

Tin 1um 10um Stress Only Quarter NP

Date	Feb 25, 2014 11:52:52 AM
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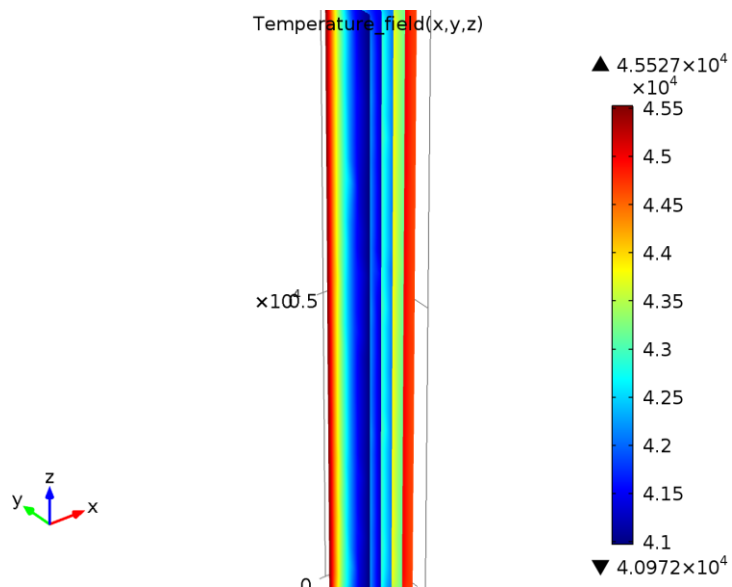
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1 Global Definitions

1.1 Functions

1.1.1 Interpolation 1

Function name	int1
Function type	Interpolation



Interpolation 1

2 Model 1 (mod1)

2.1 Definitions

2.1.1 Coordinate Systems

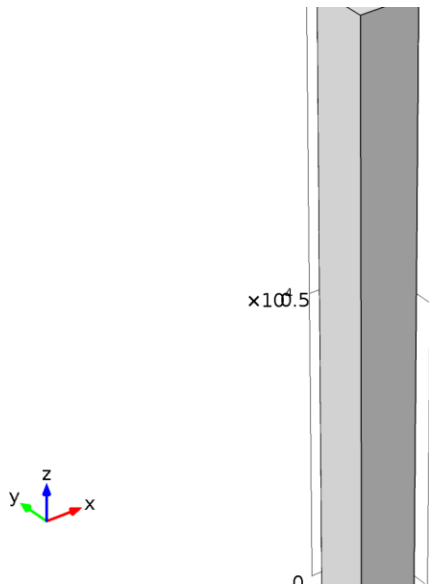
Boundary System 1

Coordinate system type	Boundary system
Identifier	sys1

Settings

Name	Value
Coordinate names	{t1, t2, n}
Create first tangent direction from	Global Cartesian (spatial)

2.2 Geometry 1



Geometry 1

units

Length unit	nm
Angular unit	deg

Geometry statistics

Property	Value
Space dimension	3

Property	Value
Number of domains	1
Number of boundaries	5
Number of edges	9
Number of vertices	6

2.2.1 Cylinder 1 (cyl1)

Position

Name	Value
Position	{0, 0, 0}

Axis

Name	Value
Radius	1000
Height	10000

2.2.2 Block 1 (blk1)

Position

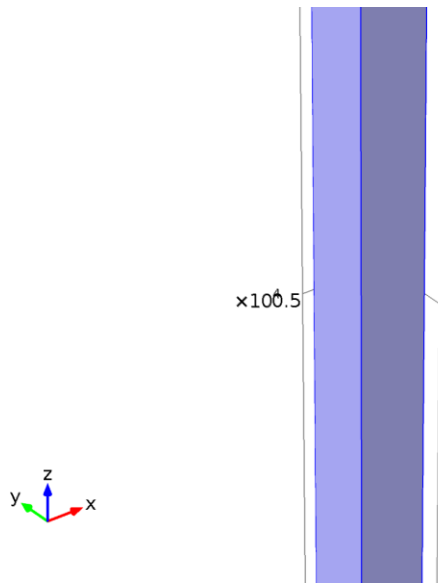
Name	Value
Position	{0, 0, 0}

Size and shape

Name	Value
Size	{1000, 1000, 10000}

2.3 Materials

2.3.1 Tin



Tin

Selection

Geometric entity level	Domain
Selection	Domain 1

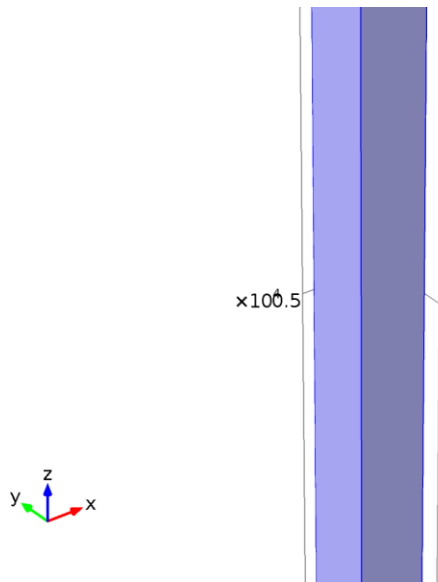
Material parameters

Name	Value	Unit
Density	7360	kg/m ³
Young's modulus	50*10 ⁹	Pa
Poisson's ratio	0.36	1

Basic Settings

Description	Value
Density	7360
Young's modulus	50*10 ⁹
Poisson's ratio	0.36

2.4 Solid Mechanics (solid)



Solid Mechanics

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

$$-\nabla \cdot \sigma = F_V$$

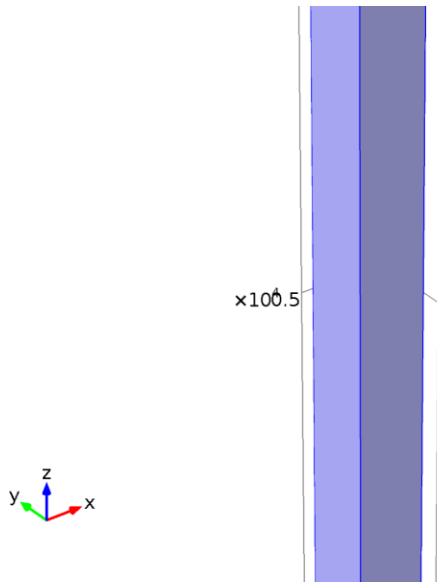
Settings

Description	Value
Structural transient behavior	Quasi - static
Show equation assuming	std2/time

Used products

COMSOL Multiphysics
Geomechanics Module
Structural Mechanics Module

2.4.1 Linear Elastic Material 1



Linear Elastic Material 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

$$-\nabla \cdot \boldsymbol{\sigma} = \mathbf{F}_V, \quad \boldsymbol{\sigma} = \mathbf{s}$$

$$\mathbf{s} - \mathbf{s}_0 = \underline{\underline{\mathbf{C}}} : (\boldsymbol{\epsilon} - \boldsymbol{\epsilon}_0 - \boldsymbol{\epsilon}_{inel})$$

$$\boldsymbol{\epsilon} = \frac{1}{2}[(\nabla \mathbf{u}_2)^T + \nabla \mathbf{u}_2]$$

Properties from material

Property	Material	Property group
Young's modulus	Tin	Basic
Poisson's ratio	Tin	Basic
Density	Tin	Basic

Variables

Name	Expression	Unit	Description	Selection
u2Xt	root.mod1.u2XTIME	1/s	Gradient of u2, first time derivative, X component	Domain 1
u2Yt	root.mod1.u2YTIME	1/s	Gradient of u2,	Domain 1

Name	Expression	Unit	Description	Selection
			first time derivative, Y component	
u2Zt	root.mod1.u2ZTIME	1/s	Gradient of u2, first time derivative, Z component	Domain 1
u2Xtt	root.mod1.u2XTIMETIME	1/s ²	Gradient of u2, second time derivative, X component	Domain 1
u2Ytt	root.mod1.u2YTIMETIME	1/s ²	Gradient of u2, second time derivative, Y component	Domain 1
u2Ztt	root.mod1.u2ZTIMETIME	1/s ²	Gradient of u2, second time derivative, Z component	Domain 1
v2Xt	root.mod1.v2XTIME	1/s	Gradient of v2, first time derivative, X component	Domain 1
v2Yt	root.mod1.v2YTIME	1/s	Gradient of v2, first time derivative, Y component	Domain 1
v2Zt	root.mod1.v2ZTIME	1/s	Gradient of v2, first time derivative, Z component	Domain 1
v2Xtt	root.mod1.v2XTIMETIME	1/s ²	Gradient of v2, second time derivative, X component	Domain 1
v2Ytt	root.mod1.v2YTIMETIME	1/s ²	Gradient of v2, second time derivative, Y component	Domain 1
v2Ztt	root.mod1.v2ZTIMETIME	1/s ²	Gradient of v2, second time	Domain 1

Name	Expression	Unit	Description	Selection
			derivative, Z component	
w2Xt	root.mod1.w2XTIME	1/s	Gradient of w2, first time derivative, X component	Domain 1
w2Yt	root.mod1.w2YTIME	1/s	Gradient of w2, first time derivative, Y component	Domain 1
w2Zt	root.mod1.w2ZTIME	1/s	Gradient of w2, first time derivative, Z component	Domain 1
w2Xtt	root.mod1.w2XTIMETIME	1/s ²	Gradient of w2, second time derivative, X component	Domain 1
w2Ytt	root.mod1.w2YTIMETIME	1/s ²	Gradient of w2, second time derivative, Y component	Domain 1
w2Ztt	root.mod1.w2ZTIMETIME	1/s ²	Gradient of w2, second time derivative, Z component	Domain 1
u2t	root.mod1.u2TIME	m/s	Structural velocity field, X component	Domain 1
v2t	root.mod1.v2TIME	m/s	Structural velocity field, Y component	Domain 1
w2t	root.mod1.w2TIME	m/s	Structural velocity field, Z component	Domain 1
u2tt	root.mod1.u2TIMETIME	m/s ²	Acceleration field, X component	Domain 1
v2tt	root.mod1.v2TIMETIME	m/s ²	Acceleration field, Y	Domain 1

Name	Expression	Unit	Description	Selection
			component	
w2tt	root.mod1.w2TIMETIME	m/s ²	Acceleration field, Z component	Domain 1
solid.E	model.input.E	Pa	Young's modulus	Domain 1
solid.nu	model.input.nu	1	Poisson's ratio	Domain 1
solid.K	solid.E/(3 - 6*solid.nu)	N/m ²	Bulk modulus	Domain 1
solid.G	0.5*solid.E/(1 + solid.nu)	N/m ²	Shear modulus	Domain 1
solid.lambLame	solid.E*solid.nu/((1 + solid.nu)*(1 - 2*solid.nu))	N/m ²	Lamé constant λ	Domain 1
solid.muLame	0.5*solid.E/(1 + solid.nu)	N/m ²	Lamé constant μ	Domain 1
solid.cp	sqrt(solid.E*(1 + solid.nu/(1 - 2*solid.nu))/((1 + solid.nu)*solid.rho))	m/s	Pressure-wave speed	Domain 1
solid.cs	sqrt(0.5*solid.E/((1 + solid.nu)*solid.rho))	m/s	Shear-wave speed	Domain 1
solid.Eequ	solid.E	Pa	Equivalent Young's modulus	Domain 1
solid.D11	solid.E*(1 + solid.nu/(1 - 2*solid.nu))/(1 + solid.nu)	Pa	Elasticity matrix, 11 component	Domain 1
solid.D21	solid.E*solid.nu/((1 + solid.nu)*(1 - 2*solid.nu))	Pa	Elasticity matrix, 21 component	Domain 1
solid.D31	solid.E*solid.nu/((1 + solid.nu)*(1 - 2*solid.nu))	Pa	Elasticity matrix, 31 component	Domain 1
solid.D41	0	Pa	Elasticity matrix, 41 component	Domain 1
solid.D51	0	Pa	Elasticity matrix, 51 component	Domain 1
solid.D61	0	Pa	Elasticity	Domain 1

Name	Expression	Unit	Description	Selection
			matrix, 61 component	
solid.D12	$\text{solid.E} * \text{solid.nu} / ((1 + \text{solid.nu}) * (1 - 2 * \text{solid.nu}))$	Pa	Elasticity matrix, 12 component	Domain 1
solid.D22	$\text{solid.E} * (1 + \text{solid.nu} / (1 - 2 * \text{solid.nu})) / (1 + \text{solid.nu})$	Pa	Elasticity matrix, 22 component	Domain 1
solid.D32	$\text{solid.E} * \text{solid.nu} / ((1 + \text{solid.nu}) * (1 - 2 * \text{solid.nu}))$	Pa	Elasticity matrix, 32 component	Domain 1
solid.D42	0	Pa	Elasticity matrix, 42 component	Domain 1
solid.D52	0	Pa	Elasticity matrix, 52 component	Domain 1
solid.D62	0	Pa	Elasticity matrix, 62 component	Domain 1
solid.D13	$\text{solid.E} * \text{solid.nu} / ((1 + \text{solid.nu}) * (1 - 2 * \text{solid.nu}))$	Pa	Elasticity matrix, 13 component	Domain 1
solid.D23	$\text{solid.E} * \text{solid.nu} / ((1 + \text{solid.nu}) * (1 - 2 * \text{solid.nu}))$	Pa	Elasticity matrix, 23 component	Domain 1
solid.D33	$\text{solid.E} * (1 + \text{solid.nu} / (1 - 2 * \text{solid.nu})) / (1 + \text{solid.nu})$	Pa	Elasticity matrix, 33 component	Domain 1
solid.D43	0	Pa	Elasticity matrix, 43 component	Domain 1
solid.D53	0	Pa	Elasticity matrix, 53 component	Domain 1
solid.D63	0	Pa	Elasticity matrix, 63 component	Domain 1
solid.D14	0	Pa	Elasticity matrix, 14	Domain 1

Name	Expression	Unit	Description	Selection
			component	
solid.D24	0	Pa	Elasticity matrix, 24 component	Domain 1
solid.D34	0	Pa	Elasticity matrix, 34 component	Domain 1
solid.D44	$0.5 * \text{solid.E} / (1 + \text{solid.nu})$	Pa	Elasticity matrix, 44 component	Domain 1
solid.D54	0	Pa	Elasticity matrix, 54 component	Domain 1
solid.D64	0	Pa	Elasticity matrix, 64 component	Domain 1
solid.D15	0	Pa	Elasticity matrix, 15 component	Domain 1
solid.D25	0	Pa	Elasticity matrix, 25 component	Domain 1
solid.D35	0	Pa	Elasticity matrix, 35 component	Domain 1
solid.D45	0	Pa	Elasticity matrix, 45 component	Domain 1
solid.D55	$0.5 * \text{solid.E} / (1 + \text{solid.nu})$	Pa	Elasticity matrix, 55 component	Domain 1
solid.D65	0	Pa	Elasticity matrix, 65 component	Domain 1
solid.D16	0	Pa	Elasticity matrix, 16 component	Domain 1
solid.D26	0	Pa	Elasticity matrix, 26 component	Domain 1

Name	Expression	Unit	Description	Selection
			component	
solid.D36	0	Pa	Elasticity matrix, 36 component	Domain 1
solid.D46	0	Pa	Elasticity matrix, 46 component	Domain 1
solid.D56	0	Pa	Elasticity matrix, 56 component	Domain 1
solid.D66	$0.5 * \text{solid.E} / (1 + \text{solid.nu})$	Pa	Elasticity matrix, 66 component	Domain 1
solid.rho	model.input.rho	kg/m ³	Density	Domain 1
solid.FdxX	$1 + u_{2X}$	1	Deformation gradient, xX component	Domain 1
solid.FdyX	v_{2X}	1	Deformation gradient, yX component	Domain 1
solid.FdzX	w_{2X}	1	Deformation gradient, zX component	Domain 1
solid.FdxY	u_{2Y}	1	Deformation gradient, xY component	Domain 1
solid.FdyY	$1 + v_{2Y}$	1	Deformation gradient, yY component	Domain 1
solid.FdzY	w_{2Y}	1	Deformation gradient, zY component	Domain 1
solid.FdxZ	u_{2Z}	1	Deformation gradient, xZ component	Domain 1
solid.FdyZ	v_{2Z}	1	Deformation gradient, yZ component	Domain 1
solid.FdzZ	$1 + w_{2Z}$	1	Deformation	Domain 1

Name	Expression	Unit	Description	Selection
			gradient, zZ component	
solid.eX	$u2X$	1	Strain tensor, X component	Domain 1
solid.eXY	$0.5*(u2Y + v2X)$	1	Strain tensor, XY component	Domain 1
solid.eXZ	$0.5*(u2Z + w2X)$	1	Strain tensor, XZ component	Domain 1
solid.eY	$v2Y$	1	Strain tensor, Y component	Domain 1
solid.eYZ	$0.5*(v2Z + w2Y)$	1	Strain tensor, YZ component	Domain 1
solid.eZ	$w2Z$	1	Strain tensor, Z component	Domain 1
solid.Ldx	root.mod1.u2XTIME	1/s	Rate of strain tensor, x component	Domain 1
solid.Ldxy	$0.5*(\text{root.mod1.u2YTIME} + \text{root.mod1.v2XTIME})$	1/s	Rate of strain tensor, xy component	Domain 1
solid.Ldxz	$0.5*(\text{root.mod1.u2ZTIME} + \text{root.mod1.w2XTIME})$	1/s	Rate of strain tensor, xz component	Domain 1
solid.Ldy	root.mod1.v2YTIME	1/s	Rate of strain tensor, y component	Domain 1
solid.Ldyz	$0.5*(\text{root.mod1.v2ZTIME} + \text{root.mod1.w2YTIME})$	1/s	Rate of strain tensor, yz component	Domain 1
solid.Ldz	root.mod1.w2ZTIME	1/s	Rate of strain tensor, z component	Domain 1
solid.Lwx	0	1/s	Spin tensor, x component	Domain 1
solid.Lwxy	$0.5*(\text{root.mod1.u2YTIME} - \text{root.mod1.v2XTIME})$	1/s	Spin tensor, xy component	Domain 1
solid.Lwxz	$0.5*(\text{root.mod1.u2ZTIME} - \text{root.mod1.w2XTIME})$	1/s	Spin tensor, xz component	Domain 1

Name	Expression	Unit	Description	Selection
solid.Lwy	0	1/s	Spin tensor, y component	Domain 1
solid.Lwyz	$0.5 * (\text{root.mod1.v2ZTIME} - \text{root.mod1.w2YTIME})$	1/s	Spin tensor, yz component	Domain 1
solid.Lwz	0	1/s	Spin tensor, z component	Domain 1
solid.el11	u2X	1	Strain tensor, local coordinate system, 11 component	Domain 1
solid.el12	$0.5 * (u2Y + v2X)$	1	Strain tensor, local coordinate system, 12 component	Domain 1
solid.el13	$0.5 * (u2Z + w2X)$	1	Strain tensor, local coordinate system, 13 component	Domain 1
solid.el22	v2Y	1	Strain tensor, local coordinate system, 22 component	Domain 1
solid.el23	$0.5 * (v2Z + w2Y)$	1	Strain tensor, local coordinate system, 23 component	Domain 1
solid.el33	w2Z	1	Strain tensor, local coordinate system, 33 component	Domain 1
solid.eel11	$u2X - \text{solid.eil11} - \text{solid.eiel11}$	1	Elastic strain tensor, local coordinate system, 11 component	Domain 1
solid.eel12	$0.5 * (u2Y + v2X) - \text{solid.eil12} - \text{solid.eiel12}$	1	Elastic strain tensor, local coordinate system, 12 component	Domain 1

Name	Expression	Unit	Description	Selection
solid.eel13	$0.5*(u_{2Z} + w_{2X}) - \text{solid.eil13} - \text{solid.eiel13}$	1	Elastic strain tensor, local coordinate system, 13 component	Domain 1
solid.eel22	$v_{2Y} - \text{solid.eil22} - \text{solid.eiel22}$	1	Elastic strain tensor, local coordinate system, 22 component	Domain 1
solid.eel23	$0.5*(v_{2Z} + w_{2Y}) - \text{solid.eil23} - \text{solid.eiel23}$	1	Elastic strain tensor, local coordinate system, 23 component	Domain 1
solid.eel33	$w_{2Z} - \text{solid.eil33} - \text{solid.eiel33}$	1	Elastic strain tensor, local coordinate system, 33 component	Domain 1
solid.eil11	0	1	Initial strain tensor, local coordinate system, 11 component	Domain 1
solid.eil12	0	1	Initial strain tensor, local coordinate system, 12 component	Domain 1
solid.eil13	0	1	Initial strain tensor, local coordinate system, 13 component	Domain 1
solid.eil22	0	1	Initial strain tensor, local coordinate system, 22 component	Domain 1
solid.eil23	0	1	Initial strain tensor, local	Domain 1

Name	Expression	Unit	Description	Selection
			coordinate system, 23 component	
solid.eil33	0	1	Initial strain tensor, local coordinate system, 33 component	Domain 1
solid.eiel11	0	1	Inelastic strain tensor, local coordinate system, 11 component	Domain 1
solid.eiel12	0	1	Inelastic strain tensor, local coordinate system, 12 component	Domain 1
solid.eiel13	0	1	Inelastic strain tensor, local coordinate system, 13 component	Domain 1
solid.eiel22	0	1	Inelastic strain tensor, local coordinate system, 22 component	Domain 1
solid.eiel23	0	1	Inelastic strain tensor, local coordinate system, 23 component	Domain 1
solid.eiel33	0	1	Inelastic strain tensor, local coordinate system, 33 component	Domain 1
solid.evol	$u2X + v2Y + w2Z$	1	Volumetric strain	Domain 1
solid.J	$\text{solid.FdxX} * \text{solid.FdyY} * \text{solid.FdzZ} +$	1	Volume ratio	Domain 1

Name	Expression	Unit	Description	Selection
	solid.FdxY*solid.FdyZ*solid .FdzX + solid.FdxZ*solid.FdyX*solid .FdzY - solid.FdxX*solid.FdyZ*solid .FdzY - solid.FdxY*solid.FdyX*solid .FdzZ - solid.FdxZ*solid.FdyY*solid .FdzX			
solid.Sil11	0	N/m ²	Initial stress tensor, local coordinate system, 11 component	Domain 1
solid.Sil12	0	N/m ²	Initial stress tensor, local coordinate system, 12 component	Domain 1
solid.Sil13	0	N/m ²	Initial stress tensor, local coordinate system, 13 component	Domain 1
solid.Sil22	0	N/m ²	Initial stress tensor, local coordinate system, 22 component	Domain 1
solid.Sil23	0	N/m ²	Initial stress tensor, local coordinate system, 23 component	Domain 1
solid.Sil33	0	N/m ²	Initial stress tensor, local coordinate system, 33 component	Domain 1
solid.SI11	solid.D11*solid.eel11 + 2*solid.D14*solid.eel12 + 2*solid.D16*solid.eel13 +	N/m ²	Second Piola-Kirchhoff stress, local coordinate	Domain 1

Name	Expression	Unit	Description	Selection
	solid.D12*solid.eel22 + 2*solid.D15*solid.eel23 + solid.D13*solid.eel33 + solid.Sil11		system, 11 component	
solid.SI12	solid.D14*solid.eel11 + 2*solid.D44*solid.eel12 + 2*solid.D46*solid.eel13 + solid.D24*solid.eel22 + 2*solid.D45*solid.eel23 + solid.D34*solid.eel33 + solid.Sil12	N/m ²	Second Piola- Kirchhoff stress, local coordinate system, 12 component	Domain 1
solid.SI13	solid.D16*solid.eel11 + 2*solid.D46*solid.eel12 + 2*solid.D66*solid.eel13 + solid.D26*solid.eel22 + 2*solid.D56*solid.eel23 + solid.D36*solid.eel33 + solid.Sil13	N/m ²	Second Piola- Kirchhoff stress, local coordinate system, 13 component	Domain 1
solid.SI22	solid.D12*solid.eel11 + 2*solid.D24*solid.eel12 + 2*solid.D26*solid.eel13 + solid.D22*solid.eel22 + 2*solid.D25*solid.eel23 + solid.D23*solid.eel33 + solid.Sil22	N/m ²	Second Piola- Kirchhoff stress, local coordinate system, 22 component	Domain 1
solid.SI23	solid.D15*solid.eel11 + 2*solid.D45*solid.eel12 + 2*solid.D56*solid.eel13 + solid.D25*solid.eel22 + 2*solid.D55*solid.eel23 + solid.D35*solid.eel33 + solid.Sil23	N/m ²	Second Piola- Kirchhoff stress, local coordinate system, 23 component	Domain 1
solid.SI33	solid.D13*solid.eel11 + 2*solid.D34*solid.eel12 + 2*solid.D36*solid.eel13 + solid.D23*solid.eel22 + 2*solid.D35*solid.eel23 + solid.D33*solid.eel33 + solid.Sil33	N/m ²	Second Piola- Kirchhoff stress, local coordinate system, 33 component	Domain 1
solid.Ws	0.5*(solid.SI11*solid.eel11 + 2*solid.SI12*solid.eel12 + 2*solid.SI13*solid.eel13 + solid.SI22*solid.eel22 +	J/m ³	Strain energy density	Domain 1

Name	Expression	Unit	Description	Selection
	$2 \cdot \text{solid.SI23} \cdot \text{solid.eel23} + \text{solid.SI33} \cdot \text{solid.eel33}$)			
solid.Ws_tot	root.mod1.solid.lemm1.int 2(0.5*(solid.SI11*solid.eel11 + 2*solid.SI12*solid.eel12 + 2*solid.SI13*solid.eel13 + solid.SI22*solid.eel22 + 2*solid.SI23*solid.eel23 + solid.SI33*solid.eel33))	J	Total strain energy	Global
solid.disp	$\sqrt{\text{real}(u2)^2 + \text{real}(v2)^2 + \text{real}(w2)^2}$)	m	Total displacement	Domain 1
solid.u_ttX	d(root.mod1.u2TIME, TIME)	m/s ²	Acceleration, X component	Domain 1
solid.u_ttY	d(root.mod1.v2TIME, TIME)	m/s ²	Acceleration, Y component	Domain 1
solid.u_ttZ	d(root.mod1.w2TIME, TIME)	m/s ²	Acceleration, Z component	Domain 1
solid.u_tX	root.mod1.u2TIME	m/s	Velocity, X component	Domain 1
solid.u_tY	root.mod1.v2TIME	m/s	Velocity, Y component	Domain 1
solid.u_tZ	root.mod1.w2TIME	m/s	Velocity, Z component	Domain 1
solid.SX	solid.SI11	N/m ²	Second Piola-Kirchhoff stress, X component	Domain 1
solid.SXY	solid.SI12	N/m ²	Second Piola-Kirchhoff stress, XY component	Domain 1
solid.SXZ	solid.SI13	N/m ²	Second Piola-Kirchhoff stress, XZ component	Domain 1
solid.SY	solid.SI22	N/m ²	Second Piola-Kirchhoff stress, Y component	Domain 1
solid.SYZ	solid.SI23	N/m ²	Second Piola-Kirchhoff stress, YZ component	Domain 1

Name	Expression	Unit	Description	Selection
solid.SZ	solid.SI33	N/m ²	Second Piola-Kirchhoff stress, Z component	Domain 1
solid.PxX	solid.FdxX*solid.SX + solid.FdxY*solid.SXY + solid.FdxZ*solid.SXZ	N/m ²	First Piola-Kirchhoff stress, xX component	Domain 1
solid.PyX	solid.FdyX*solid.SX + solid.FdyY*solid.SXY + solid.FdyZ*solid.SXZ	N/m ²	First Piola-Kirchhoff stress, yX component	Domain 1
solid.PzX	solid.FdzX*solid.SX + solid.FdzY*solid.SXY + solid.FdzZ*solid.SXZ	N/m ²	First Piola-Kirchhoff stress, zX component	Domain 1
solid.PxY	solid.FdxX*solid.SXY + solid.FdxY*solid.SY + solid.FdxZ*solid.SYZ	N/m ²	First Piola-Kirchhoff stress, xY component	Domain 1
solid.PyY	solid.FdyX*solid.SXY + solid.FdyY*solid.SY + solid.FdyZ*solid.SYZ	N/m ²	First Piola-Kirchhoff stress, yY component	Domain 1
solid.PzY	solid.FdzX*solid.SXY + solid.FdzY*solid.SY + solid.FdzZ*solid.SYZ	N/m ²	First Piola-Kirchhoff stress, zY component	Domain 1
solid.PxZ	solid.FdxX*solid.SXZ + solid.FdxY*solid.SYZ + solid.FdxZ*solid.SZ	N/m ²	First Piola-Kirchhoff stress, xZ component	Domain 1
solid.PyZ	solid.FdyX*solid.SXZ + solid.FdyY*solid.SYZ + solid.FdyZ*solid.SZ	N/m ²	First Piola-Kirchhoff stress, yZ component	Domain 1
solid.PzZ	solid.FdzX*solid.SXZ + solid.FdzY*solid.SYZ + solid.FdzZ*solid.SZ	N/m ²	First Piola-Kirchhoff stress, zZ component	Domain 1
solid.sx	solid.SX	N/m ²	Stress tensor, x component	Domain 1
solid.sxy	solid.SXY	N/m ²	Stress tensor, xy component	Domain 1
solid.sxz	solid.SXZ	N/m ²	Stress tensor, xz component	Domain 1
solid.sy	solid.SY	N/m ²	Stress tensor, y component	Domain 1
solid.syz	solid.SYZ	N/m ²	Stress tensor, yz component	Domain 1

Name	Expression	Unit	Description	Selection
			component	
solid.sz	solid.SZ	N/m ²	Stress tensor, z component	Domain 1
solid.sl11	solid.sx	N/m ²	Stress tensor, local coordinate system, 11 component	Domain 1
solid.sl12	solid.sxy	N/m ²	Stress tensor, local coordinate system, 12 component	Domain 1
solid.sl13	solid.sxz	N/m ²	Stress tensor, local coordinate system, 13 component	Domain 1
solid.sl22	solid.sy	N/m ²	Stress tensor, local coordinate system, 22 component	Domain 1
solid.sl23	solid.syz	N/m ²	Stress tensor, local coordinate system, 23 component	Domain 1
solid.sl33	solid.sz	N/m ²	Stress tensor, local coordinate system, 33 component	Domain 1
solid.sdevx	$\text{solid.sx} - (\text{solid.sx} + \text{solid.sy} + \text{solid.sz})/3$	N/m ²	Deviatoric stress tensor, x component	Domain 1
solid.sdevxy	solid.sxy	N/m ²	Deviatoric stress tensor, xy component	Domain 1
solid.sdevxz	solid.sxz	N/m ²	Deviatoric stress tensor, xz component	Domain 1
solid.sdevy	$\text{solid.sy} - (\text{solid.sx} + \text{solid.sy} + \text{solid.sz})/3$	N/m ²	Deviatoric stress tensor, y component	Domain 1
solid.sdevyz	solid.syz	N/m ²	Deviatoric	Domain 1

Name	Expression	Unit	Description	Selection
			stress tensor, yz component	
solid.sdevz	$\text{solid.sz} - (\text{solid.sx} + \text{solid.sy} + \text{solid.sz})/3$	N/m ²	Deviatoric stress tensor, z component	Domain 1
solid.SdevX	$\text{solid.SX} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3$	N/m ²	Deviatoric second Piola-Kirchhoff stress, X component	Domain 1
solid.SdevXY	solid.SXY	N/m ²	Deviatoric second Piola-Kirchhoff stress, XY component	Domain 1
solid.SdevXZ	solid.SXZ	N/m ²	Deviatoric second Piola-Kirchhoff stress, XZ component	Domain 1
solid.SdevY	$\text{solid.SY} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3$	N/m ²	Deviatoric second Piola-Kirchhoff stress, Y component	Domain 1
solid.SdevYZ	solid.SYZ	N/m ²	Deviatoric second Piola-Kirchhoff stress, YZ component	Domain 1
solid.SdevZ	$\text{solid.SZ} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3$	N/m ²	Deviatoric second Piola-Kirchhoff stress, Z component	Domain 1
solid.I1s	$\text{solid.sx} + \text{solid.sy} + \text{solid.sz}$	N/m ²	First principal invariant of stress	Domain 1
solid.I2s	$0.5 * (\text{solid.I1s}^2 - \text{solid.sx}^2 - 2 * \text{solid.sxy}^2 - 2 * \text{solid.sxz}^2 - \text{solid.sy}^2 - 2 * \text{solid.syz}^2 - \text{solid.sz}^2)$	kg ² /(m ² *s ⁴)	Second principal invariant of stress	Domain 1
solid.I3s	$\text{solid.sx} * \text{solid.sy} * \text{solid.sz} + 2 * \text{solid.sxy} * \text{solid.syz} * \text{solid.sxz} - \text{solid.sx} * \text{solid.syz}^2 - \text{solid.sxy}^2 * \text{solid.sz} - \text{solid.sy} * \text{solid.sxz}^2$	kg ³ /(m ³ *s ⁶)	Third principal invariant of stress	Domain 1

Name	Expression	Unit	Description	Selection
solid.II2s	$0.5*(\text{solid.sdevx}^2 + 2*\text{solid.sdevxy}^2 + 2*\text{solid.sdevxz}^2 + \text{solid.sdevy}^2 + 2*\text{solid.sdevyz}^2 + \text{solid.sdevz}^2)$	$\text{kg}^2/(\text{m}^2*\text{s}^4)$	Second invariant of stress deviator	Domain 1
solid.II3s	$\text{solid.sdevx}*\text{solid.sdevy}*\text{solid.sdevz} + 2*\text{solid.sdevxy}*\text{solid.sdevyz} - \text{solid.sdevxz} - \text{solid.sdevx}*\text{solid.sdevyz}^2 - \text{solid.sdevxy}^2*\text{solid.sdevz} - \text{solid.sdevy}*\text{solid.sdevxz}^2$	$\text{kg}^3/(\text{m}^3*\text{s}^6)$	Third invariant of stress deviator	Domain 1
solid.thetaL	$\text{atan2}(\text{sqrt}(\text{max}(0.14814814814814814*\text{solid.II2s}^3 - \text{solid.II3s}^2, \text{eps})), \text{solid.II3s})/3$	rad	Lode angle	Domain 1
solid.p	$-(\text{solid.sx} + \text{solid.sy} + \text{solid.sz})/3$	Pa	Pressure	Domain 1
solid.IX	$-\text{solid.SX}*\text{solid.u_tX} - \text{solid.SXY}*\text{solid.u_tY} - \text{solid.SXZ}*\text{solid.u_tZ}$	W/m^3	Mechanical energy flux, X component	Domain 1
solid.IY	$-\text{solid.SXY}*\text{solid.u_tX} - \text{solid.SY}*\text{solid.u_tY} - \text{solid.SYZ}*\text{solid.u_tZ}$	W/m^3	Mechanical energy flux, Y component	Domain 1
solid.IZ	$-\text{solid.SXZ}*\text{solid.u_tX} - \text{solid.SYZ}*\text{solid.u_tY} - \text{solid.SZ}*\text{solid.u_tZ}$	W/m^3	Mechanical energy flux, Z component	Domain 1
solid.nl	$\text{unX}*(\text{down}(\text{solid.IX}) - \text{up}(\text{solid.IX})) + \text{unY}*(\text{down}(\text{solid.IY}) - \text{up}(\text{solid.IY})) + \text{unZ}*(\text{down}(\text{solid.IZ}) - \text{up}(\text{solid.IZ}))$	W/m^3	Outward mechanical energy flux	Boundaries 1–5
solid.curlUX	$w2Y - v2Z$	1	Curl of displacement, X component	Domain 1
solid.curlUY	$-w2X + u2Z$	1	Curl of displacement, Y	Domain 1

Name	Expression	Unit	Description	Selection
			component	
solid.curlUZ	$v2X - u2Y$	1	Curl of displacement, Z component	Domain 1
solid.mises	$(3 * \text{solid.II2s})^{0.5}$	N/m ²	von Mises stress	Domain 1
solid.tresca	solid.sp1 - solid.sp3	N/m ²	Tresca stress	Domain 1
solid.RFx	react(u2)	N	Reaction force, x component	Domain 1
solid.RFy	react(v2)	N	Reaction force, y component	Domain 1
solid.RFz	react(w2)	N	Reaction force, z component	Domain 1
solid.RMx	solid.RFz*(y - solid.refpnty) - solid.RFy*(z - solid.refpntz)	N*m	Reaction moment, x component	Domain 1
solid.RMy	-solid.RFz*(x - solid.refpntx) + solid.RFx*(z - solid.refpntz)	N*m	Reaction moment, y component	Domain 1
solid.RMz	solid.RFy*(x - solid.refpntx) - solid.RFx*(y - solid.refpnty)	N*m	Reaction moment, z component	Domain 1
solid.Tax	solid.sx*solid.nx + solid.sxy*solid.ny + solid.sxz*solid.nz	N/m ²	Surface traction (force/area), x component	Boundaries 1–5
solid.Tay	solid.sxy*solid.nx + solid.sy*solid.ny + solid.syz*solid.nz	N/m ²	Surface traction (force/area), y component	Boundaries 1–5
solid.Taz	solid.sxz*solid.nx + solid.syz*solid.ny + solid.sz*solid.nz	N/m ²	Surface traction (force/area), z component	Boundaries 1–5

Shape functions

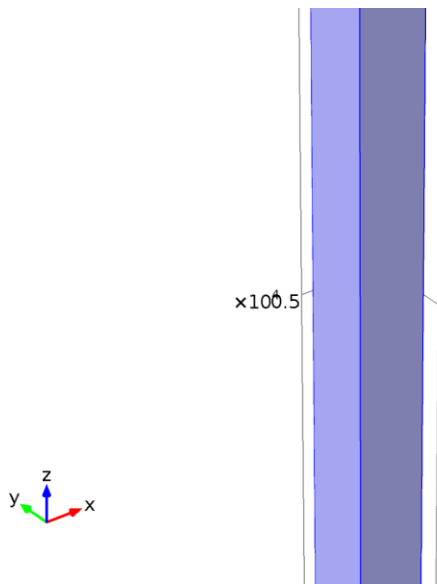
Name	Shape function	Unit	Description	Shape frame	Selection
u2	Lagrange (Quadratic)	m	Displacement field, X component	Material	Domain 1
v2	Lagrange	m	Displacement field, Y component	Material	Domain 1

Name	Shape function	Unit	Description	Shape frame	Selection
	(Quadratic)				
w2	Lagrange (Quadratic)	m	Displacement field, Z component	Material	Domain 1

Weak expressions

Weak expression	Integration frame	Selection
-solid.SI11*test(solid.el11) - 2*solid.SI12*test(solid.el12) - 2*solid.SI13*test(solid.el13) - solid.SI22*test(solid.el22) - 2*solid.SI23*test(solid.el23) - solid.SI33*test(solid.el33)	Material	Domain 1

Thermal Expansion 1



Thermal Expansion 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

$$\mathbf{s} - \mathbf{s}_0 = \mathbf{C} : (\boldsymbol{\epsilon} - \boldsymbol{\epsilon}_0 - \boldsymbol{\epsilon}_{inel}), \quad \boldsymbol{\epsilon}_{inel} = \boldsymbol{\alpha}(T - T_{ref})$$

Settings

Settings

Description	Value
-------------	-------

Description	Value
Coefficient of thermal expansion	User defined
Coefficient of thermal expansion	{{6.60E-05, 0, 0}, {0, 6.60E-05, 0}, {0, 0, 6.60E-05}}

Used products

COMSOL Multiphysics
Structural Mechanics Module

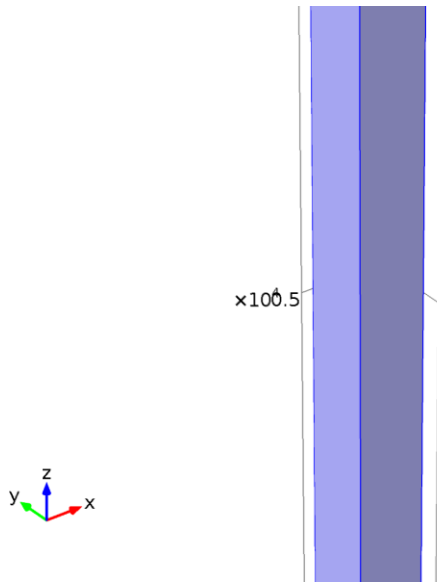
Variables

Name	Expression	Unit	Description	Selection
solid.eiel11	solid.eth11	1	Inelastic strain tensor, local coordinate system, 11 component	Domain 1
solid.eiel12	solid.eth12	1	Inelastic strain tensor, local coordinate system, 12 component	Domain 1
solid.eiel13	solid.eth13	1	Inelastic strain tensor, local coordinate system, 13 component	Domain 1
solid.eiel22	solid.eth22	1	Inelastic strain tensor, local coordinate system, 22 component	Domain 1
solid.eiel23	solid.eth23	1	Inelastic strain tensor, local coordinate system, 23 component	Domain 1
solid.eiel33	solid.eth33	1	Inelastic strain tensor, local coordinate system, 33 component	Domain 1
solid.alpha11	6.6E-5	1/K	Coefficient of	Domain 1

Name	Expression	Unit	Description	Selection
			thermal expansion, 11 component	
solid.alpha21	0	1/K	Coefficient of thermal expansion, 21 component	Domain 1
solid.alpha31	0	1/K	Coefficient of thermal expansion, 31 component	Domain 1
solid.alpha12	0	1/K	Coefficient of thermal expansion, 12 component	Domain 1
solid.alpha22	6.6E-5	1/K	Coefficient of thermal expansion, 22 component	Domain 1
solid.alpha32	0	1/K	Coefficient of thermal expansion, 32 component	Domain 1
solid.alpha13	0	1/K	Coefficient of thermal expansion, 13 component	Domain 1
solid.alpha23	0	1/K	Coefficient of thermal expansion, 23 component	Domain 1
solid.alpha33	6.6E-5	1/K	Coefficient of thermal expansion, 33 component	Domain 1
solid.Tref	293.15[K]	K	Strain reference temperature	Domain 1
solid.T	model.input.minput_temperature	K	Temperature	Domain 1
solid.Tdiff	solid.T - solid.Tref	K	Temperature	Domain 1

Name	Expression	Unit	Description	Selection
			difference	
solid.eth11	solid.alpha11*solid.Tdiff	1	Thermal strain tensor, local coordinate system, 11 component	Domain 1
solid.eth12	solid.alpha12*solid.Tdiff	1	Thermal strain tensor, local coordinate system, 12 component	Domain 1
solid.eth13	solid.alpha13*solid.Tdiff	1	Thermal strain tensor, local coordinate system, 13 component	Domain 1
solid.eth22	solid.alpha22*solid.Tdiff	1	Thermal strain tensor, local coordinate system, 22 component	Domain 1
solid.eth23	solid.alpha23*solid.Tdiff	1	Thermal strain tensor, local coordinate system, 23 component	Domain 1
solid.eth33	solid.alpha33*solid.Tdiff	1	Thermal strain tensor, local coordinate system, 33 component	Domain 1

Plasticity 1



Plasticity 1

Selection

Geometric entity level	Domain
Selection	Domain 1

Equations

$$\mathbf{s} - \mathbf{s}_0 = \mathbf{C} : (\underline{\underline{\epsilon}} - \underline{\underline{\epsilon}}_0 - \underline{\underline{\epsilon}}_{inel}), \quad \underline{\underline{\epsilon}}_{inel} = \underline{\underline{\epsilon}}_p$$

$$F(\sigma, \sigma_{ys}) < 0, \quad \dot{\underline{\underline{\epsilon}}}_p = \lambda \frac{\partial Q}{\partial \sigma}$$

Settings

Settings

Description	Value
Initial yield stress	User defined
Initial yield stress	50*10^6
Hardening model	Perfectly plastic

Used products

COMSOL Multiphysics
Geomechanics Module

Variables

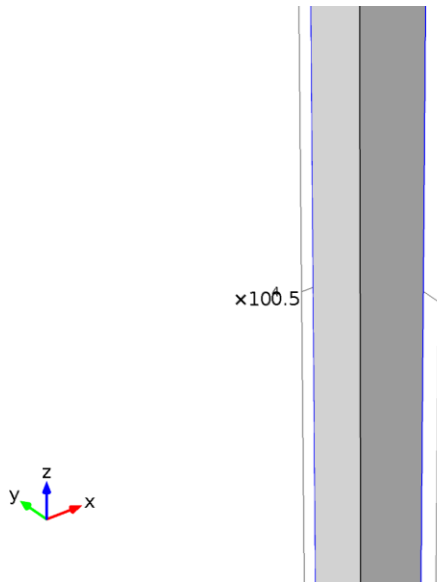
Name	Expression	Unit	Description	Selection
------	------------	------	-------------	-----------

Name	Expression	Unit	Description	Selection
solid.eiel11	solid.epX	1	Inelastic strain tensor, local coordinate system, 11 component	Domain 1
solid.eiel12	solid.epXY	1	Inelastic strain tensor, local coordinate system, 12 component	Domain 1
solid.eiel13	solid.epXZ	1	Inelastic strain tensor, local coordinate system, 13 component	Domain 1
solid.eiel22	solid.epY	1	Inelastic strain tensor, local coordinate system, 22 component	Domain 1
solid.eiel23	solid.epYZ	1	Inelastic strain tensor, local coordinate system, 23 component	Domain 1
solid.eiel33	solid.epZ	1	Inelastic strain tensor, local coordinate system, 33 component	Domain 1
solid.sigmag	50000000	Pa	Initial yield stress	Domain 1
solid.epvol	solid.epX + solid.epY + solid.epZ	1	Volumetric plastic strain	Domain 1
solid.sY	solid.sigmag	Pa	Current yield stress	Domain 1
solid.I1sEff	solid.SX + solid.SY + solid.SZ	N/m ²	First principal invariant of effective stress	Domain 1
solid.I2sEff	0.5*((solid.SX + solid.SY + solid.SZ) ² - solid.SX ² -	kg ² /(m ² *s ⁴)	Second principal	Domain 1

Name	Expression	Unit	Description	Selection
	$2 \cdot \text{solid.SXY}^2 - 2 \cdot \text{solid.SXZ}^2 - \text{solid.SY}^2 - 2 \cdot \text{solid.SYZ}^2 - \text{solid.SZ}^2$		invariant of effective stress	
solid.I3sEff	$\text{solid.SX} \cdot \text{solid.SY} \cdot \text{solid.SZ} + 2 \cdot \text{solid.SXY} \cdot \text{solid.SYZ} \cdot \text{solid.SXZ} - \text{solid.SX} \cdot \text{solid.SYZ}^2 - \text{solid.SXY}^2 \cdot \text{solid.SZ} - \text{solid.SY} \cdot \text{solid.SXZ}^2$	$\text{kg}^3/(\text{m}^3 \cdot \text{s}^6)$	Third principal invariant of effective stress	Domain 1
solid.II2sEff	$0.5 \cdot ((\text{solid.SX} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2 + 2 \cdot \text{solid.SXY}^2 + 2 \cdot \text{solid.SXZ}^2 + (\text{solid.SY} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2 + 2 \cdot \text{solid.SYZ}^2 + (\text{solid.SZ} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2)$	$\text{kg}^2/(\text{m}^2 \cdot \text{s}^4)$	Second invariant of effective stress deviator	Domain 1
solid.II3sEff	$(\text{solid.SX} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3) \cdot (\text{solid.SY} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3) \cdot (\text{solid.SZ} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3) + 2 \cdot \text{solid.SXY} \cdot \text{solid.SYZ} \cdot \text{solid.SXZ} - (\text{solid.SX} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3) \cdot \text{solid.SYZ}^2 - \text{solid.SXY}^2 \cdot (\text{solid.SZ} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3) - (\text{solid.SY} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3) \cdot \text{solid.SXZ}^2$	$\text{kg}^3/(\text{m}^3 \cdot \text{s}^6)$	Third invariant of effective stress deviator	Domain 1
solid.thetaLEff	solid.thetaL	rad	Effective stress Lode angle	Domain 1
solid.sEff	$\text{sqrt}(1.5 \cdot ((\text{solid.SX} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2 + 2 \cdot \text{solid.SXY}^2 + 2 \cdot \text{solid.SXZ}^2 + (\text{solid.SY} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2 + 2 \cdot \text{solid.SYZ}^2 + (\text{solid.SZ} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2))$	N/m^2	Effective stress	Domain 1

Name	Expression	Unit	Description	Selection
	$- (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2 + 2*\text{solid.SYZ}^2 + (\text{solid.SZ} - (\text{solid.SX} + \text{solid.SY} + \text{solid.SZ})/3)^2)$			

2.4.2 Free 1



Free 1

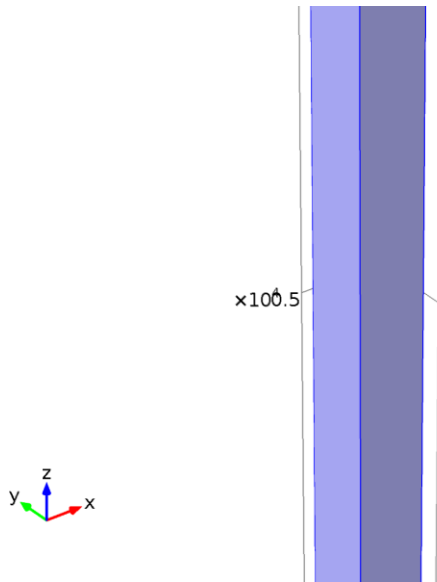
Selection

Geometric entity level	Boundary
Selection	Boundaries 4–5

Used products

COMSOL Multiphysics

2.4.3 Initial Values 1



Initial Values 1

Selection

Geometric entity level	Domain
Selection	Domain 1

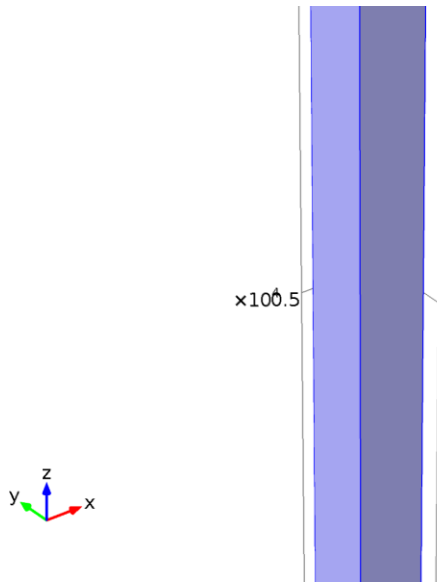
Used products

COMSOL Multiphysics

Variables

Name	Expression	Unit	Description	Selection
solid.uInitX	0	m	Initial value of displacement, X component	Domain 1
solid.uInitY	0	m	Initial value of displacement, Y component	Domain 1
solid.uInitZ	0	m	Initial value of displacement, Z component	Domain 1
solid.utInitX	0	m/s	Initial value of structural velocity, X component	Domain 1
solid.utInitY	0	m/s	Initial value of structural velocity, Y component	Domain 1
solid.utInitZ	0	m/s	Initial value of structural velocity, Z component	Domain 1

2.4.4 Symmetry 1



Symmetry 1

Selection

Geometric entity level	Boundary
Selection	Boundaries 1–3

Equations

$$\mathbf{n} \cdot \mathbf{u} = 0$$

Used products

COMSOL Multiphysics
Structural Mechanics Module

Constraints

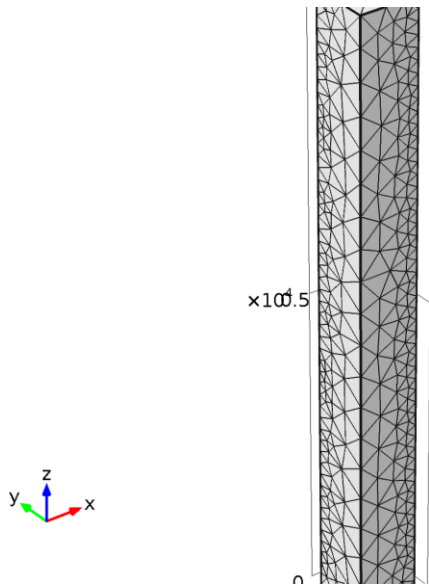
Constraint	Constraint force	Shape function	Selection
-solid.nX*u2 - solid.nY*v2 - solid.nZ*w2	test(-solid.nX*u2 - solid.nY*v2 - solid.nZ*w2)	Lagrange (Quadratic)	Boundaries 1–3

2.5 Mesh 1

Mesh statistics

Property	Value
Minimum element quality	0.2091
Average element quality	0.7283

Property	Value
Tetrahedral elements	4860
Triangular elements	1508
Edge elements	147
Vertex elements	6



Mesh 1

2.5.1 Size (size)

Settings

Name	Value
Maximum element size	550
Minimum element size	40
Resolution of curvature	0.4
Resolution of narrow regions	0.7
Maximum element growth rate	1.4
Predefined size	Finer

3 Study 1

3.1 Time Dependent

Times: range(0,10,230)

Mesh selection

Geometry	Mesh
Geometry 1 (geom1)	mesh1

Physics selection

Physics	Discretization
Solid Mechanics (solid)	physics

3.2 Solver Configurations

3.2.1 Solver 1

Compile Equations: Time Dependent (st1)

Study and step

Name	Value
Use study	Study 1
Use study step	Time Dependent

Dependent Variables 1 (v1)

General

Name	Value
Defined by study step	Time Dependent

Initial values of variables solved for

Name	Value
Solution	Zero

Values of variables not solved for

Name	Value
Solution	Zero

mod1.u2 (mod1_u2)

General

Name	Value
------	-------

Name	Value
Field components	{mod1.u2, mod1.v2, mod1.w2}

Scaling

Name	Value
Method	Manual
Scale	$1e-2 * 1.0099504938362077E-5$

Time-Dependent Solver 1 (t1)

General

Name	Value
Defined by study step	Time Dependent
Time	{0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230}

Log

Time-Dependent Solver 1 in Solver 1 started at 25-Feb-2014 14:20:53.
 Time-dependent solver (BDF)
 Number of degrees of freedom solved for: 24297 (plus 374220 internal).
 Symmetric matrices found.
 Scales for dependent variables:
 mod1.u2: 1e-007

Step	Time	Stepsize	Res	Jac	Sol	Order	Tfail	NLfail
0	0	out	3	3	3			0
1	0.23	0.23	4	4	4	1	0	0
2	0.46	0.23	5	4	5	1	0	0
3	0.92	0.46	6	4	6	2	0	0
4	1.84	0.92	7	5	7	1	0	0
5	3.68	1.84	8	6	8	1	0	0
6	7.36	3.68	9	7	9	1	0	0
	10	- out						
7	14.72	7.36	10	8	10	1	0	0
	20	- out						
8	29.44	14.72	11	9	11	1	0	0
	30	- out						
	40	- out						
	50	- out						
9	52.44	23	12	9	12	1	0	0
	60	- out						
	70	- out						
10	75.44	23	13	9	13	1	0	0
	80	- out						
	90	- out						
11	98.44	23	14	9	14	1	0	0
	100	- out						
	110	- out						
	120	- out						
12	121.44	23	15	9	15	1	0	0
	130	- out						
	140	- out						
13	144.44	23	16	9	16	1	0	0
	150	- out						
	160	- out						
14	167.44	23	17	9	17	1	0	0
	170	- out						
	180	- out						
	190	- out						
15	190.44	23	18	9	18	1	0	0
	200	- out						
	210	- out						
16	213.44	23	19	9	19	1	0	0
	220	- out						
	230	- out						
17	236.44	23	20	9	20	1	0	0

Time-stepping completed.

Time-Dependent Solver 1 in Solver 1: Solution time: 18 s.

Fully Coupled 1 (fc1)

General

Name	Value
Linear solver	Direct

4 Results

4.1 Data Sets

4.1.1 Solution 1

Selection

Geometric entity level	Domain
Selection	Geometry geom1

Solution

Name	Value
Solution	Solver 1
Model	Save Point Geometry 1

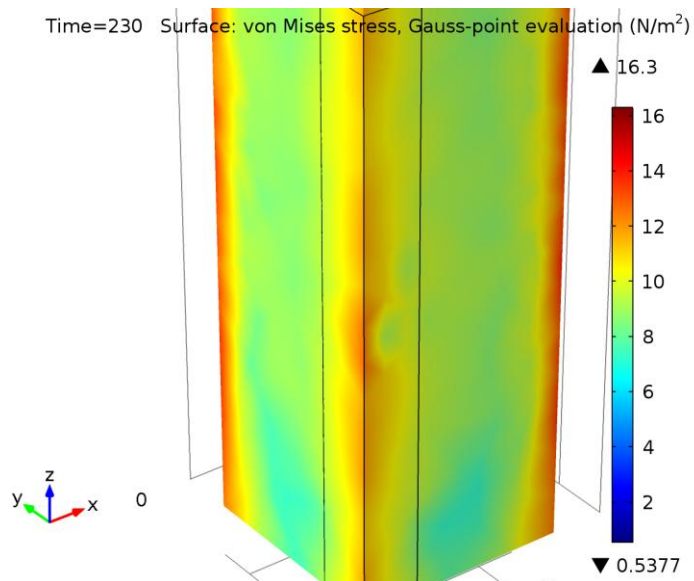
4.2 Tables

4.2.1 Evaluation 3D

Interactive 3D values

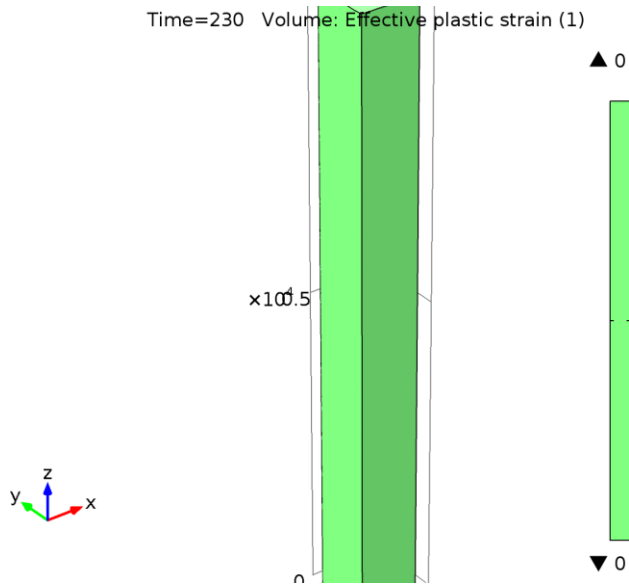
4.3 Plot Groups

4.3.1 Stress (solid)



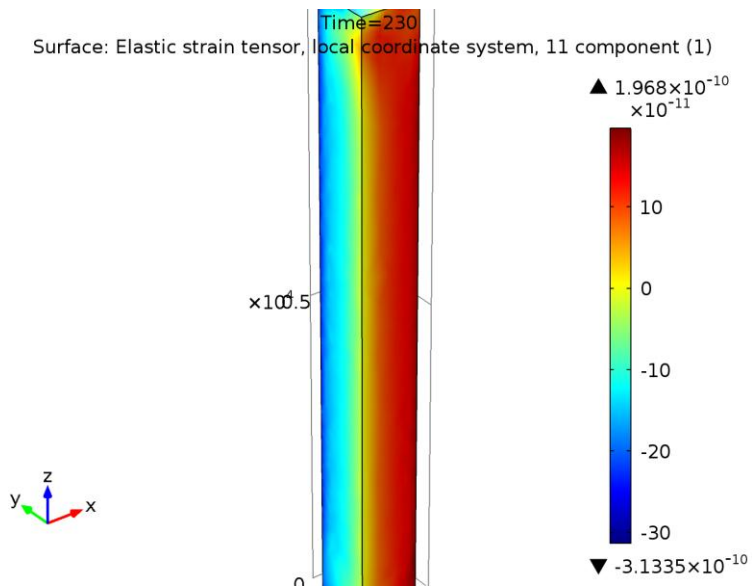
Time=230 Surface: von Mises stress, Gauss-point evaluation (N/m²)

4.3.2 3D Plot Group 2



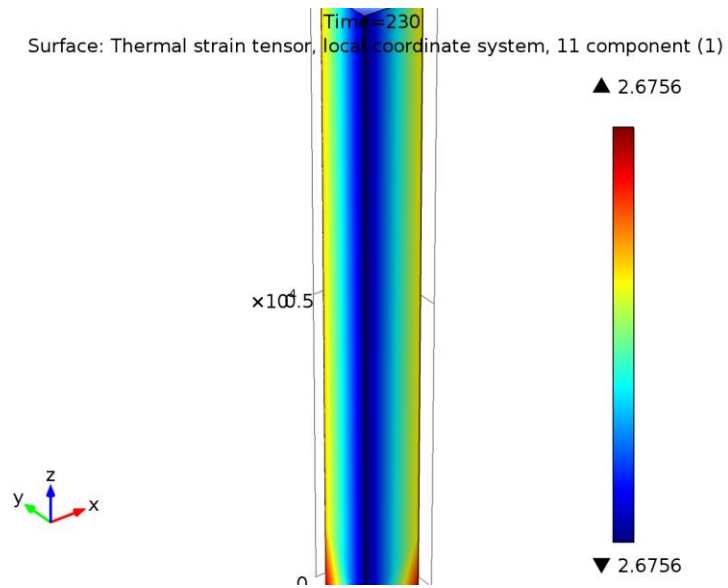
Time=230 Volume: Effective plastic strain (1)

4.3.3 3D Plot Group 3



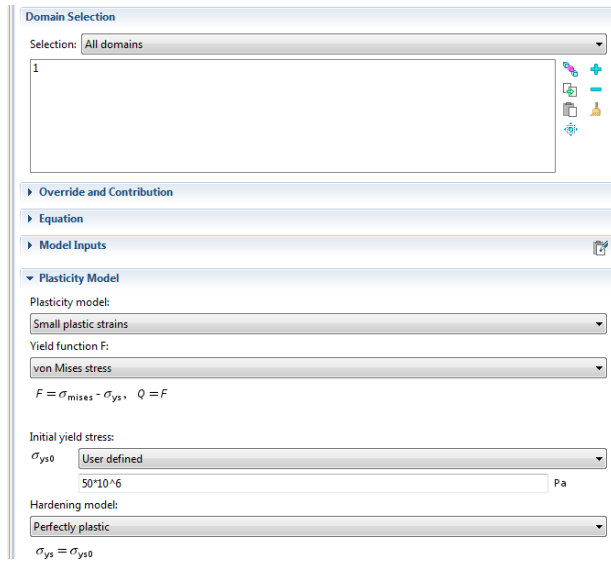
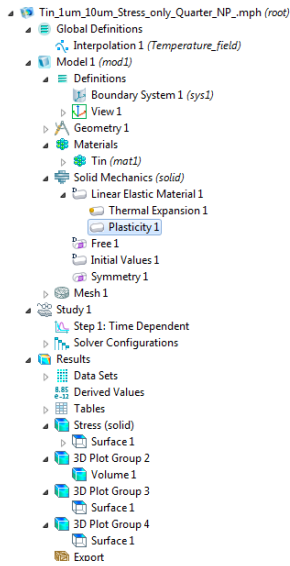
Time=230 Surface: Elastic strain tensor, local coordinate system, 11 component (1)

4.3.4 3D Plot Group 4

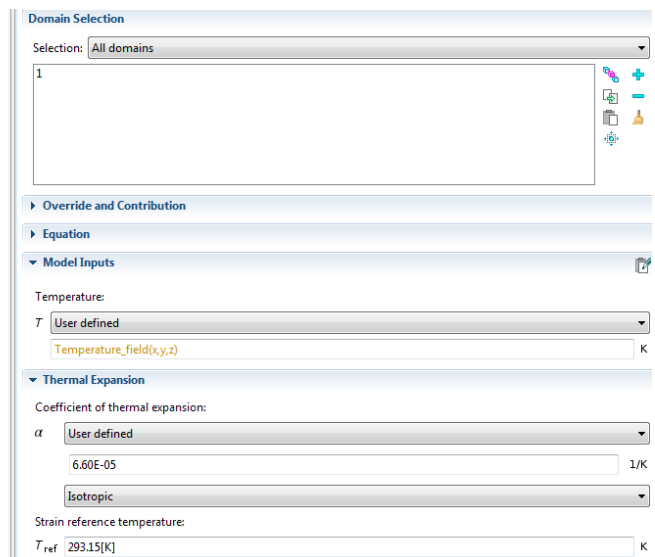
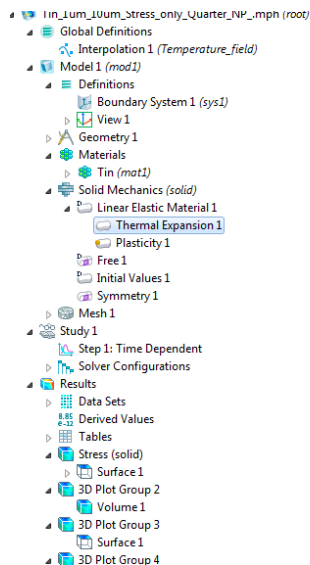


Time=230 Surface: Thermal strain tensor, local coordinate system, 11 component (1)

Plastic Conditions: Perfectly Plastic



Thermal expansion conditions



Elastic Conditions

