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.

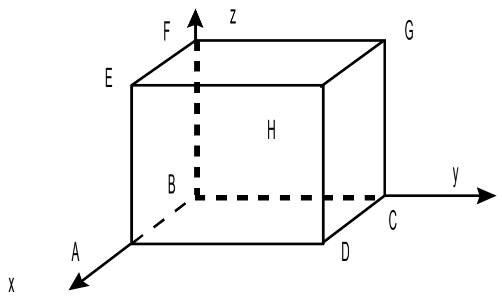
Five modelings make it possible to validate each one of these behaviors. Two additional modelings make it possible to test on the one hand the optimization of the step of time in thermal loading, and on the other hand the keyword TEMP_DEF_ALPHA.

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

Poisson's ratio: $n=0.3$,

Thermal dilation coefficient secant definite 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 work hardening: (uniaxial expression)

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

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

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

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

$C3$: Nonlinear kinematic work hardening: (uniaxial expression)

$$(\sigma - X)_{eq} = \sigma_y(T)$$
$$X = \frac{2}{3} C(T)\alpha$$
$$\dot{\alpha} = \dot{\varepsilon}^P - D(T)\alpha\dot{p}$$
$$\sigma_y(T) = 100 \quad \text{(in } MPa\text{)}$$
$$C(T) = 2.10^6 - 192500\left(\frac{T-100}{96}\right) \quad \text{(in } MPa\text{)}$$
$$D(T) = 5000 - 450\left(\frac{T-100}{96}\right)$$

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

$$(\sigma - X)_{eq} = R(T, p) + \sigma_v(T)$$
$$X = \frac{2}{3} C(T)\alpha$$
$$\dot{\alpha} = \dot{\varepsilon}^P - D(T)\alpha\dot{p}$$
$$\dot{p} = \left\langle \frac{(\sigma - X)_{eq} - R(T, p)}{K} \right\rangle^n$$
$$R(p, T) = Q(t)\left(1 - e^{-b(t)p}\right) + \sigma_y(T)$$
$$\sigma_y(T) = 200 \quad \text{(in } MPa\text{)},\ Q(t) = -100,\ b(t) = 20$$
$$C(T) = 1.10^6 - 98500\left(\frac{T-100}{96}\right)$$
$$K(T) = 300 - 300\left(\frac{T-700}{700}\right) \quad \text{(in } MPa\text{)}$$
$$n(T) = 7 - \left(\frac{T-100}{160}\right)$$
$$D(T) = 5000 - 5(T-100)$$

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 Fc producing a state of constant shearing in cube SIXY:

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

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

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moment $t(s)$	0	1	61	121	181	241	301	361	421	481
$Fc(t)$ (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	– 0.02	0
$T(t)$ ($°C$)	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 SIXX, axial deformation EPXX and of the shearing strain EPXY (in an unspecified point of volume because the fields are homogeneous there) according to time for the last cycle.

Note:

Deformation EPXX 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 EPXX.

perfect plasticity	**Moment (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 the cycle	481	– 180.52	0	$2.08\ 10^{-2}$	$1.7483\ 10^{-2}$
écr. movies. linear	**Moment (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 the cycle	481	– 75.29	0	$2.08\ 10^{-2}$	$8.2185\ 10^{-3}$
écr. movies. nonlinear	**Moment (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 the cycle	481	– 118.65	0	$2.08\ 10^{-2}$	$1.5157\ 10^{-2}$
écr. movies. nonlinear	**Moment (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 the 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 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 ф [2]Ace of March 30th, 2000: nonlinear behaviors of materials.

3 Modeling A

3.1 Characteristics of modeling

Behavior $C1$: 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	$8\ 10^{-4}$
EPXX NODE 1	481	$2.08\ 10^{-2}$

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

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 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	$8.2185\ 10^{-3}$

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	$8\ 10^{-4}$
EPXX NODE 1	481	$2.08\ 10^{-2}$

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

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	$2{,}232\ 10^{-3}$
	EPXY	121	$6{,}017\ 10^{-3}$
VMIS_CIN2_CHAB	SIXX	24	581.5
	SIXX	61	– 273.45
	SIXX	91	404.2
	SIXX	121	– 117.1
	EPXY	61	$2{,}232\ 10^{-3}$
	EPXY	121	$6{,}017\ 10^{-3}$

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	$8\ 10^{-4}$
EPXX NODE 1	579	$2.08\ 10^{-2}$

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

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	$8\ 10^{-4}$
EPXX NODE 1	481	$2.08\ 10^{-2}$

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

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	$2,232\ 10^{-3}$
	EPXY	121	$6,017\ 10^{-3}$

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 $\alpha_{tdef}(T)$ 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 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	$8\ 10^{-4}$
EPXX NODE 1	579	$2.08\ 10^{-2}$

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

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.