

## SSNA123 – Validation of the law of behavior of steels under irradiations into axisymmetric

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### Summary:

This elementary test aims to validate the law of behavior IRRAD3M steels under irradiations. Three modelings are present to validate each aspect of the law separately:

- modeling (A) concentrates on the plastic part of the law,
- modeling (b) on the irradiation part,
- modeling (c) on the swelling part.

## 1 Problem of reference

### 1.1 Geometry

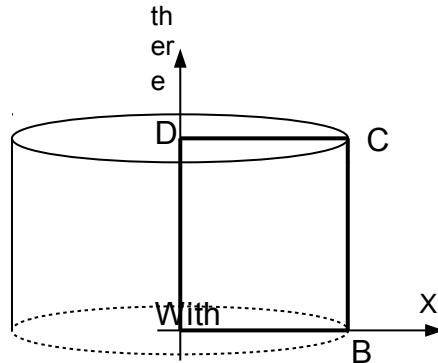


Figure 1.1-a : Geometry of the problem.

It is about a cylinder of ray  $1\text{ mm}$  and height  $1\text{ mm}$ .  
The square in fat corresponds to axisymmetric modeling.

### 1.2 Material properties

The properties materials are dependent on the type of modeling and functions of the temperature in  $^{\circ}\text{C}$  and of the irradiation in  $\text{dpa}$  (displacement per atom).

The parameters materials used in this case test **do not have to be used to make studies**. They do not correspond to real characteristics.

For all modelings

Young modulus:  $E = 210000.0 - 30.0 T$  in  $\text{MPa}$

Poisson's ratio:  $\nu = 0.30 + 5.0\text{E-}05 T$ .

Thermal dilation coefficient:  $\alpha = (15.0 + 0.002 T) 1.0\text{E-}06$

For modeling has

Plastic part

$$\kappa = 1.0$$

Elastic limit to 0.2% in  $\text{MPa}$  :  $R_{02} = R_{02}^0 \cdot C_{w\_R_e} \cdot I_{r\_R_e}$

with

$$R_{02}^0 = 270.0 - 0.65 T + 0.001 T^2$$

$$C_{w\_R_e} = 3.0$$

$$I_{r\_R_e} = \left( 2.0 - e^{\frac{-IRRA}{3}} \right)$$

Ultimate constraint in  $\text{MPa}$  :  $R_m = R_{02(T,IRRA)} + (R_m^0 - R_{02}^0) \cdot C_{w\_R_m} \cdot I_{r\_R_m}$

with

$$R_m^0 = 600.0 - 1.5 T + 0.010 T^2$$

$$C_{w\_R_m} = 0.50$$

$$I_{r\_R_m} = 0.25 - 0.10 \left( 1.0 - e^{\frac{-IRRA}{10.0}} \right) + e^{\frac{-IRRA}{3.0}}$$

Lengthening distributed:  $\epsilon_u = \ln(1.0 + \epsilon_u^0 \cdot C_{w\_ \epsilon_u} \cdot I_{r\_ \epsilon_u} * 1.0E-02)$

with

$$\epsilon_u^0 = 50.0 - 0.15 T + 0.0007 T^2$$

$$C_{w\_ \epsilon_u} = 0.25$$

$$I_{r\_ \epsilon_u} = e^{-\frac{IRRA}{2}}$$

#### Irradiation part

$$A_{i0} = 0.0 \text{ MPa}^{-1} \cdot \text{dpa}^{-1}$$

$$\eta_{is} = 1.0E+50 \text{ MPa} \cdot \text{dpa}$$

#### Swelling part

$$R = 0.0 \text{ dpa}^{-1}$$

$$\alpha = 0.0$$

$$\phi_0 = 0.0 \text{ dpa}$$

### For modeling B

#### Plastic part

$$R_{02} = 5.0E+09 \text{ Mpa} \quad R_m = 5.0E+09 \text{ Mpa} \quad \epsilon_u = 0.0$$

#### Irradiation part

$$A_{i0} = 2.0E-06 \text{ MPa}^{-1} \cdot \text{dpa}^{-1}$$

$$\eta_{is} = 1000.0 \text{ MPa} \cdot \text{dpa}$$

#### Swelling part

$$R = 0.0 \text{ dpa}^{-1}$$

$$\alpha = 0.0$$

$$\phi_0 = 0.0 \text{ dpa}$$

### For modeling C

#### Plastic part

$$R_{02} = 5.0E+09 \text{ Mpa} \quad R_m = 5.0E+09 \text{ Mpa} \quad \epsilon_u = 0.0$$

#### Irradiation part

$$A_{i0} = 0.0 \text{ MPa}^{-1} \cdot \text{dpa}^{-1}$$

$$\eta_{is} = 1.0E+06 \text{ MPa} \cdot \text{dpa}$$

#### Swelling part

$$R = 0.0025 \text{ dpa}^{-1}$$

$$\alpha = 1.0$$

$$\phi_0 = 1.0 \text{ dpa}$$

## 1.3 Boundary conditions and loadings

### Modeling has

For the edges  $AB$  and  $DC$ ,  $DY = 0$

For the edge  $AD$ ,  $DX = 0$

One applies moreover one linear slope of temperature having for maximum  $400^\circ C$ .

### Modeling B

For the edge  $AB$ ,  $DY = 0$

For the edge  $AD$ ,  $DX = 0$

For the edge  $DC$ , application of a linear slope of linear forces of maximum value  $FY = 200 \text{ N/mm}$

One applies moreover one linear slope of irradiation having for maximum  $10 \text{ dpa}$  and a slope of temperature having for maximum  $400^\circ C$

### Modeling C

For the edge  $AB$   $DY = 0$

For the edge  $AD$   $DX = 0$

## 2 Reference solution

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### 2.1 Results of reference

**Modeling has**

It is a case test of not-regression.

**Modeling B**

It is a case test of not-regression.

**Modeling C**

It is a case test of not-regression.

### 2.2 Uncertainty on the solutions

**Modeling has**

It is a case test of not-regression

**Modeling B**

It is a case test of not-regression

**Modeling C**

It is a case test of not-regression

## 3 Modeling A

### 3.1 Characteristics of modeling

The modeling used in the case test is the following one:

Elements 2D 'AXIS' (QUA4)

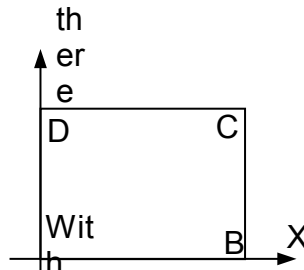


Figure 3.1-a : Geometry and grid of modeling used.

Cutting: 1 mesh QUAD4 according to the axis of  $x$   
1 mesh QUAD4 according to the axis of  $y$

Nodes:

A : mesh MI node N1  
B : mesh MI node N2  
C : mesh MI node N3  
D : mesh MI node N4

### 3.2 Characteristics of the grid

Many nodes: 4

Many meshes and types: 1 QUAD4, 3 SEG2.

### 3.3 Sizes tested and results

Identification			Field	Size	Reference	Tolerance
$t=200s$	MI	Point 1	SIEF_ELGA	SIYY	-5,40000000E+02	1.00E-04%
$t=200s$	N2		DEPL	DX	4,11705882E-03	1.00E-04%
$t=200s$	MI	Point 1	VARI_ELGA	V1	4,32941176E-04	1.00E-04%
$t=400s$	MI	Point 1	SIEF_ELGA	SIYY	-6,15143448E+02	1.00E-04%
$t=400s$	N2		DEPL	DX	8,92077868E-03	1.00E-04%
$t=400s$	MI	Point 1	VARI_ELGA	V1	3,21321491E-03	1.00E-04%

## 4 Modeling B

### 4.1 Characteristics of modeling

The modeling used in the case test is the following one:

Elements 2D 'AXIS' (QUA4)

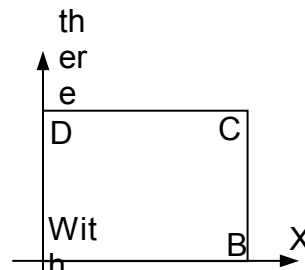


Figure 4.1-a : Geometry and grid of modeling used.

Cutting: 1 mesh QUA4 according to the axis of  $x$   
1 mesh QUA4 according to the axis of  $y$

Nodes:

$A$  : mesh  $MI$  node  $N1$

$B$  : mesh  $MI$  node  $N2$

$C$  : mesh  $MI$  node  $N3$

$D$  : mesh  $MI$  node  $N4$

It is about a test of creep to constant pressure on an axisymmetric element.

### 4.2 Characteristics of the grid

Many nodes: 4

Many meshes and types: 1 QUA4, 3 SEG2.

### 4.3 Sizes tested and results

Identification	Field	Size	Reference	Tolerance
$t=2000s$ $N4$	DEPL	DY	3,0101E-03	1.00E-04%
$t=2000s$ $MI$ Point 1	VARI ELGA	V2	2,0000E+03	1.00E-04%
$t=2000s$ $MI$ $N2$	EPSI_ELNO	EPYY	3,0101E-03	1.00E-04%

## 5 Modeling C

### 5.1 Characteristics of modeling

The modeling used in the case test is the following one:

Elements 2D 'AXIS' (QUA4)

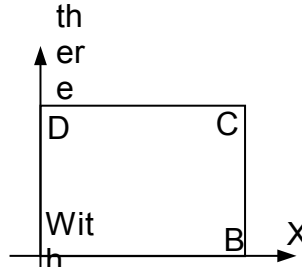


Figure 5.1-a : Geometry and grid of modeling used.

Cutting: 1 mesh QUA4 according to the axis of  $x$   
1 mesh QUA4 according to the axis of  $y$

Nodes:

A : mesh MI node N1  
B : mesh MI node N2  
C : mesh MI node N3  
D : mesh MI node N4

### 5.2 Characteristics of the grid

Many nodes: 4

Many meshes and types: 1 QUA4, 3 SEG2.

### 5.3 Sizes tested and results

Identification	Field	Size	Reference	Tolerance
$t=0.1s$ MI N2	EPSI_ELNO	EPYY	1,05722838E-02	1.0E-04%
$t=0.1s$ MI Point 1	VARI_ELGA	V4	1,05722838E-02	1.0E-04%
$t=1s$ MI N2	EPSI_ELNO	EPYY	1,15572282E-01	1.0E-04%
$t=1s$ MI Point 1	VARI_ELGA	V4	1,15572282E-01	1.0E-04%

## 6 Comments

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These cases tests make it possible to validate the law of behavior `IRRAD3M` in the elementary case into axisymmetric and activating for a given modeling only one part of the law (plasticity, irradiation and swelling).