HSNV125 - Volume element in tension/shears and temperature variables

Summarized:

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 hardening, and nonlinear kinematic 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.

One tests VMIS_CIN2_MEMO also `the model`, allowing to take into account the effect of memory maximum of hardening, with parameters chosen to correspond to `VMIS_CIN2_CHAB`.

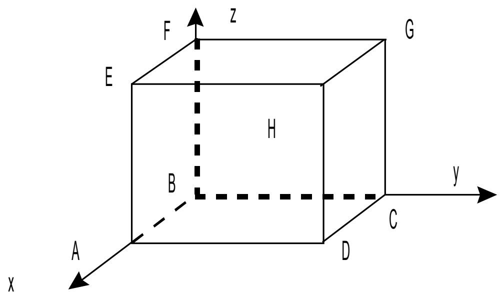
Five modelizations make it possible to validate each one of these behaviors. Two additional modelizations make it possible to test on the one hand the optimization of time step in thermal loading, and on the other hand key word `TEMP_DEF_ALPHA`.

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

1 Problem of reference

1.1 Geometry

Volume element materialized by a unit cube on side ($1\,mm$):



1.2 Properties of the materials

Modulus Young: $E(T)=2.10^5-10^5\left(\frac{T-100}{960}\right)^2$ (in MPa) T in °celcius

Poisson's ratio: $n=0.3$,

Definite secant thermal Coefficient of thermal expansion from $20\,°C$:

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

the material is elastoplastic with various types of behavior:

$C1$: Perfect plasticity:

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

$C2$: Linear kinematic hardening: (uniaxial statement)

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

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

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

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

$C3$: Nonlinear kinematic hardening: (uniaxial statement)

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

$$X = \frac{2}{3} C(T) \alpha$$

$$\dot{\alpha} = \dot{\varepsilon}^P - D(T) \alpha \dot{p}$$

$\sigma_y(T) = 100$ (in MPa)

$C(T) = 2.10^6 - 192500 \left(\frac{T-100}{96} \right)$ (in MPa)

$$D(T) = 5000 - 450 \left(\frac{T-100}{96} \right)$$

$C4$: Viscoplasticity with nonlinear kinematic hardening: (uniaxial statement)

$$(\sigma - X)_{eq} = R(T, p) + \sigma_v(T)$$

$$X = \frac{2}{3} C(T) \alpha$$

$$\dot{\alpha} = \dot{\varepsilon}^P - D(T) \alpha \dot{p}$$

$$\dot{p} = \left\langle \frac{(\sigma - X)_{eq} - R(T, p)}{K} \right\rangle^n$$

$$R(p, T) = Q(t)\left(1 - e^{-b(t) p}\right) + \sigma_y(T)$$

$\sigma_y(T) = 200$ (in MPa) $Q(t) = -100$, $b(t) = 20$

$$C(T) = 1.10^6 - 98500 \left(\frac{T-100}{96} \right)$$

$K(T) = 300 - 300 \left(\frac{T-700}{700} \right)$ (in MPa)

$$n(T) = 7 - \left(\frac{T-100}{160} \right)$$

$$D(T) = 5000 - 5(T-100)$$

1.3 Boundary conditions and loadings

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

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

Tangential forces distributed Fc producing a state of constant shears in cube SIXY:

- Fy on the sides $ADHE$ and $BCFG$
- Fx the sides $DCHG$ and $ABEF$.

Uniform temperature $T(t)$ on the cube. The reference temperature is worth $20°C$.
Dx , Fc and T vary according to time in the following way:

.

time $t(s)$	0	1	61.121 .181			241.3 01.36 1			421.4 81	
$Fc(t)$ (Mpa)	0.100		100	100.1 00.10 0			100.10 0.100			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

numerical Results got with the Zébulon™ code and suggested like reference solutions for the day ϕ^{2As} [bib1].

2.2 Results of reference

Evolution of axial stress SIXX, axial strain EPXX and shear strain EPXY (in an unspecified point of volume because the fields are homogeneous there) according to time for the last cycle.

Note:

Strain EPXX indicated in reference is the strain from time 0. In Code_Aster, one carries out a preliminary computation from one time when the temperature is equal to the reference temperature. One thus adds the strain corresponding (0.0208) to EPXX.

perfect plasticity	**Time (S)**	**SIXX (Mpa)**	**EPXX**	**EPXX early**	**EPXY**
	421	– 469.15	– 2 10-2	8 10-4	1.4658 10-2
local maximum of SIXX	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 cycle	481	– 180.52	0	2.08 10-2	1.7483 10-2

écr. movies. linear	**Time (S)**	**SIXX (Mpa)**	**EPXX**	**EPXX early**	**EPXY**
	421	– 72.91	– 2 10-2	8 10-4	5.4288 10-3
local maximum of SIXX	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 cycle	481	– 75.29	0	2.08 10-2	8.2185 10-3

écr. movies. nonlinear	**Time (S)**	**SIXX (Mpa)**	**EPXX**	**EPXX early**	**EPXY**
	421	– 414.63	– 2 10-2	8 10-4	1.1528 10-2
local maximum of SIXX	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 cycle	481	– 118.65	0	2.08 10-2	1.5157 10-2

écr. movies. nonlinear	**Time (S)**	**SIXX (Mpa)**	**EPXX**	**EPXX early**	**EPXY**
	421	– 337.04	– 2 10-2	8 10-4	1.4608 10-2
local maximum of SIXX	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 cycle	481	– 89.69	0	2.08 10-2	1.9981 10-2

One tests also the maximum in elasticity of SIXX = 884.234 MPa for a temperature of 668.2°C

2.3 Accuracy on the results of reference

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

2.4 References bibliographical

[1] IPSI: day of study ϕ^{2As} of March 30th, 2000: nonlinear behaviors of the materials.

3 Modelization A

3.1 Characteristic of the modelization

Behavior $C1$: perfect plasticity, in 3D. 1 time step enters $t=-1$ and $t=0$, 10 time step enters $t=0$ and $t=1$ 1 time step a second then.

3.2 Characteristics of the mesh

The mesh comprises a mesh HEXA8

3.3 Quantities tested and results

Forced SIXX (MPa)	Urgent (S)	Reference	*Code_Aster*	% diff
SIXX NODE 1.421		– 469.15	– 469.04	-0.02
SIXX NODE 1	447.4	349.52	351.287	0.5
SIXX NODE 1	461.8	281	279.27	-0.6
SIXX NODE 1	478.6	– 195.84	– 191.67	-2.1
SIXX NODE 1.481		– 180.52	– 180.278	-0.1

Strain EPXX	Time (S)	Reference	*Code_Aster*	% diff
EPXXNŒUD 1.421		8 10-4	8 10-4	0
EPXX NODE 1.481		2.08 10-2	2.08 10-2	0

Strain EPXY	Time (S)	Reference	*Code_Aster*	% diff
EPXY NODE 1.421		1.4658 10-2	1.4761 10-2	0.7
EPXY NODE 1	447.4	1.4832 10-2	1.4849 10-2	0.1
EPXY NODE 1	461.8	1.5527 10-2	1.5576 10-2	0.3
EPXY NODE 1	478.6	1.6161 10-2	1.6439 10-2	1.7
EPXY NODE 1.481		1.7483 10-2	1.7542 10-2	0.3

4 Modelization B

4.1 Characteristic of the modelization

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

4.2 Characteristics of the mesh

The mesh comprises a mesh HEXA8.

4.3 Quantities tested and results

Forced SIXX (MPa)	Urgent (S)	Reference	Code_Aster	% diff
SIXX NODE 1.421		– 72.91	– 72.81	-0.41
SIXX NODE 1	453.4	200.68	200.6	0
SIXX NODE 1	461.8	188.66	187	-0.36
SIXX NODE 1	471.4	5.84	5.3	-0.99
SIXX NODE 1.481		– 75.29	– 74.7	-0.88

Strain EPXX	Time (S)	Reference	Code_Aster	% diff
EPXX NODE 1.421		8 10-4	8 10-4	0
EPXX NODE 1.481		2.08 10-2	2.08 10-2	0

Strain EPXY	Time (S)	Reference	Code_Aster	% diff
EPXY NODE 1.421		5.4288 10-3	5.462 10-3	0.6
EPXY NODE 1	453.4	5.5542 10-3	5.56 10-3	0.1
EPXY NODE 1	461.8	5.7411 10-3	5.748 10-3	0.1
EPXY NODE 1	471.4	5.9022 10-3	5.9104 10-3	0.1
EPXY NODE 1.481		8.2185 10-3	8.3367 10-3	1.4

5 Modelization C

5.1 Characteristic of the modelization

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

5.2 Characteristics of the mesh

The mesh comprises a mesh HEXA8.

5.3 Quantities tested and results

Forced SIXX (MPa)	Urgent (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	-	-
SIXX NODE 1.473		-	65.45	Non regression
SIXX NODE 1.481		– 118.65	– 118.98	0.3

Strain EPXX	Time (S)	Reference	*Code_Aster*	% diff
EPXXNŒUD 1.421		8 10-4	8 10-4	0
EPXX NODE 1.481		2.08 10-2	2.08 10-2	0

Strain EPXY	Time (S)	Reference	*Code_Aster*	% diff
EPXY NODE 1.421		1.1528 10-2	1.1591 10-2	0.6
EPXY NODE 1	454.6	1.2022 10-2	1.2099 10-2	0.7
EPXY NODE 1	465.4	1.2302 10-2	1.2359 10-2	0.5
EPXY NODE 1	472.6	1.2471 10-2	1.2578 10-2	0.9
EPXY NODE 1.481		1.5157 10-2	1.5215 10-2	0.4

Behavior	Value tested	Urgent (S)	Reference	*Code_Aster*	% diff
VMIS_CIN1_CHAB	SIXX	24	581.5	581.5	< 10-4
	SIXX	61	– 273.45	– 273.45	< 10-4
	SIXX	91	404.2	404.2	< 10-4
	SIXX	121	– 117.1	– 117.1	< 10-4
	EPXY	61	2.232 10-3	2.232 10-3	< 10-4
	EPXY	121	6.017 10-3	6.017 10-3	< 10-4
VMIS_CIN2_CHAB	SIXX	24	581.5	581.5	< 10-4
	SIXX	61	– 273.45	– 273.45	< 10-4
	SIXX	91	404.2	404.2	< 10-4
	SIXX	121	– 117.1	– 117.1	< 10-4
	EPXY	61	2.232 10-3	2.232 10-3	< 10-4
	EPXY	121	6.017 10-3	6.017 10-3	< 10-4

Table 5.3-1: Values of non regression with the first cycle

6 Modelization D

6.1 Characteristic of the modelization

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

6.2 Characteristics of the mesh

The mesh comprises a mesh HEXA8.

6.3 Quantities tested and results

Forced SIXX (MPa)	Urgent (S)	Reference	*Code_Aster*	% diff
SIXX NODE 1.481		-337.04	-335.65	-0.4
SIXX NODE 1.510		320.54	318.05	-0.77
SIXX NODE 1.525		211.13	209.36	-0.8
SIXX NODE 1.534		-31.97	-28.8	-9.9
SIXX NODE 1.579		-89.79	-72.13	-19

Strain EPXX	Time (S)	Reference	*Code_Aster*	% diff
EPXXNŒUD 1.481		8 10-4	8 10-4	0
EPXX NODE 1.579		2.08 10-2	2.08 10-2	0

Strain EPXY	Time (S)	Reference	*Code_Aster*	% diff
EPXY NODE 1.481		1.4608 10-2	1.5435 10-2	5.6
EPXY NODE 1.510		1.5251 10-2	1.611 10-2	5.6
EPXY NODE 1.525		1.5917 10-2	1.6778 10-2	5.4
EPXY NODE 1.534		1.6086 10-2	1.7021 10-2	5.8
EPXY NODE 1.579		1.9981 10-2	2.1384 10-2	7

7 Modelization E

7.1 Characteristic of modelization

Behavior `VMIS_CIN2_MEMO` : nonlinear kinematic hardening, being able to take into account the effect of maximum memory of hardening. It is compared with 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 computations relating to the effect of memory without modifying the results in comparison with `VMIS_CIN2_CHAB`.

7.2 Quantities tested and results

Forced SIXX (MPa)	Urgent (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	Steps of result to this time	-
SIXX NODE 1.473		-	65.45	non regression
SIXX NODE 1.481		– 118.65	– 118.98	0.3

Strain EPXX	Time (S)	Reference	*Code_Aster*	% diff
EPXXNŒUD 1.421		8 10-4	8 10-4	0
EPXX NODE 1.481		2.08 10-2	2.08 10-2	0

Strain EPXY	Time (S)	Reference	*Code_Aster*	% diff
EPXY NODE 1.421		1.1528 10-2	1.1591 10-2	0.6
EPXY NODE 1	454.6	1.2022 10-2	1.2099 10-2	0.7
EPXY NODE 1	465.4	1.2302 10-2	1.2359 10-2	0.5
EPXY NODE 1	472.6	1.2471 10-2	1.2578 10-2	0.9
EPXY NODE 1.481		1.5157 10-2	1.5215 10-2	0.4

Behavior	Value tested	Urgent (S)	Reference	*Code_Aster*	% diff
VMIS_CIN2_MEMO	SIXX	24	581.5	581.5	< 10-4
	SIXX	61	– 273.45	– 273.45	< 10-4
	SIXX	91	404.2	404.2	< 10-4
	SIXX	121	– 117.1	– 117.1	< 10-4
	EPXY	61	2.232 10-3	2.232 10-3	< 10-4
	EPXY	121	6.017 10-3	6.017 10-3	< 10-4

Table 7.2-1: Values of non regression with the first cycle

8 Modelization F

8.1 Characteristic of the modelization

This modelization is identical to modelization b: Behavior C2: linear kinematic hardening, in 3D (behavior VMIS_CINE_LINE). 972 time step on the whole (1 step corresponds to 0.5 second).
The modelization is used to test key word TEMP_DEF_ALPHA : the secant coefficient of thermal expansion is transformed in order to be defined from TEMP_DEF_ALPHA= $Tdef=-100°C$: instead of using $\alpha(T)$ definite before: $\alpha(T)=10^{-5}+10^{-5}\left(\frac{T-100}{960}\right)^4$ (in $°C^{-1}$)

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

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

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

8.2 Characteristic of the mesh

The mesh comprises a mesh HEXA8.

8.3 Quantities tested and results

Forced SIXX (MPa)	Urgent (S)	Reference	Code_Aster	% diff
SIXX NODE 1.421		– 72.91	– 72.61	- 0.4
SIXX NODE 1	453.4	200.68	200.68	0.002
SIXX NODE 1	461.8	188.66	187.97	- 0.4
SIXX NODE 1	471.4	5.84	5.782	-1
SIXX NODE 1.481		– 75.29	– 74.63	- 0.88

Strain EPXX	Time (S)	Reference	Code_Aster	% diff
EPXX NODE 1.421		8 10-4	8 10-4	0
EPXX NODE 1.481		2.08 10-2	2.08 10-2	0

Strain EPXY	Time (S)	Reference	Code_Aster	% diff
EPXY NODE 1.421		5.4288 10-3	5.462 10-3	0.6
EPXY NODE 1	453.4	5.5542 10-3	5.56 10-3	0.12
EPXY NODE 1	461.8	5.7411 10-3	5.748 10-3	0.12
EPXY NODE 1	471.4	5.9022 10-3	5.910 10-3	0.2
EPXY NODE 1.481		8.2185 10-3	8.336 10-3	1.4

9 Modelization G

9.1 Characteristic of the modelization

the data of this modelization is identical to the modelization D: Behavior $C4$: nonlinear kinematic hardening, viscosity, in 3D, but with behavior VISC_CIN1_CHAB. 579 time step on the whole (60 steps per cycle).

9.2 Characteristics of the mesh

The mesh comprises a mesh HEXA8.

9.3 Quantities tested and results

Forced SIXX (MPa)	Urgent (S)	Reference	*Code_Aster*	% diff
SIXX NODE 1.481		-337.04	-333.65	-1
SIXX NODE 1.510		320.54	315.25	-1.6
SIXX NODE 1.525		211.13	209.91	-0.6
SIXX NODE 1.534		-31.97	-27.67	-13.5
SIXX NODE 1.579		-89.79	-71.44	-20

Strain EPXX	Time (S)	Reference	*Code_Aster*	% diff
EPXXNŒUD 1.481		8 10-4	8 10-4	0
EPXX NODE 1.579		2.08 10-2	2.08 10-2	0

Strain EPXY	Time (S)	Reference	*Code_Aster*	% diff
EPXY NODE 1.481		1.4608 10-2	1.5917 10-2	9
EPXY NODE 1.510		1.5251 10-2	1.6595 10-2	8
EPXY NODE 1.525		1.5917 10-2	1.7258 10-2	8
EPXY NODE 1.534		1.6086 10-2	1.75021 10-2	9
EPXY NODE 1.579		1.9981 10-2	2.1984 10-2	the 10

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

The tests are doubled in the command file of tests of non regression.

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 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 secant coefficient of thermal expansion different from the reference temperature.