6.12 Example L: Fatigue Damage Analysis

Sample Input File For A Fatigue Damage Analysis

The following example is used to explain how to conduct fatigue damage analysis within **MAC/GMC**.

Problem Summary:

Load Type:	Mechanical
Load History:	Cyclic
Load Control:	Stress
Load Component:	11 - direction (in the fiber direction)
Load History Data: $\Delta D = 0.15$	$\sigma_{11max} = 115.$ ksi, $\dot{\sigma}_{11} = 128.$ ksi/sec, $\Delta t_{constant}$= 0.01797 sec
Micromechanics model:	Double Periodic
Fiber Packing Arrangement:	Square Pack at 35% fiber volume ratio
Integration Algorithm:	Forward Euler
Constituent Material Model:	Elastic (fiber) and Bodner-Partom (matrix)
Constituents:	Fiber: SCS-6 (input manually) Matrix: Ti - 15 - 3 (at 800°F, input manually)

☞ **Note:** A similar example problem is described in more detail in:
Wilt, T.E., Arnold, S. M., and Saleeb, A.F.: A Coupled/Uncoupled Computational Scheme for Deformation and Fatigue Damage Analysis of Unidirectional Metal Matrix Composites, Applications of Continuum Damage Mechanics to Fatigue and Fracture, ASTM STP 1315, D.L. McDowell, Ed., American Society for Testing and Materials, pp. 65-82, 1997.

The purpose here is to demonstrate how to use the ***DAMAGE** option.

```
Longitudinal fatigue analysis of square packed SCS6/Ti-15-3 system
*PRINT
  NPL=0%
*LOAD
  LCON=2 LOP=1 LSS=2 %
*MECH
 NPTW=3 TI=0.,0.89844,1.79688 LO=0.,115.,0. %
*MODEL
  MOD=1 %
*DAMAGE
  NCY=12 D=0.15 DMAX=1.0 FG=0 FL=1%
*SOLVER
  NTF=1 NPTS=3 TIM=0.,0.89844,1.79688 STP=0.01797,0.01797 %
*FIBER
  NFIBS=1
  NF=1 MF=6 NDPT=1 MAT=U IFM=1 &
  EL=58.E3,58.E3,0.25,0.25,23.2E3,3.5E-6,3.5E-6
  ANG=1. BN=2. BP=4. OMU=1. OMFL=1. OMM=1. ETU=1. &
  ETFL=1. ETM=1. BE=1. A=1. SFL=1. XML=1.   &
  SU=1. SK=1
# Note sk=1 means skip fatigue damage for fiber, so damage properties are
# meaningless - but failure criteria is still applicable.
  T=1 IC=1 V=320. %
*MATRIX
  NMATX=1
  NM=1 MM=1 NDPT=1 MAT=U IFM=1 &
  EL=12770.,12770.,0.32,0.32,4837.12,21.06E-6,21.06E-6  &
  VI=1000.,120.,120.,10.,3.,1.
  ANG=0. BN=0. BP=0. OMU=1. OMFL=1. OMM=1. ETU=1. &
  ETFL=1. ETM=1. BE=2.27 A=0.2302 SFL=20.3 XML=900. &
  SU=128. SK=0
  T=2 IC=1 V=0.01 %
*MRVE
  IDP=1 VF=0.35 %
*CURVE
  NP=1 %
*MACRO
  NT=1
  NC=1 X=1 Y=7 NAM=apdxl %
*END
```

The following results is contained in the output file: **dam2.data**

```
 Calculated Cycles To Failure At Increment 100 Applied Load Cycle   1

Subcell #       Nf
    1      0.100000E+10
    2      0.613603E+05
    3      0.613603E+05
    4      0.664385E+05
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    60494.2250830768
 NF =>    60494.0000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    60494.0000000000
 *** AFTER APPLIED LOAD CYCLE            1
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 200 Applied Load Cycle   2

Subcell #       Nf
    1      0.100000E+10
    2      0.116736E+04
    3      0.116736E+04
    4      0.545641E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    674.890587838351
 NF =>    674.000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    61168.0000000000
 *** AFTER APPLIED LOAD CYCLE            2
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 300 Applied Load Cycle   3

Subcell #       Nf
    1      0.100000E+10
    2      0.709630E+03
    3      0.709630E+03
    4      0.438086E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    419.320819753184
 NF =>    419.000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    61587.0000000000
```

```
 *** AFTER APPLIED LOAD CYCLE            3
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 400 Applied Load Cycle   4

Subcell #       Nf
    1      0.100000E+10
    2      0.463247E+03
    3      0.463247E+03
    4      0.361975E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            3 *****
 NF =>    307.516313605484
 NF =>    307.000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    61894.0000000000
 *** AFTER APPLIED LOAD CYCLE            4
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 500 Applied Load Cycle   5

Subcell #       Nf
    1      0.100000E+10
    2      0.295356E+03
    3      0.295356E+03
    4      0.301874E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    232.831665300220
 NF =>    232.000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    62126.0000000000
 *** AFTER APPLIED LOAD CYCLE            5
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 600 Applied Load Cycle   6

Subcell #       Nf
    1      0.100000E+10
    2      0.166907E+03
    3      0.166907E+03
    4      0.253239E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    158.292840626614
 NF =>    158.000000000000
```

```
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    62284.0000000000
 *** AFTER APPLIED LOAD CYCLE            6
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 700 Applied Load Cycle   7

Subcell #       Nf
    1      0.100000E+10
    2      0.620698E+02
    3      0.620698E+02
    4      0.214841E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            3 *****
 NF =>    62.0697834887934
 NF =>    62.0000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    62346.0000000000
 *** AFTER APPLIED LOAD CYCLE            7
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 800 Applied Load Cycle   8

Subcell #       Nf
    1      0.100000E+10
    2      0.735691E+01
    3      0.735691E+01
    4      0.195843E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    7.35691370876420
 NF =>    7.00000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    62353.0000000000
 *** AFTER APPLIED LOAD CYCLE            8
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment 900 Applied Load Cycle   9

Subcell #       Nf
    1      0.100000E+10
    2      0.290197E+01
    3      0.290197E+01
    4      0.194075E+04
 ****************************************
 ****************************************
 ****************************************
```

```
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    2.90196867892969
 NF =>    2.00000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    62355.0000000000
 *** AFTER APPLIED LOAD CYCLE            9
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment *** Applied Load Cycle  10

Subcell #       Nf
    1      0.100000E+10
    2      0.202802E+01
    3      0.202802E+01
    4      0.193669E+04
 ****************************************
 ****************************************
 ****************************************
 ***** CONTROLLING SUBCELL            2 *****
 NF =>    2.02801986635817
 NF =>    2.00000000000000
 ****************************************
 ****************************************
 **** CURRENT TOTAL # CYCLES =    62357.0000000000
 *** AFTER APPLIED LOAD CYCLE           10
 ****************************************
 ****************************************
 Calculated Cycles To Failure At Increment *** Applied Load Cycle  11

Subcell #       Nf
    1      0.100000E+10
    2     -0.999000E+03
    3     -0.999000E+03
    4      0.193110E+04
 SUBCELL            2 FAILED ... SKIPPED
 **** WARNING ****  DELN < 1 FOR CELL            2
 SUBCELL            3 FAILED ... SKIPPED
 **** WARNING ****  DELN < 1 FOR CELL            3
 **** WARNING ****  DELN < 1 FOR CELL            4
 SORTN: **** STOP ****  DELN < 1
```

At this point the matrix subcells have all failed and the analysis stops.

Thus the life of the composite is <u>62357</u> cycles.

The following results is contained in the output file: **dam3.data**

```
****************************
SUBCELL #            1
IDAM  F
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  F
CYCLES TO FAILURE XNF    61360.2956047440
****************************
****************************
SUBCELL #            3
IDAM  F
CYCLES TO FAILURE XNF    61360.2956047440
****************************
****************************
SUBCELL #            4
IDAM  F
CYCLES TO FAILURE XNF    66438.5151084627
****************************
****************************************
** Current Damage At Increment 100 Applied Load Cycle   1
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.149958E+00   0.850042E+00
   3  0.149958E+00   0.850042E+00
   4  0.632021E-03   0.999368E+00
****************************
SUBCELL #            1
IDAM  F
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    1167.36343322662
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    1167.36343322663
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    5456.41016344678
****************************
****************************************
** Current Damage At Increment 200 Applied Load Cycle   2
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.299638E+00   0.700362E+00
```

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   3  0.299638E+00   0.700362E+00
   4  0.141115E-02   0.998589E+00
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    709.630361973297
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    709.630361973300
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    4380.85967672225
****************************
****************************************
** Current Damage At Increment 300 Applied Load Cycle   3
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.449466E+00   0.550534E+00
   3  0.449466E+00   0.550534E+00
   4  0.243012E-02   0.997570E+00
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    463.247417312908
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    463.247417312908
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    3619.74747832020
****************************
****************************************
** Current Damage At Increment 400 Applied Load Cycle   4
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.599071E+00   0.400929E+00
```

```
   3  0.599071E+00   0.400929E+00
   4  0.375666E-02   0.996243E+00
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    295.355917088531
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    295.355917088531
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    3018.74014755274
****************************
****************************************
** Current Damage At Increment 500 Applied Load Cycle   5
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.748061E+00   0.251939E+00
   3  0.748061E+00   0.251939E+00
   4  0.539214E-02   0.994608E+00
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    166.907472034450
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    166.907472034450
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    2532.39380892976
****************************
****************************************
** Current Damage At Increment 600 Applied Load Cycle   6
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.897013E+00   0.102987E+00
   3  0.897013E+00   0.102987E+00
   4  0.707338E-02   0.992927E+00
```

```
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    62.0697834887973
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    62.0697834887934
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    2148.40603399676
****************************
****************************************
** Current Damage At Increment 700 Applied Load Cycle   7
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.987089E+00   0.129106E-01
   3  0.987089E+00   0.129106E-01
   4  0.796197E-02   0.992038E+00
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    7.35691370876420
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    7.35691370914608
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    1958.42907053144
****************************
****************************************
** Current Damage At Increment 800 Applied Load Cycle   8
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.994882E+00   0.511765E-02
   3  0.994882E+00   0.511765E-02
   4  0.807672E-02   0.991923E+00
```

```
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    2.90196867892969
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    2.90196868203595
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    1940.74760195980
****************************
****************************************
** Current Damage At Increment 900 Applied Load Cycle   9
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.996420E+00   0.357991E-02
   3  0.996420E+00   0.357991E-02
   4  0.811000E-02   0.991890E+00
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF    2.02801986635817
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF    2.02801987334260
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    1936.69355062971
****************************
****************************************
** Current Damage At Increment *** Applied Load Cycle  10
SUBCELL #     D        1-D
   1  0.000000E+00   0.100000E+01
   2  0.999034E+00   0.966462E-03
   3  0.999034E+00   0.966462E-03
   4  0.814345E-02   0.991857E+00
```

```
****************************
SUBCELL #            1
IDAM  T
CYCLES TO FAILURE XNF    1000000000.00000
****************************
****************************
SUBCELL #            2
IDAM  T
CYCLES TO FAILURE XNF   -999.000000000000
****************************
****************************
SUBCELL #            3
IDAM  T
CYCLES TO FAILURE XNF   -999.000000000000
****************************
****************************
SUBCELL #            4
IDAM  T
CYCLES TO FAILURE XNF    1931.10439061903
*
```