HSNV140 - Thermoplasticity with restoration of work hardening: test of blocked dilatometry

Summary:

This test of thermomechanical quasi-static nonlinear consists in applying several cycles of thermal loading to a steel 316L test-tube. Two ends of the test-tube are blocked in displacement. This kind of test is also known under the name of Satoh test.
In this test, the incompatibility of the deformations involves a cyclic plasticity in traction and compression and residual stresses appear. The phenomenon of restoration of work hardening, present at high temperature, must be taken into account without what the residual stresses will be badly estimated.

The objective of this case test is to validate the taking into account of the phenomenon of restoration of work hardening for elastoplastic laws of behaviour to isotropic, kinematic and mixed work hardening.

A linear isotropic work hardening is considered in modeling A, B and C, respectively in 3D, 2D axisymmetric and 2D forced plane.

The law with linear kinematic work hardening is applied in modeling E, in 2D axisymmetric.

Modeling F tests mixed work hardening linéiare in 2D forced plane.

In modelings A, B, C, D and E, the coefficient of restoration of work hardening varies according to the temperature.

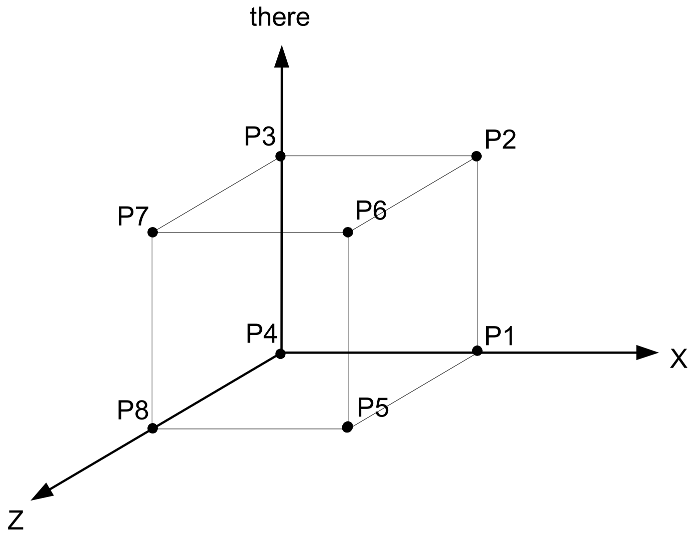
In modeling F, the coefficient of restoration of work hardening is one according to the temperature and of time.

The digital results are confronted with the experimental results.

1 Problem of reference

1.1 Geometry

Axisymmetric cylinder (modelings B and D) or rectangular plate (modelings B and E) or parallelepiped 3D (modeling A)



1.2 Material properties

The properties materials are those of steel 316L, described by the following parameters:

Thermal parameters:

Voluminal heat-storage capacity $\rho C_p = 3.9 \times 10^6 (J.m^{-3.} \circ C^{-1})$

Conductivity $\lambda (W.m^{-1} \circ C^{-1})$:

T (°C)	λ
20.	14.
100.	15.2
200.	16.6
300.	17.9
400.	19.0
500.	20.6
600.	21.8
700.	23.1
800.	24.3
900.	26.
1000.	27.3
1200.	29.9
1450.	35.
1500.	70.

Thermomechanical parameters:

- Thermoelastic parameters:

Young modulus $E(Pa)$
Poisson's ratio: $\nu=0.3$
Thermal dilation coefficient α
Temperature of definition of the dilation coefficient: $T_{ref}=20°C$
Elastic limit $\sigma_y(Pa)$

T (°C)	$E(\times 10^6)$
20.	195600.
100.	191200.
200.	185700.
300.	179600.
400.	172600.
500.	164500.
600.	155000.
700.	144100.
800.	131400.
900.	116800.
1000.	100000.
1100.	80000.
1200.	57000.
1300.	30000.
1400.	2000.
1500.	1000.

T (°C)	$\alpha(\times 10^{-6})$
20.	14.56
100.	15.39
200.	16.21
300.	16.86
400.	17.37
500.	17.78
600.	18.12
700.	18.43
800.	18.72
900.	18.99
1000.	19.27
1100.	19.53
1200.	19.79
1300.	20.02
1600.	20.02

T (°C)	$\sigma_y(\times 10^6)$
20.	286.
200.	212.
400.	180.
600.	137.
800.	139.
1000.	70.
1100.	35.
1200.	16.
1300.	10.
1500.	10.

- Thermoplastic parameters (law with linear work hardening)

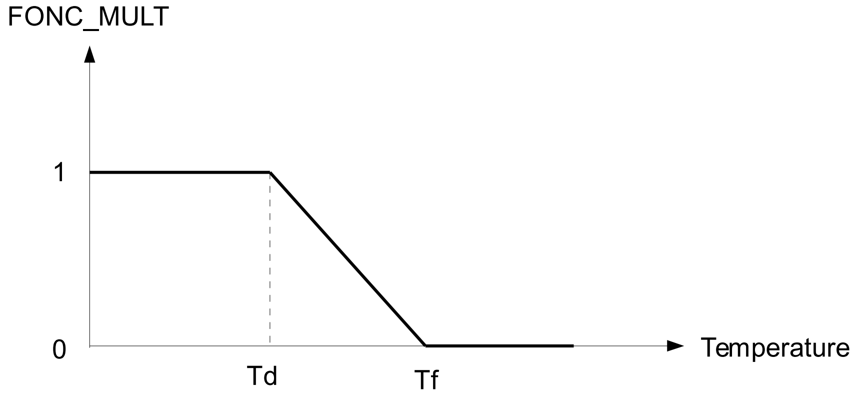
Tangent module $E_T(Pa)$
Constant of Prager $C(Pa)$ (mixed work hardening)

T (°C)	$E_T(\times 10^6)$
20.	2400.
700.	2400.
800.	2350.
900.	1500.
1000.	800.
1100.	725.
1200.	150.
1300.	10.

T (°C)	$C(\times 10^6)$
20.	1200.
700.	1200.
800.	1175.
900.	750.
1000.	400.
1100.	362.5
1200.	75.
1300.	5.

- Parameter of restoration of work hardening: multiplicative function `FONC_MULT`

  Initial temperature of restoration: Td = 600°C
  Temperature of end of restoration: Tf = 1000°C



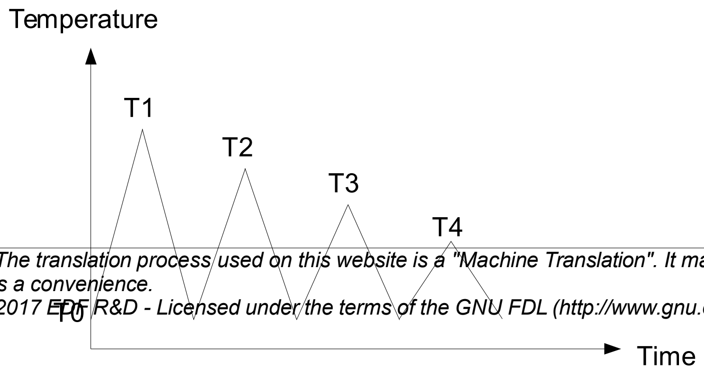
1.3 Boundary conditions and loadings

- Modeling a:
  uy = 0 on faces (P1P4P8P5) and (P2P3P7P6)
  ux = 0 and uz =0 in P4
  ux = 0 in P3

- Modelings B and D:
  uy = 0 in P1, P2, P3 and P4

- Modelings C and E:
  uy = 0 at the points P1, P2, P3 and P4
  ux = 0 in P3

For 5 modelings A-F, the following thermal loading is applied to all the grid:



T0	20°C
T1	1125°C
T2	932°C
T3	685°C
T4	473°C

2 Reference solution

2.1 Nature of the reference solution

The reference solution is extracted from experimental tests described in [1].

2.2 Results of reference

One will be interested in the values of the constraint σ_{yy} at the end of each thermal cycle, and with the values of the cumulated plastic deformation p and of the component X_{11} kinematic tensor of work hardening X at the end of the restoration of work hardening.

2.3 Uncertainty on the solution

Experimental values for σ_{yy} .
Data-processing test for p and X_{11} .

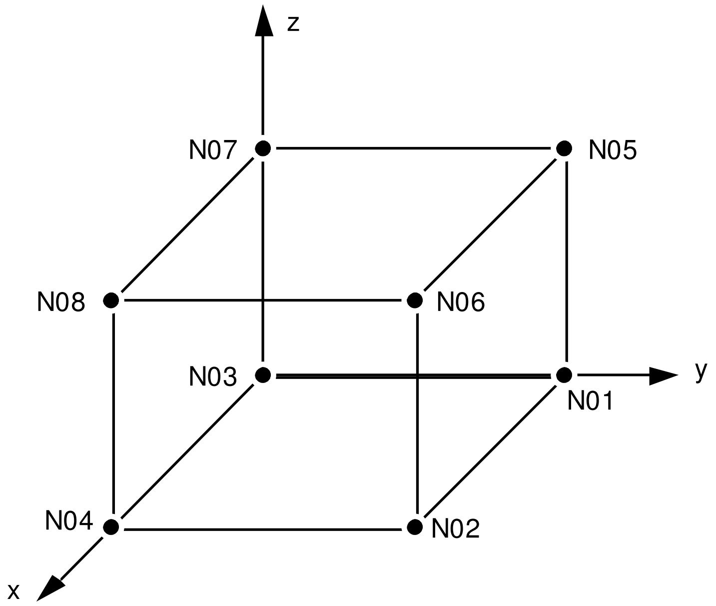
2.4 Bibliographical references

[1] L. DEPRADEUX, Digital simulation of welding for the prediction of the distortions and residual stresses – experimental validation on case tests of reference – Steel 316L, Doctorate: National institute of Applied sciences of Lyon, 2004.

3 Modeling A

3.1 Characteristics of modeling

Modeling 3D.



The boundary conditions are modelled by:

On the node N07, DX=DY=0
On the node N03, DX=DY=DZ=0
On the nodes (N01, N02, N04, N05, N06, N08), DY=0.

Mechanical calculation is carried out with the elastoplastic law of behavior of VonMises with linear isotropic work hardening (keyword 'RELATION = VMIS_ISOT_LINE')

3.2 Characteristics of the grid

Many nodes: 8
Number of meshs and type: 1 HEXA8

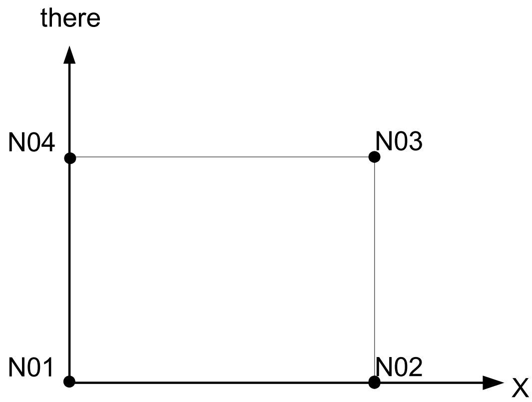
3.3 Sizes tested and results

Variables	Moments (s)	Type of Reference	Reference	% tolerance
p	89	SOURCE_EXTERNE	0	$1.E^{-4}$
σ_{yy}	200	SOURCE_EXTERNE	303.0E+06	10.
σ_{yy}	400	SOURCE_EXTERNE	316.0E+06	10.
σ_{yy}	600	SOURCE_EXTERNE	325.0E+06	10.
σ_{yy}	800	SOURCE_EXTERNE	327.0E+06	10.

4 Modeling B

4.1 Characteristics of modeling

Axisymmetric modeling 2D.



The boundary conditions are modelled by:

On the nodes `(N01, N02, N03, N04), DY=0.`

Mechanical calculation is carried out with the elastoplastic law of behavior of Von Mises with linear isotropic work hardening (keyword `'RELATION = VMIS_ISOT_LINE')`

4.2 Characteristics of the grid

Many nodes: 4
Number of meshs and type: 1 `QUAD4`

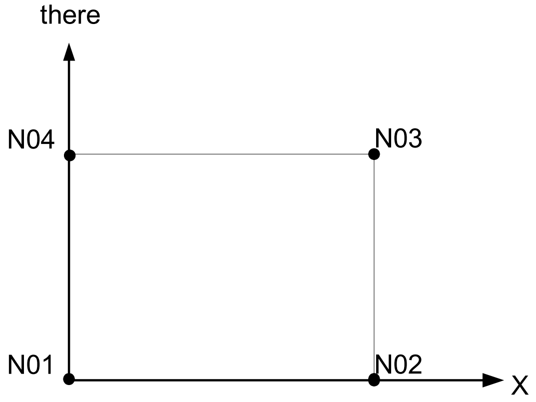
4.3 Sizes tested and results

Variables	Moments (s)	Type of Reference	Reference	% tolerance
p	89	SOURCE_EXTERNE	0	$1.E^{-4}$
σ_{yy}	200	SOURCE_EXTERNE	303.0E+06	10.
σ_{yy}	400	SOURCE_EXTERNE	316.0E+06	10.
σ_{yy}	600	SOURCE_EXTERNE	325.0E+06	10.
σ_{yy}	800	SOURCE_EXTERNE	327.0E+06	10.

5 Modeling C

5.1 Characteristics of modeling

Modeling 2D forced plane.



The boundary conditions are modelled by:

On the nodes `(N01, N02, N03), DY=0.`
On the node `N04, DX=DY=0.`

Mechanical calculation is carried out with the elastoplastic law of behavior of Von Mises with linear isotropic work hardening (keyword `'RELATION = VMIS_ISOT_LINE'`)

5.2 Characteristics of the grid

Many nodes:	4
Number of meshs and type:	1 `QUAD4`

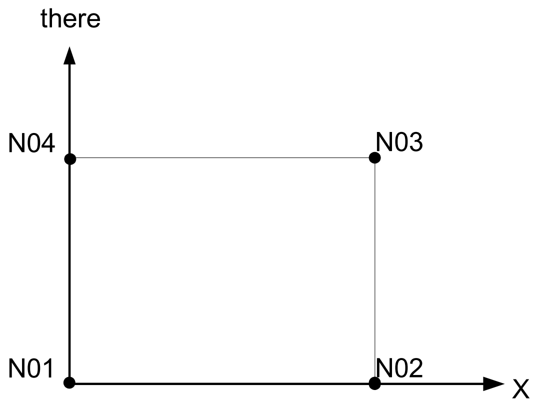
5.3 Sizes tested and results

Variables	Moments (s)	Type of Reference	Reference	% tolerance
p	89	SOURCE_EXTERNE	0	$1.E^{-4}$
σ_{yy}	200	SOURCE_EXTERNE	303.0E+06	10.
σ_{yy}	400	SOURCE_EXTERNE	316.0E+06	10.
σ_{yy}	600	SOURCE_EXTERNE	325.0E+06	10.
σ_{yy}	800	SOURCE_EXTERNE	327.0E+06	10.

6 Modeling D

6.1 Characteristics of modeling

Axisymmetric modeling 2D.



The boundary conditions are modelled by:

On the nodes `(N01, N02, N03, N04), DY=0.`

Mechanical calculation is carried out with the elastoplastic law of behavior of Von Mises with linear kinematic work hardening (keyword `'RELATION = VMIS_CINE_LINE')`.

6.2 Characteristics of the grid

Many nodes: 4
Number of meshs and type: 1 QUAD4

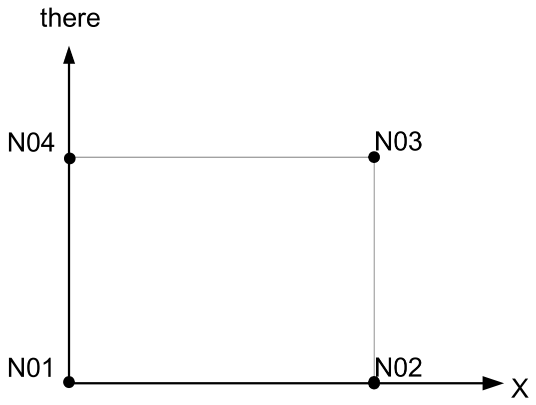
6.3 Sizes tested and results

Variables	Moments (s)	Type of Reference	Reference	% tolerance
X_{11}	89	SOURCE_EXTERNE	0	$1.E^{-4}$
σ_{yy}	200	SOURCE_EXTERNE	303.0E+06	10.
σ_{yy}	400	SOURCE_EXTERNE	316.0E+06	10.
σ_{yy}	600	SOURCE_EXTERNE	325.0E+06	10.
σ_{yy}	800	SOURCE_EXTERNE	327.0E+06	10.

7 Modeling E

7.1 Characteristics of modeling

Modeling 2D forced plane.



The boundary conditions are modelled by:

On the nodes (N01, N02, N03), DY=0.
On the node N04, DX=DY=0.

Mechanical calculation is carried out with the elastoplastic law of behavior of Von Mises with linear mixed work hardening (keyword 'RELATION = VMIS_ECMI_LINE').

7.2 Characteristics of the grid

Many nodes: 4
Number of meshs and type: 1 QUAD4

7.3 Sizes tested and results

Variables	Moments (s)	Type of Reference	Reference	% tolerance
p	89	SOURCE_EXTERNE	0	$1.E^{-4}$
σ_{yy}	200	SOURCE_EXTERNE	303.0E+06	10.
σ_{yy}	400	SOURCE_EXTERNE	316.0E+06	10.
σ_{yy}	600	SOURCE_EXTERNE	325.0E+06	10.
σ_{yy}	800	SOURCE_EXTERNE	327.0E+06	10.

8 Summary of the results

The results are satisfactory: the taking into account of the restoration of work hardening makes it possible to obtain a good approximation of the constraints in the case of a test of blocked dilatometry.