Example 2d: Shape Memory Alloy (SMA)

This example problem generates the tensile response of a NiTi shape memory alloy (SMA), using a specially designed constitutive model, which accounts for phase changes within the material. This model is a new capability within MAC/GMC 4.0. Cyclic strain-controlled mechanical loading is applied to the monolithic SMA at a rate of 0.001/sec.

MAC/GMC Input File: `example_2d.mac`

```
MAC/GMC 4.0 Example 2d - Shape Memory Alloy
*CONSTITUENTS
  NMATS=1
  M=1 CMOD=30 TREF=71.1 MATID=A
#  M=1 CMOD=30 TREF=2.2 MATID=A
*RUC
  MOD=1 M=1
*MECH
  LOP=1
  NPT=3 TI=0.,45.,90. MAG=0.,0.045,0. MODE=1,1
*SOLVER
  METHOD=1 NPT=3 TI=0.,45.,90. STP=0.25,0.25
*PRINT
  NPL=6
*XYPLOT
  FREQ=1
  MACRO=1
   NAME=example_2d X=1 Y=7
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

2) Constituent materials (**`*CONSTITUENTS`**) [KM_2]:

Number of materials:	1	(`NMATS=1`)
Constitutive models:	Graesser – Cozzarelli – Witting SMA model	(`CMOD=30`)
Materials:	NiTi SMA	(`MATID=A`)
Reference Temperatures:	71.1. °C, 2.2 °C	(`TREF=71.1` or `TREF=2.2`)

3) Analysis type (**`*RUC`**) → Repeating Unit Cell Analysis [KM_3]:

Analysis model:	Monolithic material	(`MOD=1`)
Material assignment:	SMA	(`M=1`)

4) Loading:

a) Mechanical (**`*MECH`**) [KM_4]:

Loading option:	1	(LOP=1)
Number of points:	3	(NPT=3)
Time points:	0., 45., 90. sec.	(TI=0.,45.,90.)
Load magnitude:	0., 0.045, 0.	(MAG=0.,0.045,0.)
Loading mode:	strain control	(MODE=1,1)

In order to illustrate the unique features of the SMA constitutive model, a complete mechanical loading and unloading cycle has been employed.

b) Thermal (***THERM**): None

c) Time integration (***SOLVER**) [KM_4]:

Time integration method:	Forward Euler	(METHOD=1)
Number of time points:	3	(NPT=3)
Time points:	0., 45., 90. sec.	(TI=0.,45.,90.)
Time step sizes:	0.25, 0.25 sec.	(STP=0.25,0.25)

5) Damage and Failure: None

6) Output:

a) Output file print level (***PRINT**) [KM_6]:

Print level:	6	(NPL=6)

b) x-y plots (***XYPLOT**) [KM_6]:

Frequency:	5	(FREQ=5)
Number of macro plots:	1	(MACRO=1)
Macro plot name:	example_2d	(NAME=example_2d)
Macro plot x-y quantities:	ε_{11}, σ_{11}	(X=1 Y=7)
Number of micro plots:	0	(MICRO=0)

7) End of file keyword: (***END**)

Results

Figure 2.4 shows that, at both temperatures, the implemented constitutive model captures the superelastic behavior of the NiTi SMA. That is, upon mechanical unloading, the SMA returns to its original shape. This "shape memory" behavior is due to stress-induced phase transformations that occur in the NiTi during loading and unloading, as modeled by the Graesser – Cozzarelli – Witting SMA constitutive model. Upon complete mechanical unloading, the stress-strain curves return to the origin, indicating that no permanent or irreversible deformation has occurred.

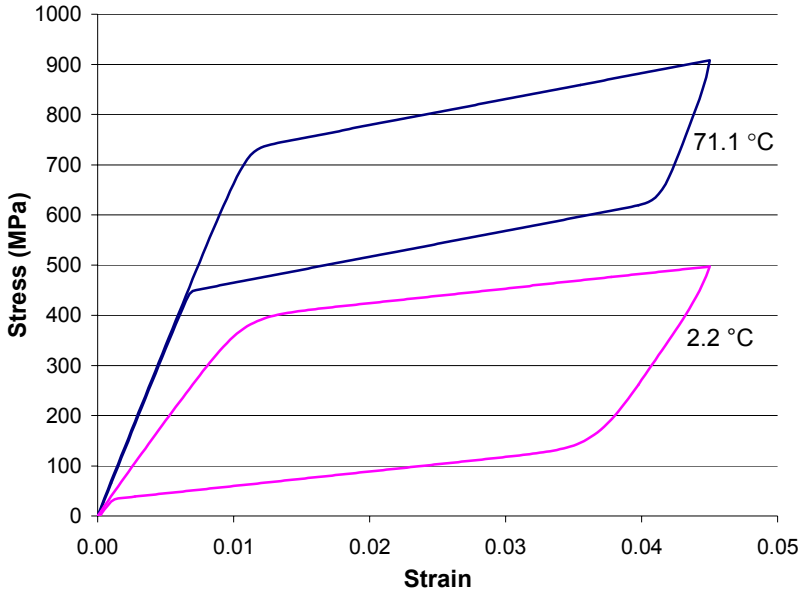

Figure 2.4 Example 2d: plots of the tensile stress-strain response of the NiTi SMA as simulated using the Graesser – Cozzarelli – Witting constitutive model at 71.1 °C and 2.2 °C.