UHARD/VUHARD subroutines

User subroutine to define the yield surface size and hardening parameters for isotropic plasticity or combined hardening models

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(V)UHARD subroutine

UHARD: User subroutine to define the yield surface size and hardening parameters for isotropic plasticity or combined hardening models.

VUHARD: User subroutine to define the yield surface size and hardening parameters for isotropic plasticity or combined hardening models.

(V)UHARD subroutine

From the ABAQUS documentation:

ABAQUS/standard

Overview

User subroutine **`UHARD`**:

- is called at all material calculation points of elements for which the material definition includes user-defined isotropic hardening or cyclic hardening for metal plasticity;
- can be used to define a material's isotropic yield behavior;
- can be used to define the size of the yield surface in a combined hardening model;
- can include material behavior dependent on field variables or state variables; and
- requires, when appropriate, that the values of the derivatives of the yield stress (or yield surface size in combined hardening models) be defined with respect to the strain, strain rate, and temperature.

ABAQUS/explicit

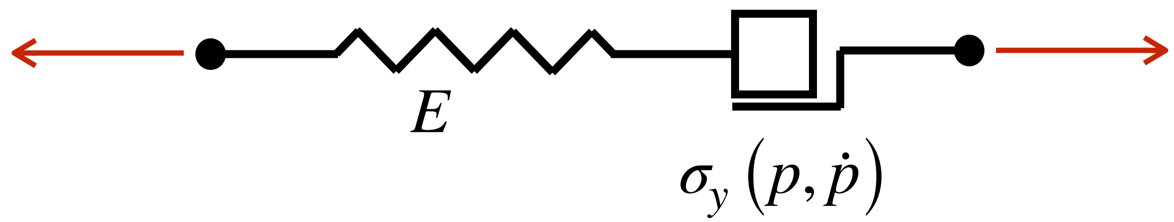
Overview

User subroutine **`VUHARD`**:

- is called at all material points of elements for which the material definition includes user-defined isotropic hardening or cyclic hardening for metal plasticity;
- can be used to define a material's isotropic yield behavior;
- can be used to define the size of the yield surface in a combined hardening model;
- can include material behavior dependent on field variables or state variables; and
- requires that the derivatives of the yield stress (or yield surface size in combined hardening models) be defined with respect to the appropriate independent variables, such as strain, strain rate, and temperature.

(V)UHARD subroutine

In this example, we want to develop an elasto-visco-plastic model.



Hypo-elasticity:

$$\hat{\mathbf{D}} = \hat{\mathbf{D}}_e + \hat{\mathbf{D}}_p$$

Isotropic elastic:

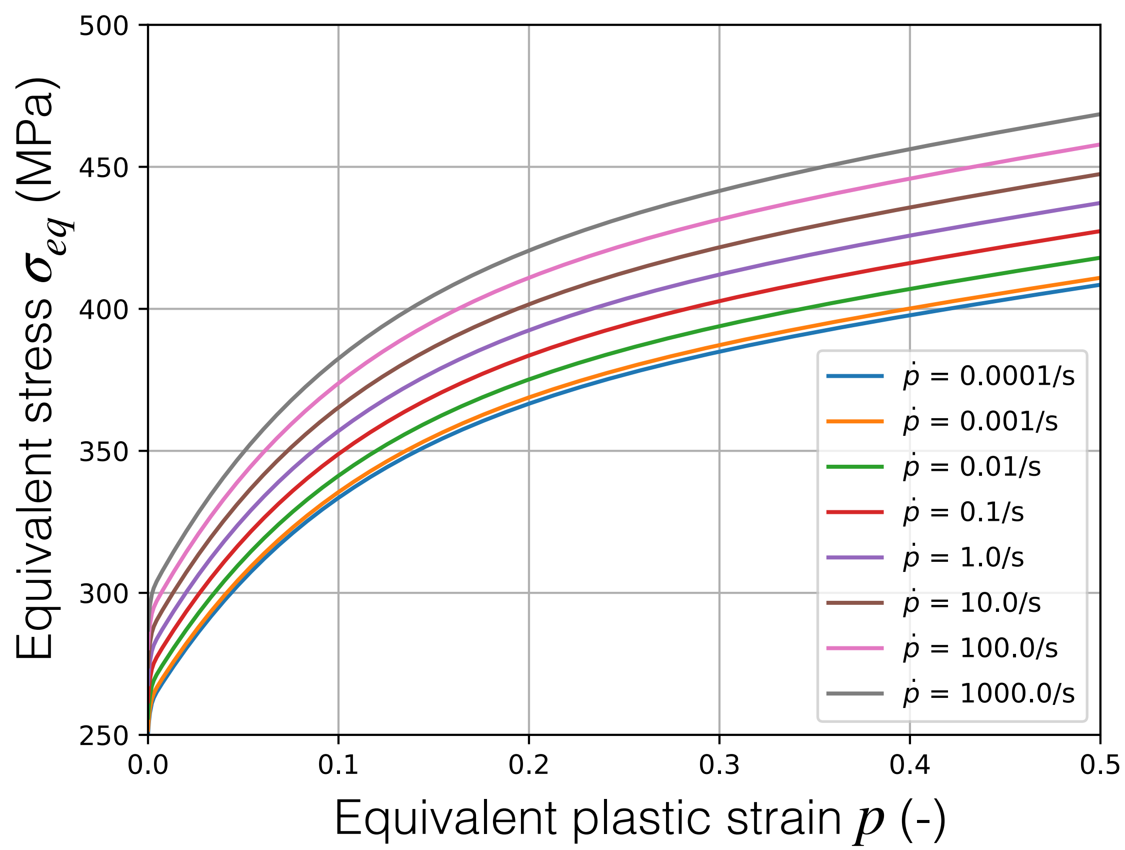
$$\dot{\hat{\boldsymbol{\sigma}}} = \frac{E}{1+\nu}\hat{\mathbf{D}}_e^{'} + \frac{E}{3\left(1-2\nu\right)}\mathrm{tr}\hat{\mathbf{D}}_e\mathbf{I}$$

Isotropic hardening:

$$\sigma_y = \sigma_0 + \sum_{i=1}^{3} Q_i\left[1-\exp\left(-\frac{\theta_i}{Q_i}p\right)\right]$$

Visco-plasticity:

$$\dot{p} = \dot{p}_0\left\langle\left(\frac{\sigma_{eq}}{\sigma_y}\right)^{1/C} - 1\right\rangle$$



(V)UHARD subroutine

Overall goal of UHARD/VUHARD:

$$p, \dot{p}, T \longrightarrow \boxed{\text{UHARD/VUHARD}} \longrightarrow \sigma_y\left(p, \dot{p}, T\right), \frac{\partial \sigma_y}{\partial p}, \frac{\partial \sigma_y}{\partial \dot{p}}, \frac{\partial \sigma_y}{\partial T}$$

Where p is the equivalent plastic strain, $\dot{p}$ is the equivalent plastic strain rate, T is the temperature and σ_y is the current yield stress

Description of the arguments for UHARD/VUHARD:

ABAQUS/standard

```
 SUBROUTINE UHARD(SYIELD,HARD,EQPLAS,EQPLASRT,
+ TIME,DTIME,TEMP,DTEMP,
+ NOEL,NPT,LAYER,KSPT,KSTEP,KINC,CMNAME,NSTATV,
+ STATEV,NUMFIELDV,PREDEF,DPRED,NUMPROPS,PROPS)
```

SYIELD: $\sigma_y\left(p, \dot{p}, T\right)$; HARD: $\frac{\partial \sigma_y}{\partial p}, \frac{\partial \sigma_y}{\partial \dot{p}}, \frac{\partial \sigma_y}{\partial T}$; EQPLAS: p; EQPLASRT: $\dot{p}$; TEMP: T

ABAQUS/explicit

```
 SUBROUTINE VUHARD(NBLOCK,JELEM,KINTPT,KLAYER,KSECPT,
. LANNEAL,STEPTIME,TOTALTIME,DT,CMNAME,
. NSTATEV,NFIELDV,NPROPS,
. PROPS,TEMPOLD,TEMPNEW,FIELDOLD,FIELDNEW,
. STATEOLD,
. EQPS,EQPSRATE,
. YIELD,DYIELDDTEMP,DYIELDDEQPS,
. STATENEW)
```

TEMPNEW: T; EQPS: p; EQPSRATE: $\dot{p}$; YIELD: $\sigma_y\left(p, \dot{p}, T\right)$; DYIELDDTEMP: $\frac{\partial \sigma_y}{\partial T}$; DYIELDDEQPS: $\frac{\partial \sigma_y}{\partial p}, \frac{\partial \sigma_y}{\partial \dot{p}}$

(V)UHARD subroutine

ABAQUS/standard

```
!----------------------------------------------------------------------
!     Compute yield stress and derivatives
!----------------------------------------------------------------------
      SYIELD = (SIGMA0+Q1*(1.0-exp(-T1oQ1*EQPLAS))
     +                 +Q2*(1.0-exp(-T2oQ2*EQPLAS))
     +                 +Q3*(1.0-exp(-T3oQ3*EQPLAS)))
!----------------------------------------------------------------------
!     Compute yield stress derivatives
!----------------------------------------------------------------------
c     Derivative with respect to equivalent plastic strain
      HARD(1) =(T1*exp(-T1oQ1*EQPLAS)
     +         +T2*exp(-T2oQ2*EQPLAS)
     +         +T3*exp(-T3oQ3*EQPLAS))
c     Derivative with respect to equivalent plastic strain rate
      HARD(2) =(SIGMA0+Q1*(1.0-exp(-T1oQ1*EQPLAS))
     +                 +Q2*(1.0-exp(-T2oQ2*EQPLAS))
     +                 +Q3*(1.0-exp(-T3oQ3*EQPLAS)))
c     Derivative with respect to temperature
      HARD(3) = 0.0
!----------------------------------------------------------------------
```

σ_y (SYIELD); $\frac{\partial \sigma_y}{\partial p}$ (HARD(1)); $\frac{\partial \sigma_y}{\partial \dot{p}}$ (HARD(2)); $\frac{\partial \sigma_y}{\partial T}$ (HARD(3))

ABAQUS/explicit

```
!----------------------------------------------------------------------
!     Compute yield stress and its derivatives
!----------------------------------------------------------------------
      do i=1,nblock
        yield(i) =(SIGMA0+Q1*(1.0-exp(-T1oQ1*eqps(i)))
     +                   +Q2*(1.0-exp(-T2oQ2*eqps(i)))
     +                   +Q3*(1.0-exp(-T3oQ3*eqps(i))))
c       Derivative with respect to equivalent plastic strain
        dyieldDeqps(i,1) =(T1*exp(-T1oQ1*eqps(i))
     +                    +T2*exp(-T2oQ2*eqps(i))
     +                    +T3*exp(-T3oQ3*eqps(i)))
c       Derivative with respect to equivalent plastic strain rate
        dyieldDeqps(i,2) = 0.0
c       Derivative with respect to temperature
        dyieldDtemp(i)   = 0.0
      enddo
!----------------------------------------------------------------------
```

σ_y (yield(i)); $\frac{\partial \sigma_y}{\partial p}$ (dyieldDeqps(i,1)); $\frac{\partial \sigma_y}{\partial \dot{p}}$ (dyieldDeqps(i,2)); $\frac{\partial \sigma_y}{\partial T}$ (dyieldDtemp(i))

(V)UHARD subroutine

ABAQUS/standard

```
**-------------------------------------------------------------------------
*material,name=EXAMPLE_UHARD_RATE
*elastic
210000.0, 0.3
*plastic, hardening=user, properties=16
** SIGMA0,       T1,     Q1,       T2,     Q2,     T3,       Q3, BLANK
    250.0, 10000.0,   10.0, 1000.0, 100.0, 100.0, 1000.0,    0.0
**        C,    PDOT0, BLANK,   BLANK, BLANK, BLANK,   BLANK, BLANK
     0.01,    0.001,    0.0,      0.0,    0.0,    0.0,     0.0,    0.0
**-------------------------------------------------------------------------
```

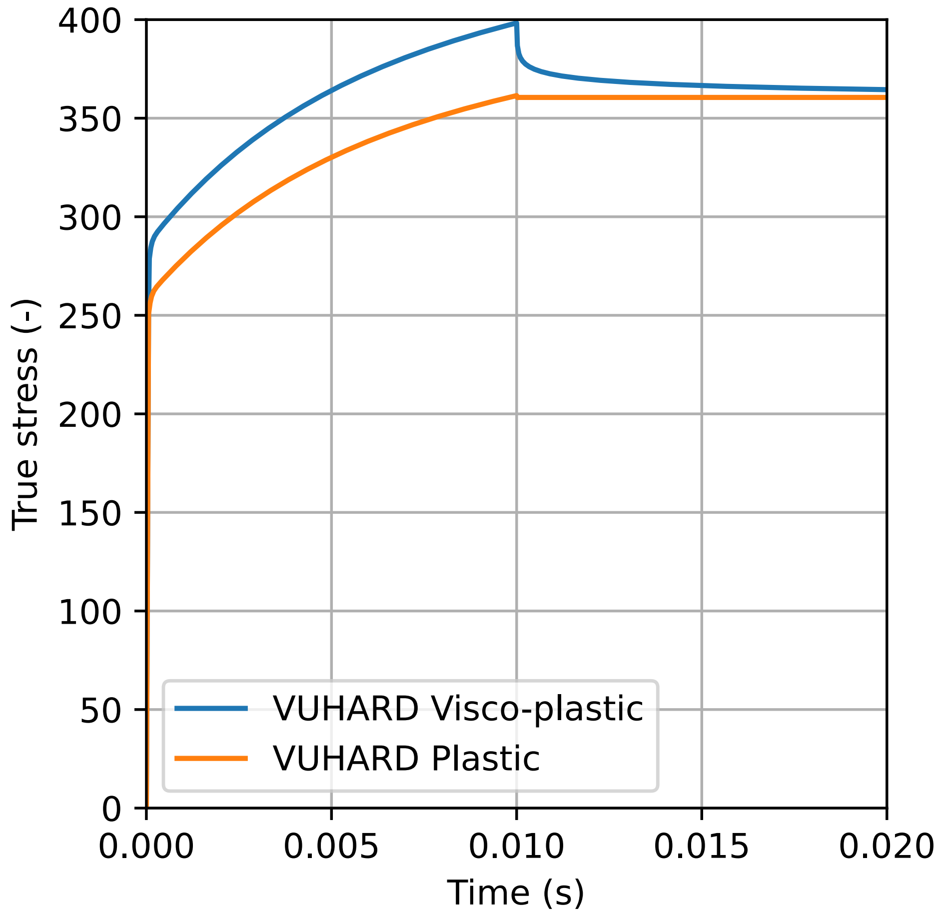
Call to VUHARD/
UHARD subroutine

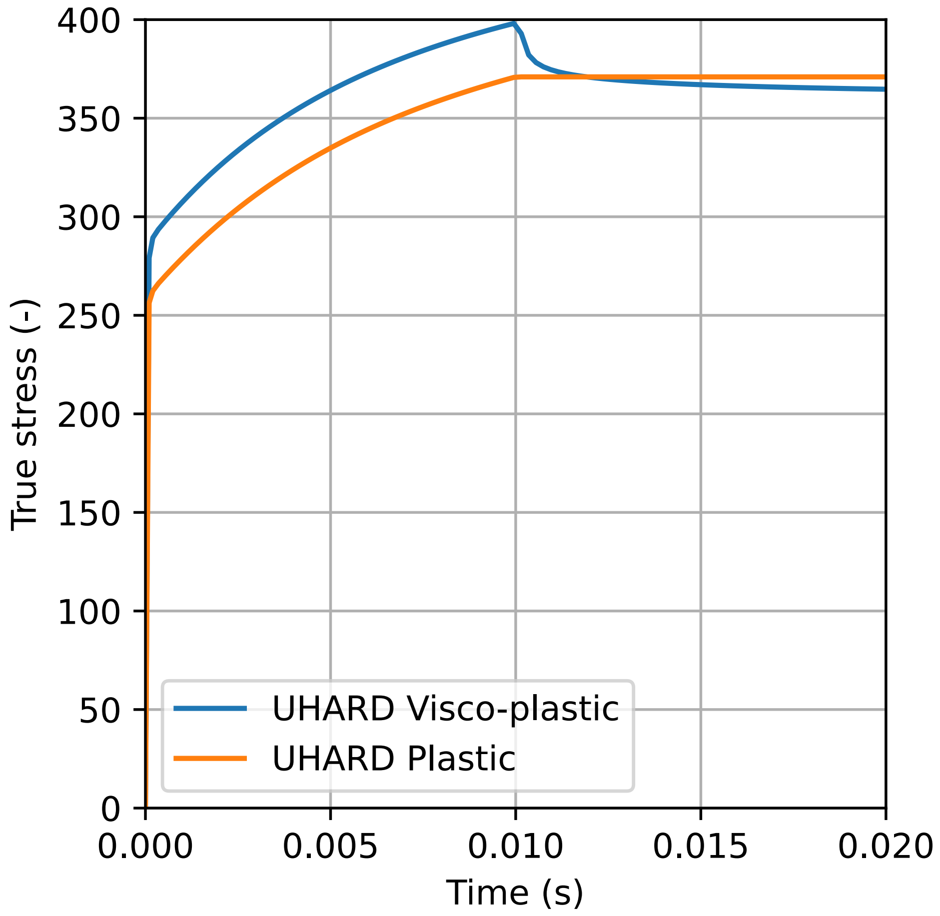
ABAQUS/explicit

```
**-------------------------------------------------------------------------
*material,name=EXAMPLE_VUHARD_RATE
*density
7.8e-9
*elastic
210000.0, 0.3
*plastic, hardening=user, properties=16
** SIGMA0,       T1,     Q1,       T2,     Q2,     T3,       Q3, BLANK
    250.0, 10000.0,   10.0, 1000.0, 100.0, 100.0, 1000.0,    0.0
**        C,    PDOT0, BLANK,   BLANK, BLANK, BLANK,   BLANK, BLANK
     0.01,    0.001,    0.0,      0.0,    0.0,    0.0,     0.0,    0.0
**-------------------------------------------------------------------------
```

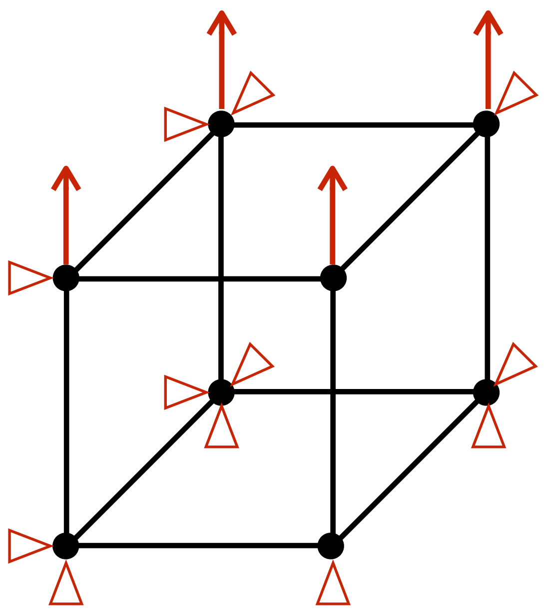
(V)UHARD subroutine

Results from the UHARD_V1 and VUHARD_V1 subroutines



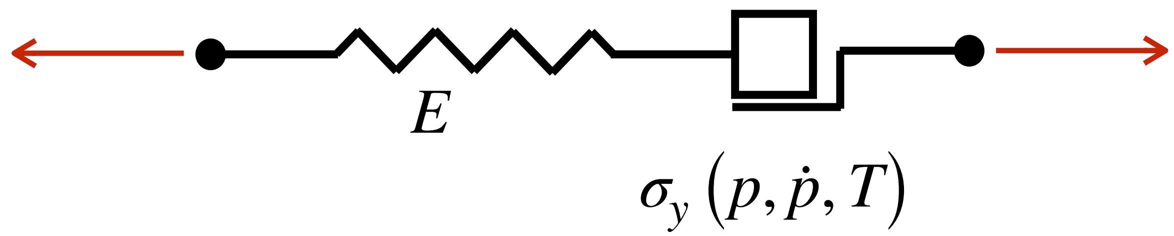


Single solid element
in uniaxial tension



(V)UHARD subroutine

In this example, we want to develop an elasto-visco-thermo-plastic model.



$$\sigma_y = \left(\sigma_0 + R\right) . \left(1 + \frac{\dot{p}}{\dot{p}_0}\right)^C . \left(1 - \left(\frac{T - T_r}{T_m - Tr}\right)^m\right)$$

Isotropic hardening:

$$R = \sum_{i=1}^{3} Q_i \left(1 - \exp\left(-\frac{\theta_i}{Q_i} p\right)\right)$$

Visco-plasticity

Thermo-plasticity

Temperature: $T = T_0 + \Delta T$ with $\Delta T = \int_0^p \beta \frac{\sigma_{eq} dp}{\rho C_p}$

Adiabatic heating

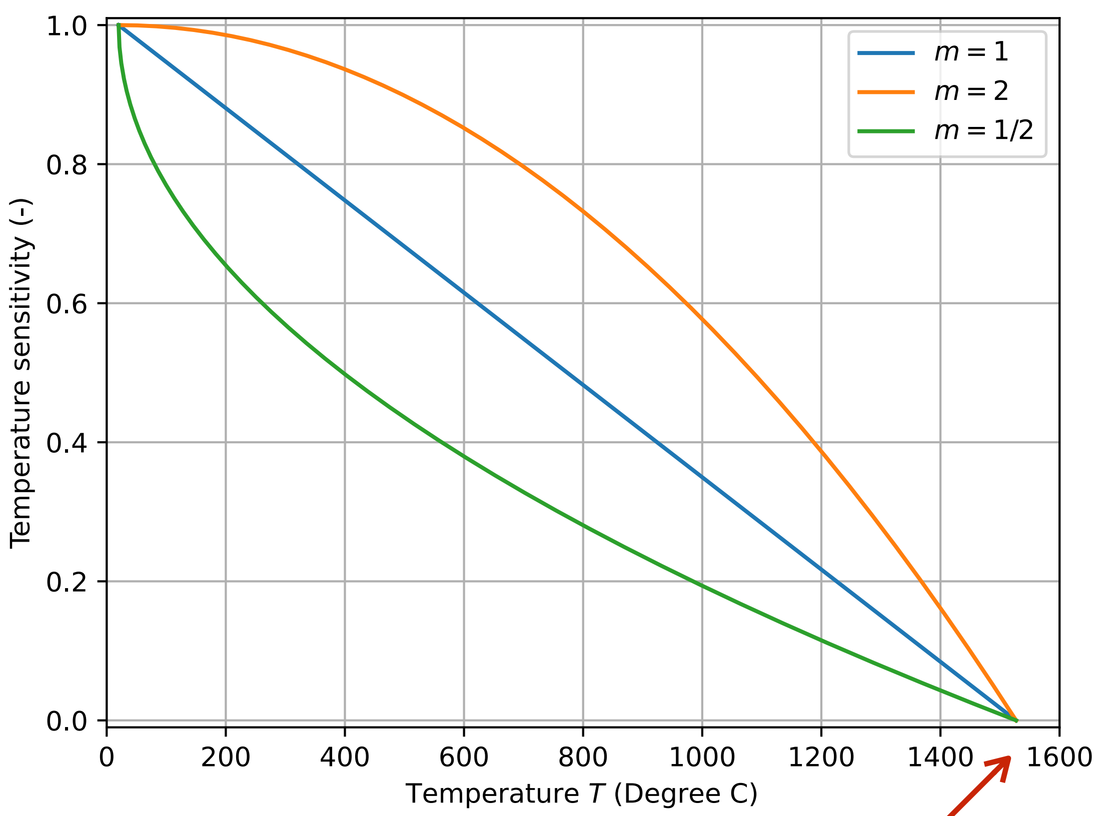
(V)UHARD subroutine

Starting from the VUHARD_V1.f subroutine:

```
!-----------------------------------------------------------------------
!     Apply temperature-sensitivity if needed
!-----------------------------------------------------------------------
      if((m.gt.0.0).and.(Tm.gt.0.0))then
         do i=1,nblock
c           Compute rate effects and its derivative
            Teff = ((min(TEMPNEW(i),0.99*Tm)-Tr)/(Tm-Tr))
            tp   = (1.0-Teff**m)
            dtp  =-(m/(Tm-Tr))*(Teff**(m-1.0))
c           Apply rate effects to the required quantities
            dyieldDtemp(i)   = yield(i)*dtp
            dyieldDeqps(i,2) = dyieldDeqps(i,2)*tp
            dyieldDeqps(i,1) = dyieldDeqps(i,1)*tp
            yield(i) = yield(i)*tp
         enddo
      endif
!-----------------------------------------------------------------------
```

$T \leq 99\,\%\, T_m$

$\dfrac{\partial \sigma_y}{\partial T}$



$T = T_m$ gives $\sigma_y = 0$

(V)UHARD subroutine

Material card

$$\Delta T = \int_0^p \beta \frac{\sigma_{eq} dp}{\rho C_p}$$

```
**---------------------------------------------------------------
*material,name=EXAMPLE_VUHARD_RATE
*density
7.8e-9
*elastic
210000.0, 0.3
*specific heat
4.52e8,
*inelastic heat fraction
0.9,
*plastic, hardening=user, properties=16
** SIGMA0,      T1,     Q1,      T2,      Q2,     T3,      Q3, BLANK
     777.0,  3693.4, 125.2, 240.34, 2670.5,    0.0,     0.0,    0.0
**       C,   PDOT0,      m,     Tr,      Tm, BLANK,  BLANK, BLANK
      0.01,  0.0005,    1.0,  293.0, 1800.0,    0.0,     0.0,    0.0
**---------------------------------------------------------------
```

Extra keywords

```
*initial conditions, type=temperature
TENS_2-1.NODES, 293.0
```

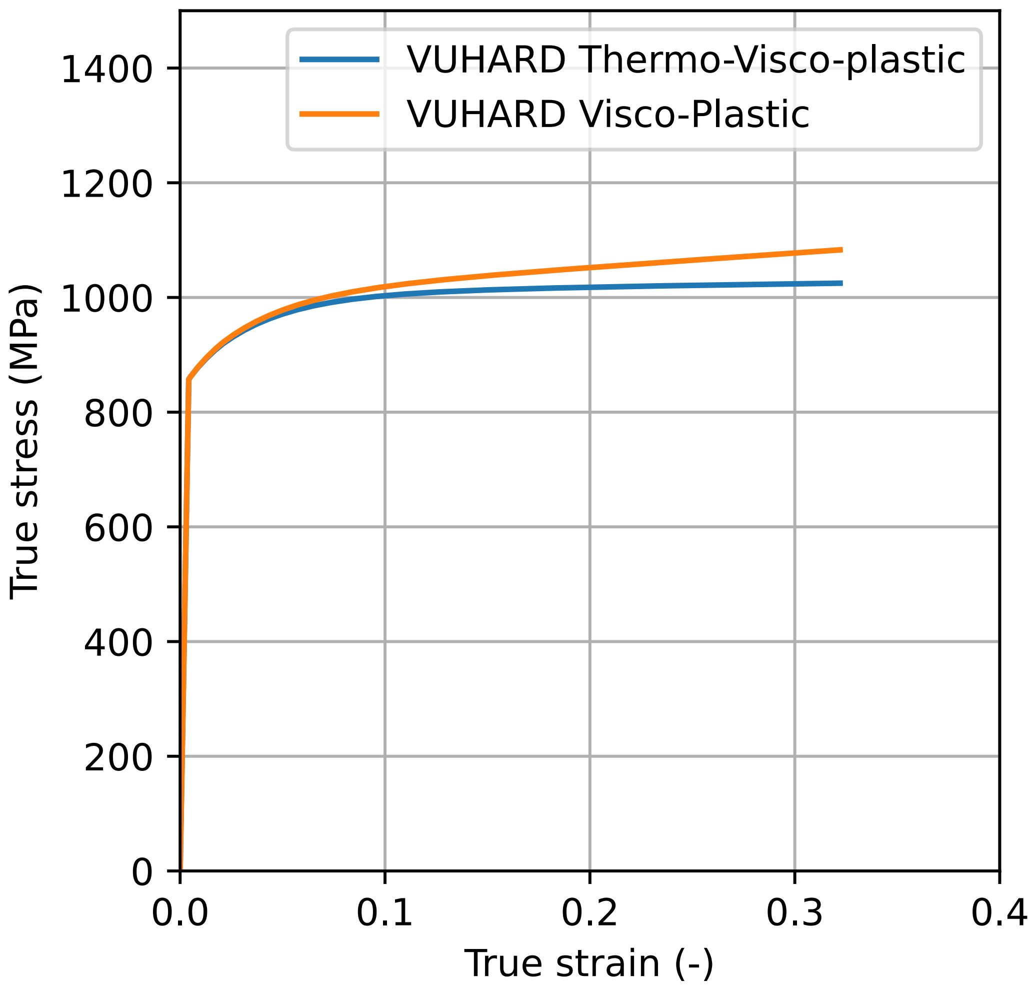
Node set

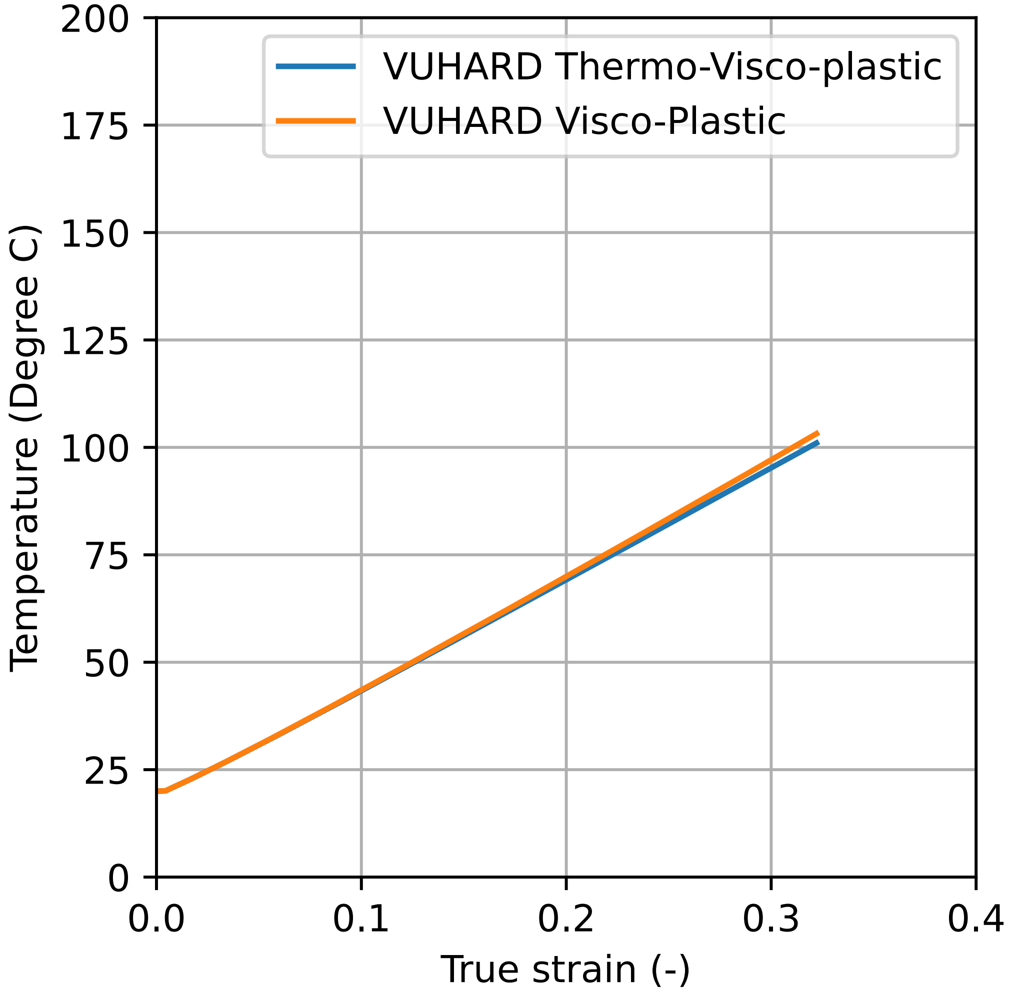
```
**----------------------------------------------
** STEP
**----------------------------------------------
*Step, name=LOADING
*Dynamic, Explicit,scale factor=0.5, ADIABATIC
, 0.02
*Bulk Viscosity
0.06, 1.2
**----------------------------------------------
```

$$T = T_0 + \Delta T$$

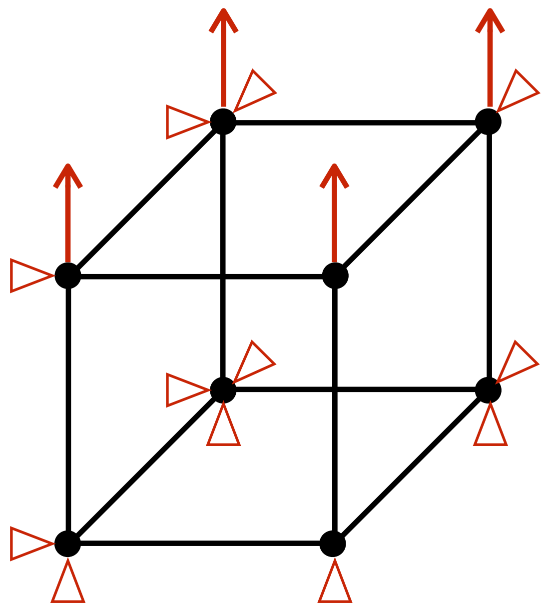
(V)UHARD subroutine

Results from the VUHARD_V2 subroutine





Single solid element
in uniaxial tension



(V)UHARD subroutine

Can be used with:

- a von Mises/Hill/Raghava yield surface
- the Gurson model
- A combined isotropic/kinematic hardening model