Example 2c: Incremental Plasticity

This example problem generates the room-temperature tensile response of the materials associated with the incremental plasticity constitutive model within the MAC/GMC 4.0 internal material database. Incremental plasticity represents a special case for the code in that, due to the presence of a yield surface, global iterations must occur at each increment of the applied loading in order to ensure that the plastically deforming material remains on the yield surface. Further, while the incremental plasticity constitutive model is history-dependent, the modeled inelastic behavior is independent of strain rate. The inelastic behavior of the material is defined by a yield stress and a number of stress-total strain pairs that dictate the path of the stress-strain response after yielding. These stress-total strain pairs can be obtained from experimental stress-strain curves for the material. In the simplest case, if only one post-yield stress-strain pair is specified, bilinear plasticity results. If more than one post-yield stress-strain pair is specified, point-wise plasticity results. The MAC/GMC 4.0 internal material database contains materials with bilinear incremental plasticity responses and two materials with point-wise incremental plasticity responses. This example problem considers the monolithic materials and applies strain at a rate of 10^{-4}/sec.

MAC/GMC Input File: **example_2c.mac**

```
MAC/GMC 4.0 Example 2c - Incremental Plasticity
*CONSTITUENTS
  NMATS=4
# -- OFHC Copper - Bilinear
  M=1 CMOD=21 TREF=23. MATID=A
# -- Ti-24-11 - Bilinear
  M=2 CMOD=21 TREF=23. MATID=B
# -- Ti-15-3 - Point-wise
  M=3 CMOD=21 TREF=23. MATID=C
# -- Ti-24-11 - Point-wise
  M=4 CMOD=21 TREF=23. MATID=D
*RUC
  MOD=1 M=1
#  MOD=1 M=2
#  MOD=1 M=3
#  MOD=1 M=4
*MECH
  LOP=1
  NPT=2 TI=0.,20. MAG=0.,0.02 MODE=1
*SOLVER
  METHOD=1 NPT=2 TI=0.,20. STP=0.1 ITMAX=20 ERR=0.0001
*PRINT
  NPL=6
*XYPLOT
  FREQ=5
  MACRO=1
   NAME=example_2c X=1 Y=7
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

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

Number of materials:	4	(`NMATS=4`)
Constitutive models:	Incremental plasticity	(`CMOD=21`)
Materials:	OFHC Cu – bilinear	(`MATID=A`)
	Ti-24-11 – bilinear	(`MATID=B`)
	Ti-15-3 – point-wise	(`MATID=C`)
	Ti-24-11 – point-wise	(`MATID=D`)
Reference Temperature:	23. °C	(`TREF=23.`)

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

Analysis model:	Monolithic material	(`MOD=1`)
Material assignment:	Each constituent successively	(`M=1-4`)

Each of the materials in ***CONSTITUENTS** is assigned to the monolithic material successively by commenting and uncommenting the appropriate lines.

4) Loading:

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

Loading option:	1	(`LOP=1`)
Number of points:	2	(`NPT=2`)
Time points:	0., 20. sec.	(`TI=0.,20.`)
Load magnitude:	0., 0.02	(`MAG=0.,0.02`)
Loading mode:	strain control	(`MODE=1`)

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

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

Time integration method:	Forward Euler	(`METHOD=1`)
Number of time points:	2	(`NPT=2`)
Time points:	0., 20. sec.	(`TI=0.,20.`)
Time step sizes:	0.1 sec.	(`STP=0.1`)
Max. number of iterations	20	(`ITMAX=20`)
Max. permitted error fraction	0.0001	(`ERR=0.0001`)

Due to the necessity of iteration at each time step in the simulation, two additional specifiers are required under ***SOLVER** when incremental plasticity is employed for a constituent material. These are the maximum number of iterations permitted at a particular time step (`ITMAX`) and the maximum permitted error fraction for convergence (`ERR`). The maximum number of iterations places a ceiling on the number of iterations at a particular time step. Once this number of iterations is reached, the code will advance to the next time step regardless of whether or not convergence has occurred (in which case a warning will be written to the output file). Generally, this non-convergent situation should be avoided by using a large value for `ITMAX`. The maximum permitted error fraction is the fractional change in the local effective plastic strain increment between iterations that can be considered "small enough". That is, for example, if the largest fractional change in the effective plastic strain increment over all subcells at a particular time step is 0.00009, and `ERR` has been set to 0.0001, convergence is considered to have been achieved for that time step. The appropriate value for `ERR` is case dependent, and there is an inverse relationship between the time step size and `ERR`. If oscillations are present in the results, a lower value of `ERR` and/or a smaller time step should be employed.

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_2c	(`NAME=example_2c`)
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

The results for this example problem are plotted in Figure 2.3. The difference between bilinear and point-wise representations of the material stress-strain response is clear.

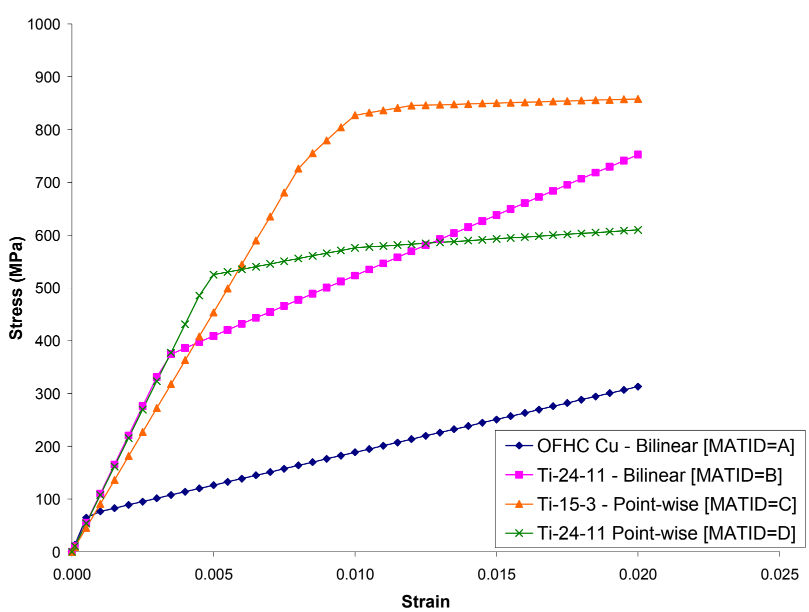

Figure 2.3 Example 2c: plots of the room-temperature tensile stress-strain response of OFHC Cu, Ti-24-11 (bilinear), Ti-15-3, and Ti-24-11 (point-wise) as modeled by the incremental plasticity constitutive model.