SSNV172 – Single-crystal viscoplastic behaviors

Summary:

This test makes it possible to validate the single-crystal behaviors in a uniaxial situation. The treated geometry is a cube, the stress and strain state is homogeneous. In order to test the laws of behavior as well as possible, independently of the definition of the systems of slip, here a system of particular slip, nonphysical is used, which represents a slip in only one direction. This makes it possible to compare two of the single-crystal viscoplastic behaviors, (with kinematic work hardening defined by a variable of recall) with the macroscopic viscoplastic behavior of Chaboche.

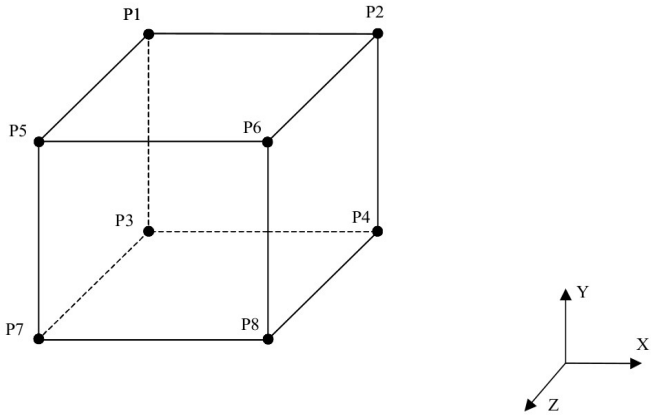
For the other behaviors (in particular KOCKS_RAUCH) one checks to only it not regression of the results.

All these tests are carried out in modeling A (3D).

Modeling B makes it possible to validate, always by intercomparison with the law of Chaboche, the single-crystal behaviors in 2D (C_PLAN).

1 Problem of reference

1.1 Geometry



One defines a material point, represented in modeling A (3D) by an element of volume $MA1$, containing the nodes $P1$, $P2$, $P3$, $P4$, $P5$, $P6$, $P7$ and $P8$.

1.2 Material properties

Elastic behavior with: Young modulus : $E=145200\ MPa$
Poisson's ratio: $\nu=0.3$

1.2.1 Calculation of reference : Comportement VISC_CIN1_CHAB

It is the reference solution used in modelings A and B. the parameters material are:

```
CIN1_CHAB=_F (R_0=75.5 MPa
              R_I=85.27 MPa
              B=19.34,
              C_I=10.0 MPa
              K=1.0,
              W=0.0,
              G_0=36.68,
              A_I=1.0,),
LEMAITRE=_F (N=10.0,
             UN_SUR_K=0.025 Mpa -1
             UN_SUR_M=0.0,),
```

1.2.2 Single-crystal behavior of type 1, with system of slip UNIAXIAL

The parameters used here, into uniaxial, correspond to those used for VISC_CIN1_CHAB, by noticing simply that $Q=R_I-R_0$. One must thus get the same results as VISC_CIN1_CHAB.

These behaviors are tested in 3D (in modeling A) and in 2D plane constraints (in modeling B).

- Type of flow: **MONO_VISC1** whose parameters are:
  $c=10\ MPa$, $n=10$, $K=40\ MPa$
- Isotropic type of work hardening: **MONO_ISOT1** whose parameters are:
  $R_0=75.5\ MPa$ $b=19.34$ $Q=9.77\ MPa$ $h=0$
- Kinematic type of work hardening: **MONO_CINE1** whose parameters are:

$d = 36.68$

The family of the systems of slip is: **UNIAXIAL**

Two calculations are carried out: one with implicit local integration, the other with explicit local integration. It is checked that these two calculations provide identical results (with the temporal discretization near).

1.2.3 Single-crystal behavior of type 2, comparable to type 1, with system of slip UNIAXIAL

The behavior of the monocrystal is defined in such way that one is reduced to the behavior of the type 1. The results must thus correspond. The parameters are:

- Type of flow: **MONO_VISC2** whose parameters are:
  $n = 10$, $k = 40\,MPa$, $c = 10\,MPa$, $d = 0$, $a = 0$
- Isotropic type of work hardening: **MONO_ISOT2** whose parameters are:
  $R_0 = 75.5 \quad b_1 = 19.34 \quad b_2 = 0 \quad Q_1 = 9.77\,MPa \quad Q_2 = 0$
- Kinematic type of work hardening: **MONO_CINE2** whose parameters are:
  $d = 36.68 \quad M = 0 \quad m = 0 \quad c = 0$

The family of the systems of slip is: **UNIAXIAL**

Two calculations are carried out: one with implicit local integration, the other with explicit local integration. It is checked that these two calculations provide results identical to those of the single-crystal behavior of type 1.

1.2.4 Single-crystal behaviour of type 2, complete test

The parameters of the behavior of the monocrystal of the type 2 are all nonworthless:

- Type of flow: **MONO_VISC2** whose parameters are:
  $n = 10$, $k = 40\,MPa$, $c = 10\,MPa$, $d = 0.1$, $a = 0.5$
- Isotropic type of work hardening: **MONO_ISOT2** whose parameters are:
  $R_0 = 75.5 \quad b_1 = 19.34 \quad b_2 = 10 \quad Q_1 = 9.77\,MPa \quad Q_2 = 10$
- Kinematic type of work hardening: **MONO_CINE2** whose parameters are:
  $d = 36.68 \quad M = 10 \quad m = 0{,}1 \quad c = 10$

The family of the systems of slip is: **UNIAXIAL.** The tests are of nonregression.

1.2.5 Calculation with the behavior monocrystal of the type 1 and one orthotropic elasticity

parameters of the orthotropism correspond in fact to the isotropy:

```
ELAS_ORTH=_F (  E_L = 145200.0,
                E_T = 145200.0,
                E_N = 145200.0,
                NU_LT = 0. ,
                NU_LN = 0. ,
                NU_TN = 0. ,
                G_LT = 72600. ,
                G_LN = 72600. ,
                G_TN = 72600),
```

The results must thus correspond to the calculation of reference. Two calculations are carried out: one with implicit local integration, the other with explicit integration.

1.2.6 Calculation with the behavior monocrystal of the type 1 and systems of slip of ZIRCONIUM

Five calculations are carried out with this family of systems of slip:
1. a calculation of nonregression with the family defined in the code
2. a comparative calculation with the first, by providing a table containing the matrix of interaction
3. a comparative calculation with the precedents, with a polycrystal comprising only one grain,
4. a comparative calculation with the precedents, by providing five families defined starting from a table containing the systems of slip. The whole of these systems corresponds to the Zirconium family. This tests the possibility of defining different coefficients material according to the systems of slip considered,
5. a calculation identical to the precedent, with a polycrystal comprising only one grain.

1.2.7 Kocks-Rauch behavior: single-crystal, with system of slip BCC24

The behavior of the monocrystal is defined by the flow: **MONO_DD_KR** whose parameters are:

```
K      = 8.62E-5,
TAUR   = 498. ,
TAU0   = 132. ,
GAMMA0 = 1.E6,
DELTAG0= 0,768,
BSD    = 2.514E-5,
GCB    = 31,822,
KDCS   = 22.9,
P      = 0,335,
Q      = 1.12,
H1     = 0.25,
H2     = 0.25,
H3     = 0.25,
H4     = 0.25
```

Three calculations are carried out with this behavior:
1) A calculation MONOCRYSTAL implicit
2) A calculation MONOCRYSTAL explicit
3) A calculation POLYCRYSTAL clarify, with only one phase
These three calculations must lead to the same results.

1.3 Boundary conditions and loadings

Node $P4$	: $DX=DY=0$
Node $P8$	: $DX=DY=DZ=0$
Nodes $P2$ and $P6$	: $DX=0$
Nodes $P1$, $P3$, $P5$ and $P7$	: that is to say $FX=25$, that is to say $DX=0.001$

The loading in imposed force is increasing of $FX=0$ with $FX=25\times0.755\,N$, in an increment, which leads to a uniaxial state of stresses of $75.5\,MPa$ (limit of linearity)
The loading believes then until $FX=25\times0.955\,N$ in n increments. The calculation of reference is obtained with $n=100$. Single-crystal calculations are carried out with $n=20$.

With regard to the behaviors MONO_VISC2 and MONO_DD_KR, the loading is a varying imposed displacement of 0, at the initial moment, 0,001 at moment 2, in m increments.

For the implicit resolutions, $m=20$, and for the explicit resolutions, $m=100$.

For modeling B the loading is a varying imposed displacement of 0, at the initial moment, 0,001 at moment 3, in 20 increments.

2 Reference solution

2.1 Method of calculating

In 3D, (modeling A), the first calculation (behavior VISC_CIN1_CHAB) is used as reference. The values obtained with the last increment are (in any point of the mesh):

Constraint	*SIXX*	-9.55E+01
Total deflection	*EPXX*	-6.76443E-04
Plastic deformation	*EPXX*	-1.87292E-05

Calculations with MONO_ISOT1 or the first calculations with MONO_ISOT2are validated by comparison with this result or intercomparison.

On the other hand, other calculations (behaviors MONO_VISC2, MONO_DD_KR) do not have a value of reference. The tests are thus of not-regression. Moreover, five calculations corresponding to Zirconium do not have a reference solution but must give only one and even solution.

In 2D, (modeling B), the first calculation (behavior VISC_CIN1_CHAB) is used as reference. The values obtained with the last increment are (in any point of the mesh, because one imposes a uniform deformation):

Constraint	*SIXX*	95.999316

The second and the third calculations (behavior MONOCRYSTAL with system of slip UNIAXIAL) are validated by comparison with this result.

The third calculation uses an integration clarifies (RUNGE_KUTTA), whereas the second calculation uses an implicit integration.

3 Modeling A

3.1 Characteristics of the grid

Many nodes: 8. Modeling 3D : 1 element of quadratic volume: **HEXA8**.
The structure contains only one grain, the stress and strain state is homogeneous.

3.2 Sizes tested and results

3.2.1 Behavior of the type 1: MONO_VISC1 , MONO_ISOT1 , MONO_CINE1

Integration	Identification	Reference	% Tolerance
implicit	ε_{xx} of EPSI_ELGA	-6.764427E-04	0.10
implicit	ε_{xx} of EPSP_ELGA	-1.87292E-05	2.0
explicit	ε_{xx} of EPSI_ELGA	-6.764427E-04	0.2
explicit	ε_{xx} of EPSP_ELGA	-1.87292E-05	4.0

3.2.2 Behavior of the type 2: MONO_VISC2 , MONO_ISOT2 , MONO_CINE2

Comparison enters MONO_VISC2 , MONO_ISOT2 , MONO_CINE2 and MONO_VISC1, MONO_ISOT1, MONO_CINE1

Integration	Identification	Reference	% Tolerance
implicit	ε_{xx} of EPSI_ELGA	-6.76241E-04	0.10
implicit	ε_{xx} of EPSP_ELGA	-1.85279E-05	0.10
explicit	ε_{xx} of EPSI_ELGA	-6.757537E-04	0.10
explicit	ε_{xx} of EPSP_ELGA	-1.804038E-05	0.10

3.2.3 Behavior of the type 2: MONO_VISC2 , MONO_ISOT2 , MONO_CINE2

Not regression for MONO_VISC2 , MONO_ISOT2 , MONO_CINE2

Integration	Identification	Reference	% Tolerance
implicit	σ_{xx} of EPSI_ELGA	-95.9311	0.10
implicit	ε_{xx} of EPSP_ELGA	-1.3393175E-03	0.10

3.2.4 Behavior of the type 1 with ELAS_ORTH

Comparison enters MONO_VISC1 , MONO_ISOT1 , MONO_CINE1, with ELAS and with ELAS_ORTH

Integration	Identification	Reference	% Tolerance
implicit	ε_{xx} of EPSI_ELGA	-6.76241E-04	0.10
explicit	ε_{xx} of EPSI_ELGA	-6.75754E-04	0.10

3.2.5 Behavior of the type 1: MONO_VISC1 , MONO_ISOT1 , MONO_CINE1 for ZIRCONIUM

The first calculation: matrix of interaction (matrix identity h=0) and systems of slip defined in Code_Aster:

Integration	Identification	Reference	% Tolerance
Implicit	σ_{xx} of SIEF_ELGA	-212,31	0.1
implicit	ε_{xx} of EPSP_ELGA	-5,3785E-04	0.1
implicit	v_{92} of VARI_ELGA	5,2868E-04	0.1

The second calculation: systems of slip defined in Code_Aster, matrix of interaction defined by the user (matrix identity, provided in data in a table). Comparison with the first calculation.

Integration	Identification	Reference	% Tolerance
Implicit	σ_{xx} of SIEF_ELGA	-212,3	0.1
implicit	ε_{xx} of EPSP_ELGA	-5,3785E-04	0.1
implicit	v_{92} of VARI_ELGA	5,2868E-04	0.1

The third calculation: systems of slip defined in Code_Aster, matrix of interaction defined by the user (matrix identity, provided in data in a table), and behavior POLYCRYSTAL :

Integration	Identification	Reference	% Tolerance
Polycrystal	σ_{xx} of SIEF_ELGA	-212,3	0.1
Polycrystal	ε_{xx} of EPSP_ELGA	-5,3785E-04	0.1
Polycrystal	v_{99} of VARI_ELGA	5,2868E-04	0.1

The fourth calculation: systems of slip and matrix of interaction defined by the user:

Integration	Identification	Reference	% Tolerance
Implicit	σ_{xx} of SIEF_ELGA	-212,3	0.1
implicit	ε_{xx} of EPSP_ELGA	-5,3785E-04	0.1
implicit	v_{92} of VARI_ELGA	5,2868E-04	0.1

The fifth calculation: systems of slip and matrix of interaction defined by the user, and behavior POLYCRYSTAL (only one phase, to allow the comparison with preceding calculations):

Integration	Identification	Reference	% Tolerance
Polycrystal	σ_{xx} of SIEF_ELGA	-212,3	0.1
Polycrystal	ε_{xx} of EPSP_ELGA	-5,3785E-04	0.3
Polycrystal	v_{99} of VARI_ELGA	5,2868E-04	0.8

3.2.6 Behavior: MONO_DD_KR

Integration	Identification	Reference	% Tolerance
implicit	σ_{xx} of SIEF_ELGA	-324.37	0.40
implicit	ε_{xx} of EPSP_ELGA	-8.1822E-04	0.20
explicit	σ_{xx} of SIEF_ELGA	-324.37	0.40
explicit	ε_{xx} of EPSP_ELGA	-8.1822E-04	0.05
Polycrystal	σ_{xx} of SIEF_ELGA	-324.37	0.40
Polycrystal	ε_{xx} of EPSP_ELGA	-8.1822E-04	0.05

4 Modeling B

4.1 Characteristics of the grid

Many nodes: 4.
1 mesh **QUAD4**.
Modeling C_PLAN (by the method DEBORST).

4.2 Sizes tested and results

The second calculation (implicit, MONO_VISC1, MONO_ISOT1, MONO_CINE1)

Identification	Reference	% Tolerance
σ_{xx} of SIEF_ELGA	-95.9993	0.10

The third calculation (clarifies, MONO_VISC1, MONO_ISOT1, MONO_CINE1)

Identification	Reference	% Tolerance
σ_{xx} of SIEF_ELGA	-95.9993	0.10

5 Summary of the results

The got results are in concord with the reference solution. The noted difference ($3{,}6\%$ to the maximum) comes from the different digital diagrams, sensitive to the temporal discretization.