²
écr. movies. linear	Moment (S)	S _{IXX} (Mpa)	EP _{XX}	EP _{XX} early	EP _{XY}
	421	- 72.91	- 2 10 ⁻²	8 10 ⁻⁴	5.4288 10 ⁻³
local maximum of S _{IXX}	453.4	200.68			5.5542 10 ⁻³
	461.8	188.66			5.7411 10 ⁻³
	471.4	5.84			5.9022 10 ⁻³
end of the cycle	481	- 75.29	0	2.08 10 ⁻²	8.2185 10 ⁻³
écr. movies. nonlinear	Moment (S)	S _{IXX} (Mpa)	EP _{XX}	EP _{XX} early	EP _{XY}
	421	- 414.63	- 2 10 ⁻²	8 10 ⁻⁴	1.1528 10 ⁻²
local maximum of S _{IXX}	454.6	369.6			1.2022 10 ⁻²
	465.4	284.24			1.2302 10 ⁻²
	472.6	79.88			1.2471 10 ⁻²
end of the cycle	481	- 118.65	0	2.08 10 ⁻²	1.5157 10 ⁻²
écr. movies. nonlinear	Moment (S)	S _{IXX} (Mpa)	EP _{XX}	EP _{XX} early	EP _{XY}
	421	- 337.04	- 2 10 ⁻²	8 10 ⁻⁴	1.4608 10 ⁻²
local maximum of S _{IXX}	449.8	320.54			1.5251 10 ⁻²
	465.4	211.13			1.5917 10 ⁻²
	473.8	-31.97			1.6086 10 ⁻²
end of the cycle	481	- 89.69	0	2.08 10 ⁻²	1.9981 10 ⁻²

One tests also the maximum in elasticity of $S_{IXX} = 884.234 \text{ MPa}$ for a temperature of 668.2°C .

2.3 Precision on the results of reference

The results strongly depending on the temporal discretization, one can estimate the precision of the solution, obtained for a fine discretization, to 1%.

2.4 References bibliographical

- [1] IPSI: day of study ϕ^2 Ace of March 30th, 2000: nonlinear behaviors of materials.

3 Modeling A

3.1 Characteristics of modeling

Behavior *CI* : perfect plasticity, in 3D. 1 pas de time enters $t=-1$ and $t=0$, 10 pas de time enters $t=0$ and $t=1$ and 1 pas de time a second then.

3.2 Characteristics of the grid

The grid comprises a mesh HEXA8

3.3 Sizes tested and results

Constraint SIXX (MPa)	Moment (S)	Reference
SIXX NODE 1	421	- 469.15
SIXX NODE 1	447.4	349.52
SIXX NODE 1	461.8	281
SIXX NODE 1	478.6	- 195.84
SIXX NODE 1	481	- 180.52

Deformation EPXX	Moment (S)	Reference
EPXX NODE 1	421	$8 \cdot 10^{-4}$
EPXX NODE 1	481	$2.08 \cdot 10^{-2}$

Deformation EPXY	Moment (S)	Reference
EPXY NODE 1	421	$1.4658 \cdot 10^{-2}$
EPXY NODE 1	447.4	$1.4832 \cdot 10^{-2}$
EPXY NODE 1	461.8	$1.5527 \cdot 10^{-2}$
EPXY NODE 1	478.6	$1.6161 \cdot 10^{-2}$
EPXY NODE 1	481	$1.7483 \cdot 10^{-2}$

4 Modeling B

4.1 Characteristics of modeling

Behavior *C2* : linear kinematic work hardening, in 3D (behavior *VMIS_CINE_LINE*). 972 pas de time on the whole (1 pas corresponds to 0.5 second). One simulates also this behavior with *VMIS_CIN1_CHAB*. The results are identical.

4.2 Characteristics of the grid

The grid comprises a mesh *HEXA8*.

4.3 Sizes tested and results

Constraint <i>SIXX</i> (MPa)	Moment (S)	Reference
<i>SIXX</i> NODE 1	421	- 72.91
<i>SIXX</i> NODE 1	453.4	200.68
<i>SIXX</i> NODE 1	461.8	188.66
<i>SIXX</i> NODE 1	471.4	5.84
<i>SIXX</i> NODE 1	481	- 75.29

Deformation <i>EPXX</i>	Moment (S)	Reference
<i>EPXX</i> NODE 1	421	$8 \cdot 10^{-4}$
<i>EPXX</i> NODE 1	481	$2.08 \cdot 10^{-2}$

Deformation <i>EPXY</i>	Moment (S)	Reference
<i>EPXY</i> NODE 1	421	$5.4288 \cdot 10^{-3}$
<i>EPXY</i> NODE 1	453.4	$5.5542 \cdot 10^{-3}$
<i>EPXY</i> NODE 1	461.8	$5.7411 \cdot 10^{-3}$
<i>EPXY</i> NODE 1	471.4	$5.9022 \cdot 10^{-3}$
<i>EPXY</i> NODE 1	481	$8.2185 \cdot 10^{-3}$

5 Modeling C

5.1 Characteristics of modeling

Behavior $C3$: nonlinear kinematic work hardening in 3D. It is modelled with the behaviors VMIS_CIN1_CHAB and VMIS_CIN2_CHAB, which gives the same result.

5.2 Characteristics of the grid

The grid comprises a mesh HEXA8.

5.3 Sizes tested and results

Constraint SIXX (MPa)	Moment (S)	Reference
SIXX NODE 1	421	- 414.63
SIXX NODE 1	454.6	369.6
SIXX NODE 1	465.4	284.24
SIXX NODE 1	472.6	79.88
SIXX NODE 1	473	-
SIXX NODE 1	481	- 118.65

Deformation EPXX	Moment (S)	Reference
EPXX NODE 1	421	$8 \cdot 10^{-4}$
EPXX NODE 1	481	$2.08 \cdot 10^{-2}$

Deformation EPXY	Moment (S)	Reference
EPXY NODE 1	421	$1.1528 \cdot 10^{-2}$
EPXY NODE 1	454.6	$1.2022 \cdot 10^{-2}$
EPXY NODE 1	465.4	$1.2302 \cdot 10^{-2}$
EPXY NODE 1	472.6	$1.2471 \cdot 10^{-2}$
EPXY NODE 1	481	$1.5157 \cdot 10^{-2}$

Behavior	Value tested	Moment (S)	Reference
VMIS_CIN1_CHAB	SIXX	24	581.5
	SIXX	61	- 273.45
	SIXX	91	404.2
	SIXX	121	- 117.1
	EPXY	61	$2,232 \cdot 10^{-3}$
	EPXY	121	$6,017 \cdot 10^{-3}$
VMIS_CIN2_CHAB	SIXX	24	581.5
	SIXX	61	- 273.45
	SIXX	91	404.2
	SIXX	121	- 117.1
	EPXY	61	$2,232 \cdot 10^{-3}$
	EPXY	121	$6,017 \cdot 10^{-3}$

Table 5.3-1: Values of nonregression to the first cycle

6 Modeling D

6.1 Characteristics of modeling

Behavior *C4* : viscoplasticity with nonlinear kinematic work hardening in 3D. It is modelled with the behavior *viscochab*.

6.2 Characteristics of the grid

The grid comprises a mesh HEXA8.

6.3 Sizes tested and results

Constraint SIXX (MPa)	Moment (S)	Reference
SIXX NODE 1	481	-337.04
SIXX NODE 1	510	320.54
SIXX NODE 1	525	211.13
SIXX NODE 1	534	-31.97
SIXX NODE 1	579	-89.79

Deformation EPXX	Moment (S)	Reference
EPXX NODE 1	481	$8 \cdot 10^{-4}$
EPXX NODE 1	579	$2.08 \cdot 10^{-2}$

Deformation EPXY	Moment (S)	Reference
EPXY NODE 1	481	$1.4608 \cdot 10^{-2}$
EPXY NODE 1	510	$1.5251 \cdot 10^{-2}$
EPXY NODE 1	525	$1.5917 \cdot 10^{-2}$
EPXY NODE 1	534	$1.6086 \cdot 10^{-2}$
EPXY NODE 1	579	$1.9981 \cdot 10^{-2}$

7 Modeling E

7.1 Characteristics of modeling

Behavior VMIS_CIN2_MEMO : nonlinear kinematic work hardening, being able to take into account the effect of maximum memory of work hardening. It is compared with the behaviors VMIS_CIN1_CHAB and VMIS_CIN2_CHAB.

The parameters managing the effect of memory are:

- $ETA=0.5$
- $Q0=Qm=0$
- $Mu=0$

What results in carrying out all calculations relating to the effect of memory without modifying the results in comparison with VMIS_CIN2_CHAB.

7.2 Sizes tested and results

Constraint SIXX (MPa)	Moment (S)	Reference	Code_Aster	% diff
SIXX NODE 1	421	- 414.63	- 415.03	0.1
SIXX NODE 1	454.6	369.6	369.52	-0.02
SIXX NODE 1	465.4	284.24	290.9 (t=465)	2.3
SIXX NODE 1	472.6	79.88	Pas de result at this moment	-
SIXX NODE 1	473	-	65.45	not regression
SIXX NODE 1	481	- 118.65	- 118.98	0.3

Deformation EPXX	Moment (S)	Reference
EPXX NODE 1	421	$8 \cdot 10^{-4}$
EPXX NODE 1	481	$2.08 \cdot 10^{-2}$

Deformation EPXY	Moment (S)	Reference
EPXY NODE 1	421	$1.1528 \cdot 10^{-2}$
EPXY NODE 1	454.6	$1.2022 \cdot 10^{-2}$
EPXY NODE 1	465.4	$1.2302 \cdot 10^{-2}$
EPXY NODE 1	472.6	$1.2471 \cdot 10^{-2}$
EPXY NODE 1	481	$1.5157 \cdot 10^{-2}$

Behavior	Value tested	Moment (S)	Reference
VMIS_CIN2_MEMO	SIXX	24	581.5
	SIXX	61	- 273.45
	SIXX	91	404.2
	SIXX	121	- 117.1
	EPXY	61	$2,232 \cdot 10^{-3}$
	EPXY	121	$6,017 \cdot 10^{-3}$

Table 7.2-1: Values of nonregression to the first cycle

8 Modeling F

8.1 Characteristics of modeling

This modeling is identical to modeling b: C2 Behavior: linear kinematic work hardening, in 3D (behavior VMIS_CINE_LINE). 972 pas de time on the whole (1 pas corresponds to 0.5 second). Modeling is used to test the keyword TEMP_DEF_ALPHA : the secant dilation coefficient is transformed in order to be defined from TEMP_DEF_ALPHA= Tdef = -100 °C : instead of using $\alpha(T)$ defined

before: $\alpha(T) = 10^{-5} + 10^{-5} \left(\frac{T-100}{960} \right)^4$ (in °C⁻¹)

one uses $\alpha_{def}(T)$ with:

$$\alpha_{def}(T) = \frac{\alpha(T)(T - T_{ref}) + \alpha(T_{Def})(T_{ref} - T_{Def})}{(T - T_{Def})} = \frac{\alpha(T)(T - 20) + \alpha(-100)(20 - (-100))}{(T - (-100))}$$

This transformation should not change the results, which must remain identical to modeling B.

8.2 Characteristics of the grid

The grid comprises a mesh HEXA8.

8.3 Sizes tested and results

Constraint SIXX (MPa)	Moment (S)	Reference
SIXX NODE 1	421	- 72.91
SIXX NODE 1	453.4	200.68
SIXX NODE 1	461.8	188.66
SIXX NODE 1	471.4	5.84
SIXX NODE 1	481	- 75.29

Deformation EPXX	Moment (S)	Reference
EPXX NODE 1	421	8 10 ⁻⁴
EPXX NODE 1	481	2.08 10 ⁻²

Deformation EPXY	Moment (S)	Reference
EPXY NODE 1	421	5.4288 10 ⁻³
EPXY NODE 1	453.4	5.5542 10 ⁻³
EPXY NODE 1	461.8	5.7411 10 ⁻³
EPXY NODE 1	471.4	5.9022 10 ⁻³
EPXY NODE 1	481	8.2185 10 ⁻³

9 Modeling G

9.1 Characteristics of modeling

The data of this modeling is identical to modeling D: Behavior *C4*: nonlinear kinematic work hardening, viscosity, in 3D, but with the behavior `VISC_CIN1_CHAB`. 579 pas de time on the whole (60 pas by cycle).

9.2 Characteristics of the grid

The grid comprises a mesh HEXA8.

9.3 Sizes tested and results

Constraint SIXX (MPa)	Moment (S)	Reference
SIXX NODE 1	481	-337.04
SIXX NODE 1	510	320.54
SIXX NODE 1	525	211.13
SIXX NODE 1	534	-31.97
SIXX NODE 1	579	-89.79

Deformation EPXX	Moment (S)	Reference
EPXX NODE 1	481	$8 \cdot 10^{-4}$
EPXX NODE 1	579	$2.08 \cdot 10^{-2}$

Deformation EPXY	Moment (S)	Reference
EPXY NODE 1	481	$1.4608 \cdot 10^{-2}$
EPXY NODE 1	510	$1.5251 \cdot 10^{-2}$
EPXY NODE 1	525	$1.5917 \cdot 10^{-2}$
EPXY NODE 1	534	$1.6086 \cdot 10^{-2}$
EPXY NODE 1	579	$1.9981 \cdot 10^{-2}$

The relatively important variations are due to the discretization in time (relatively coarse here, allowing complete calculation in 60s approximately). By refining the step of time, convergence is good.

The tests are doubled in the command file of tests of nonregression.

10 Summary of the results

This test makes it possible to highlight the effects of loadings cyclic (accommodation or ratchet) with variation of the coefficients of the elastoplastic behaviors with the temperature.

This test thus makes it possible to validate the integration of the behaviors VMIS_ISOT_LINE, VMIS_CINE_LINE, VMIS_CIN1_CHAB, VMIS_CIN2_CHAB, VISC_CIN1_CHAB, VMIS_CIN2_MEMO and VISCOCHAB compared to the variation of the coefficients with the temperature and the taking into account of the cyclic loadings.

It makes it possible of more than validate the good taking into account of a temperature of definition of the dilation coefficient secant different from the temperature of reference.