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Micromechanics Analysis Code Post-Processing (MACPOST) User Guide

Version 1.0

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1.0 Introduction

As advanced composite materials have gained wider usage, the need for analytical models and computer codes to predict the thermomechanical deformation response of these materials has increased significantly. Furthermore, micromechanics techniques are often utilized which allow the prediction of the average (macro) response of a composite given the properties of the individual constituents and their geometrical arrangement. Ideally, a model will utilize physically based deformation constitutive models, and is able to generate accurate displacement and stress fields at both the macro (average) and micro (constituent) level.

Recently, a micromechanics technique called the generalized method of cells (GMC) [1] has been developed, which has the potential to fulfill these goals. In the generalized method of cells, a continuously reinforced fiber composite can be modeled as a periodic array of fibers embedded in a matrix phase. A unit cell is identified, which consists of one or more fibers and the surrounding matrix. The unit cell is the smallest section of the composite for which the response can be considered to be representative of the composite as a whole. The unit cell is divided up into an arbitrary number of subcells. A linear displacement field is assumed in each subcell, and continuity of tractions and displacements is imposed across both subcell and unit cell boundaries. The macroscopic stresses and strains are then defined in terms of the microscopic (subcell) stresses and strains, and the overall macroscopic constitutive equations of the composite can be determined.

Unlike the finite element method, GMC is fully analytical and yields closed-form expressions for the effective properties of heterogeneous materials. However, like the finite element method, GMC predicts multi-axial local field quantities throughout such a material. Thus, as is the case with the finite element method, the ability to represent the predicted local field quantities graphically is highly desirable. **MACPOST** provides this capability.

The three-dimensional version of GMC (GMC-3D) [2] is similar to GMC, but it allows subcell discretization in all three Cartesian coordinate directions. This further generalization makes possible the ready analysis of short-fiber, particle, and woven reinforced composites. Both GMC and GMC-3D recently have been reformulated to improve significantly their computational efficiency [3,4], thus allowing quick analysis of complex and finely discretized unit cells.

To provide a framework for GMC and GMC-3D, the Micromechanics Analysis Code with Generalized Method of Cells (MAC/GMC) [5] has been developed at NASA Glenn Research Center. Through MAC/GMC, various thermal, mechanical and thermomechanical load histories can be imposed, different integration algorithms can be selected, many different fiber architectures can be utilized and a variety of fiber and matrix constitutive models are available. In the original version of MAC/GMC, results could be output through the generation of ASCII files containing columns of X-Y pairs, which could then be plotted using a separate graphing program. In addition, geometry, stress and strain data could be generated at selected time steps in a form that could be read in by the MSC/PATRAN [6] graphical pre- and post-processing package for display in a graphical format.

With the updating of MAC/GMC, significant improvements have been made to the post-processing capabilities of the code. Through the **MACPOST** program, which operates directly within the MSC/PATRAN environment, a direct link between the analysis capabilities of MAC/GMC and the post-processing capabilities of MSC/PATRAN has been established. **MACPOST** has simplified the production, printing, and exportation of results for unit cells analyzed by MAC/GMC. Furthermore, **MACPOST** allows different micro-level quantities to be plotted quickly and easily for any subcell. In addition, meaningful data for X-Y plots can be examined in **MACPOST** and exported for use in creating graphs with an external plotting package. Thus, by providing access to the post processing capabilities of MSC/PATRAN, **MACPOST** serves as an important analysis and visualization tool for the macro- and micro-level data generated by MAC/GMC.

The **MACPOST** program is written in Patran Command Language (PCL), an internal C-like programming language that allows for the development and execution of user-created programs directly within the MSC/PATRAN environment. MSC/PATRAN commands and directives are directly incorporated into the programming structure.

MACPOST reads in results data generated by MAC/GMC and can display the results in two different formats. X-Y plots can be generated to display the variation of parameters as a function of other parameters or of time. Such X-Y plots can be generated for either macro-level (effective) response parameters or for the response of individual subcell(s) (micro-level response parameters). Secondly, contour plots can be generated which allow the graphical display of the variation of a particular stress or strain component or invariant over the geometry of the unit cell at a particular point in time. By combining both types of output within a single application, the user can employ the X-Y plotting capability to determine, in a general sense, the variation of parameters such as stress and strain with time. Then, at particular points of interest, contour plots of the various micro field quantities can be generated to allow for detailed observation and analysis of the material behavior. The X-Y plotting data can then be exported in a manner to allow for further manipulation by an external plotting package.

This report serves as the user's manual for the **MACPOST** program. The reader is assumed to be familiar with, and have the user's manual for, the MAC/GMC analysis program (Version 3.0). Furthermore, it would be helpful if the user has at least some familiarity with the MSC/PATRAN software. Since **MACPOST** executes totally within the MSC/PATRAN environment, **MACPOST** should function properly on any computer platform where the user executes MSC/PATRAN. First, the procedures required to compile and execute **MACPOST** will be described, and the overall program flow and methodology will be presented. Next, the required input and the generated output of the

MAC/GMC code, which are required in order to generate results in a format suitable for **MACPOST**, will be discussed. Details of the procedures, menus and forms required for generating X-Y plot results will be presented, followed by a detailed description of the procedures, menus and forms utilized to generate contour plots. Finally, the execution of **MACPOST** for a sample problem will be described, including the specific forms utilized and the displayed results.

2.0 MACPOST Execution

2.1 Initialization of MACPOST

MACPOST executes within the environment of the MSC/PATRAN pre- and post-processor. Therefore, to execute **MACPOST**, the user first must invoke MSC/PATRAN utilizing whatever setup and execution procedures are required for their individual system.

Inside MSC/PATRAN, the user must perform two tasks: open a new database, and initialize execution of **MACPOST**. First, to open a new database, the user should click on the **"File"** menu in the main menu bar with the mouse and select the **"New"** option from this menu. A database name should be entered in the **"New Database Name"** databox on the form that appears, and the "default" template should be selected (if it has not already been so by default). At this point, the **"OK"** button should be selected to create the required MSC/PATRAN database.

Once the database has been created, the **MACPOST** program must be loaded and executed. If a file named "macpost.plb" is not present in the directory from which MSC/PATRAN is being executed, or if the source code has been changed (and thus needs to be recompiled), the session file called **"macpost.ses"** must be executed. This file contains functions that compile the source code and create a library for the compiled functions. Execution of this session file is accomplished by first, clicking on the "**File**" menu in the main menu bar with the mouse, selecting the "**Session**" option from the resulting menu, and selecting the "**Play**" option from the pull-down menu. At this point, a form will be displayed listing the session files present in the current directory. In the databox labeled "**Session File List**", select the file "**macpost.ses**" by clicking on the file name with the mouse, resulting in a dark background surrounding the file name. Then selecting the "**Apply**" button results in the execution of the file which compiles the source code into a library.

Once this library is created (or is already present in the user's directory), the session file **"macpost2.ses"** is executed to call this library into active memory and define the **MACPOST** menu button on the main MSC/PATRAN menu bar. Execution is accomplished by repeating the same procedure described previously, only now the file "**macpost2.ses**" is selected and executed instead. Again, note that if the source code has not been changed, and the library file is present in the user directory (or has been created), only the **"macpost2.ses"** file must be executed.

Once **MACPOST** has been initialized, a new menu option, labeled **"MAC"**, is present on the main MSC/PATRAN menu bar, as shown in Figure 1. To execute the **MACPOST** program, the user should click on the **"MAC"** icon on the main menu bar, and select the **"RVE Post Processor"** option. At this point, **MACPOST** will begin executing, and the first form will be displayed.

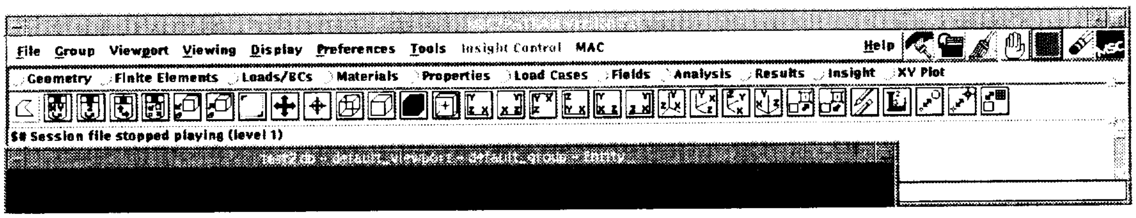

Figure 1: Main MSC/PATRAN menu bar with MACPOST "MAC" option

2.2 Program Flow

2.2.1 X-Y Plot Generation

There are three primary sections of the program flow, correlating to the three types of results which can be generated: X-Y plots of macroscopic results, X-Y plots of microscopic results (from individual subcells), and micro quantity contour plots. The user can easily switch between all three result types, and no particular order is required. Since both types of X-Y plots are generated using similar procedures, they will be explained simultaneously.

X-Y plot generation consists of creating curves that are selectively grouped and combined into plots. To create a curve, the user selects the independent and dependent variables (X-axis and Y-axis values, respectively) and indicates a label for the curve to be included in the legend (curve title). For a plot of a microscopic response parameter, the specific subcell whose response is to be plotted is also indicated. When the first curve of a plot is generated, the user can also enter a title for the plot. It is important to note that the results will be displayed using whatever system of units was specified in the original MAC/GMC analysis.

For each curve, the user can elect to 1) "shift" the X-axis values so that the curve will begin at an X-value of zero (0), 2) shift the curve by a specified amount, 3) not to shift the curve at all. The user can also elect to start the plotting of the results at a specified time. An example of a situation where these types of options would be useful is an analysis where a stress-strain curve for a material that has residual stresses applied is generated and is to be compared to an experimental stress-strain curve. For example, applying a temperature cool-down for a specified period of time (to simulate the fabrication process) followed by the application of a mechanical load is a typical MAC/GMC analysis problem which results in a compressive strain state at the point where mechanical loading is first applied. However, the experimentally generated stress-strain curve most likely starts at a strain value of zero, as the compressive strains generated by fabrication would not be included or known. In order to easily compare the experimental and analytical results, it would be helpful to have the analytical stress-strain curve also start at a macro strain of zero and to only include the data points in the curve that were generated during the mechanical load application. **MACPOST**, through the options described above, allows such a procedure to be carried out conveniently.

After each curve of a given plot is created, the user is given several choices. These choices include: creating another curve to be included on the current plot, creating an entirely new plot (containing a new curve or curves) of either the same type (macro or micro) or of the alternate type, displaying previously created plots, creating contour plots, or terminating the execution of **MACPOST**. The data files generated through the creation of X-Y plots by **MACPOST** can also be used to create more detailed graphs using an external plotting package.

2.2.2 Contour Plot Generation

The creation of contour plots involves a two step process. First, the first time a contour plot is to be generated, the model geometry of the unit cell is imported into MSC/PATRAN by reading and processing an input file, which is generated by MAC/GMC and contains the required data. The geometry is represented in the MSC/PATRAN database through the generation of nodes and elements. Each element represents a subcell. Even though a finite element analysis is not carried out, defining the unit cell model in this fashion facilitates the display of results data. Once the model geometry has been imported, it need not be imported again, and this step can be skipped if another contour plot is to be displayed.

The second step in the creation of contour plots involves specifying the results displayed over the unit cell geometry. The user enters the desired result type and the desired time step at which results are to be displayed. The time can either be entered directly by the user, or in an indirect manner by specifying that the results are to be displayed at a time step at which a particular macroscopic result occurs. For example, the user can specify that the contour results are to be displayed at the point that the predicted effective (macro) stress in the 33-direction is equal to 200. In all contour plots, the system of units that is utilized is the system of units that was utilized in the original MAC/GMC analysis. Once the result of interest is displayed, the user has the option of creating another contour plot, generating either "macro" or "micro" X-Y plots, or terminating execution of **MACPOST**.

3.0 Revisions to MAC/GMC Input/Output

3.1 Input

The PATRAN option of the input for MAC/GMC is as follows. The format of the input is:

*PATRAN
FN=**prefix** TPRE=**tpre** STP=**npstp**

where:
prefix = the filename that is prefixed to all MAC/GMC PATRAN output files for the given unit cell

tpre = preloading time before which results output does not occur

npstp = the increment counter which controls the frequency of results output

EXAMPLE:

*PATRAN
FN=test1 TPRE=57600 STP=2

This example would create a "geometry" file with the name "**test1.macgeo**" and would output the results to the other 13 files described below at every other time increment after a preloading time of 57600 units had occurred. The preloading time allows the user to only output the results data that is of interest. By reducing the amount of result data, the computational efficiency of MAC/GMC is improved. Furthermore, decreasing the amount of result data can significantly reduce the size of the output files.

3.2 Output

The output files generated by MAC/GMC 3.0 when the PATRAN option is activated have changed significantly from older versions. First, the prefix.patgeo, prefix.patstr, prefix.patepsin, and prefix.patepsto files are no longer created since the **MACPOST** software does not use these files. Alternatively, the following files are created, with formats as described in Appendix A. One important point to note is that these files can be somewhat large, on the order of 100KB each for the macroscopic results files and up to 4MB each for the microscopic and contour results. Proper use of the "**TPRE**" and "**STP**" options described in Section 3.1 can help to reduce the file sizes. For example, if only contour plots are desired, it is suggested that the results be output infrequently by using a large value of "npstp" described in Section 3.1. The specific output files that are generated are described below.

A. **prefix.macgeo:** This file contains the "geometry" information for the unit cell. The geometry is defined in terms of nodes and elements, where each subcell is treated as an element. The nodes are used to define and construct the elements. The geometry is defined in this manner to facilitate the processing of contour plot results by **MACPOST**. **Note that this file is NOT in standard MSC/PATRAN neutral file format.** The file contains nodal ID's and coordinates, element ID's and element connectivity data. The exact file format is shown in Appendix A.

B. **macro1_pat.data, macro2_pat.data, macro3_pat.data, macro4_pat.data:** These files contain the macroscopic (effective composite) results data at a time frequency determined by the STP option in the MAC/GMC input. **macro1_pat.data** contains all components of the total strain (11, 22, 33, 23, 13, and 12). **macro2_pat.data** contains the stress components, **macro3_pat.data** contains the inelastic strain components, and **macro4_pat.data** contains the normal thermal strain components (11, 22 and 33), the creep time, the temperature and the stress invariant (I1 and J2) data. All four files also contain the total time for each time step output. The file format, explained in more detail in Appendix A, consists of one row for each output time step.

C. **micro1_pat.data, micro2_pat.data, micro3_pat.data, micro4_pat.data:** These files contain the microscopic (subcell) results data for each subcell in a format suitable for X-Y plotting. The format is similar to that used for the macroscopic output data, except that the data is printed out for each subcell with the subcell number as a "header". The data for all time steps is printed out for each subcell in order (i.e. the data for subcell 1 is printed out for all time steps, then the data for subcell 2 is printed out for all time steps, etc.). Further details on the file format can be found in Appendix A.

D. **micro1_pat.contour, micro2_pat.contour, micro3_pat.contour, micro4_pat.contour:** These files contain the microscopic (subcell) results data for each subcell in a format suitable for contour plots. The file format is similar to that discussed previously, except the data for all subcells is printed out for each time step in order. For example, the data for all of the subcells is printed out for the first output time step, then the data for all of the subcells is printed out for the second output time step, etc. The time value is used as a "header" for each set of subcell values. Further details on the file format can be found in Appendix A.

E. **total_pat.data:** This small file is used to record the total number of output time steps and the total number of subcells in the model. It is used as part of the results generation process in **MACPOST** to control the processing of the results data. The format for this file is found in Appendix A.

Note: The **"prefix."** heading that is added to the **"macro*_pat.data"**, **"micro*_pat.data"**, **"micro*_pat.contour"** and **"total_pat.data"** files by MAC/GMC **MUST** be removed by the user prior to using **MACPOST**. Otherwise, these file names will not be recognized by **MACPOST**. Other than this one required modification to the file names, it is very important that the output file names **NOT** be changed before being utilized by **MACPOST**. With the exception of the **"prefix.macgeo"** file that is used to generate the geometry, all of the other file names are "hard-coded" into **MACPOST**, and the code looks for these file names. If the user wishes to save the output data under different file names to allow for easier identification and distinction of results data, copies of the files with the default file names must be created and stored in the directory from which **MACPOST** is being executed before using **MACPOST**. Errors will result otherwise. Allowing for the use of the **"prefix."** heading for the other files is not possible at this time due to limitations of the PCL programming language that was used to create **MACPOST**.

Note: The shear strain components contained in all files are engineering strains as opposed to tensorial strains.

4.0 Using MACPOST

4.1 Initial Result Type Selection

Once execution of **MACPOST** is initiated as described in Section 2.1, an initial form appears as shown in Figure 2. The initial form contains three labeled buttons corresponding to the three result type options (micro X-Y plots, macro X-Y plots, contour plots) that are available for the user to select. Clicking on one of the three labeled buttons will invoke the input form for the corresponding result type. The input forms for X-Y plot generation are described in Section 4.2, and the input forms for contour plot generation are described in Section 4.3. The **"Cancel"** button on the form, if selected, causes the form to be erased from the screen and **MACPOST** program execution to terminate. **MACPOST** execution can be reinitiated by following the procedures indicated in Section 2.1. It should be noted that if **MACPOST** is reinitiated in this manner, all of the settings and results generated in the previous execution of **MACPOST** are retained.

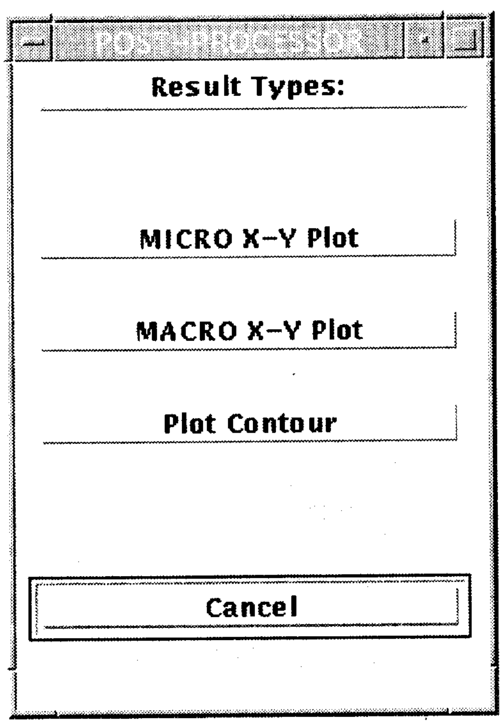

Figure 2: Result type selection form

4.2 X-Y Plot Generation

Once the user elects to generate an X-Y plot of microscopic (subcell) results, the form shown in Figure 3 is displayed. If the user elects to generate an X-Y plot of macroscopic (effective) results, the form shown in Figure 4 is displayed. Since the procedures involved in generating both types of X-Y plots are nearly identical, the two input forms will be described simultaneously. However, features that only pertain to one plot type or the other will be pointed out explicitly.

Note: There is a limit of 12 curves per plot, and that in a single MSC/PATRAN session only six (6) macroscopic X-Y plots and six (6) microscopic X-Y plots can be generated.

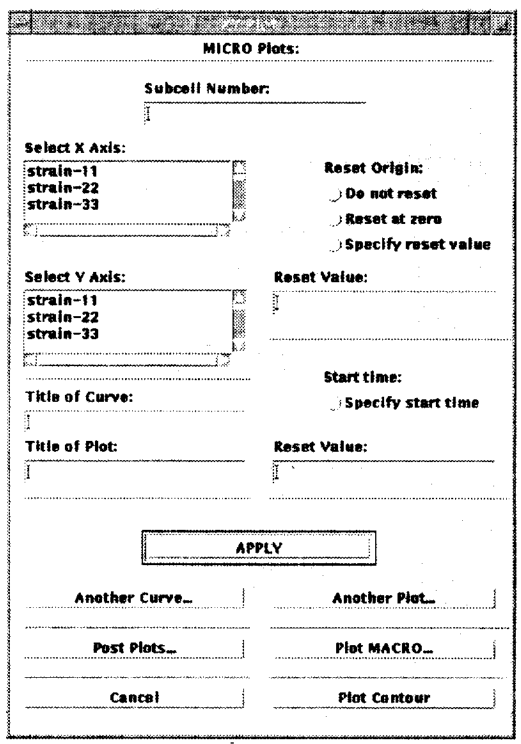

Figure 3: Micro X-Y plot generation form

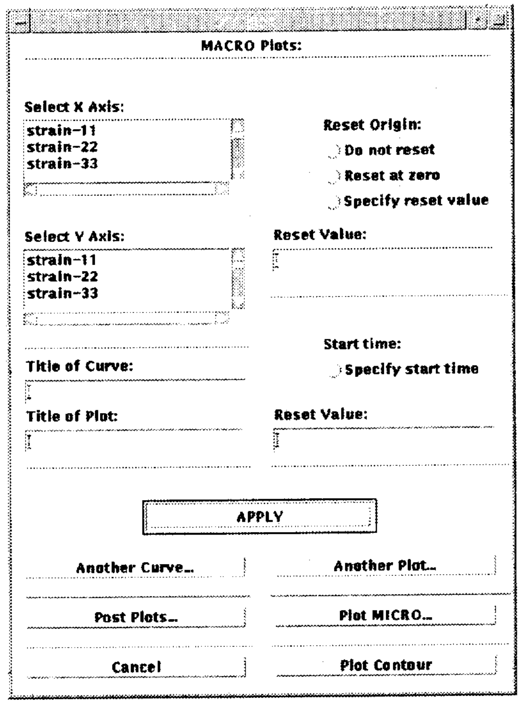

Figure 4: Macro X-Y plot generation form

4.2.1 Subcell Number (microscopic results only)

On the form to generate a micro X-Y plot, the topmost databox, **"Subcell Number"**, is where the user should indicate the number of the subcell whose results are to be displayed. The numbering scheme for the subcells corresponds to that utilized in the MAC/GMC manual [5]. If the user leaves this block blank or enters a subcell number greater than the number of subcells present in the model which was analyzed, an error form similar to that shown in Figure 5 is displayed. On this error form, the type of error that was encountered is shown in the text field. If the user wishes to correct the error and continue program execution, the **"Yes"** button should be selected and user will be returned to the original input form. If the user selects the **"No"** button on the input form, the program execution will terminate and all displayed forms will be erased.

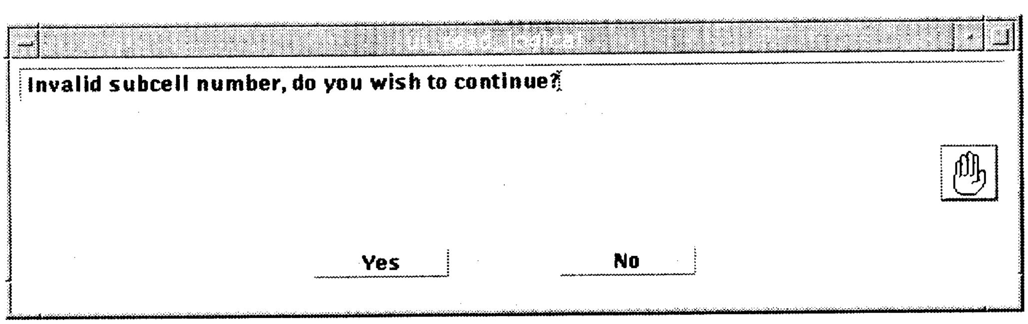

Figure 5: Generic error check notification form

4.2.2 Result Quantities

In the top left section of both X-Y plot generation forms, two listboxes are displayed which list the result quantities which can be plotted in an X-Y plot. In the box labeled **"Select X Axis"**, the result quantity which is to serve as the independent variable and plotted along the X-axis in the X-Y plot is selected. In the box labeled **"Select Y Axis"**, the result quantity which is to serve as the dependent variable and plotted along the Y-axis in the X-Y plot is selected.

The user must select one result quantity from each of the databoxes. If the user does not carry out this procedure, an error form similar to that shown in Figure 5 will be displayed, and the procedures described in Section 4.2.1 must be carried out. To select a result quantity, the scroll bar along the right side of the listboxes is used until the user locates the desired result quantity. Once the desired quantity is found, it is selected by clicking on the name, which results in a darkened surrounding area indicating that the particular quantity has been selected.

The result quantities used to generate the first curve of a plot are also used as the corresponding axis titles. The axis titles are not changed if additional curves are added to the plot, even if the result quantities that are plotted are changed. If the user desires to create a plot with new axis titles, a new plot must be created.

A list of the 26 result quantities, in the order that they appear in the listboxes, are presented below:

1. strain-11
2. strain-22
3. strain-33
4. strain-23
5. strain-13
6. strain-12
7. stress-11
8. stress-22
9. strain-33
10. stress-23
11. stress-13
12. stress-12
13. IN.strain-11
14. IN.strain-22
15. IN.strain-33
16. IN.strain-23
17. IN.strain-13
18. IN.strain-12
19. TH.strain-11
20. TH-strain-22
21. TH.strain-33
22. total time
23. creep time
24. temperature
25. stress-I1
26. stress-J2

Note: IN.strain refers to inelastic strain, TH.strain refers to thermal strain.

4.2.3 Title of Curve

In this databox, which is present in both plot types, the user may enter a title that will be used to label the generated curve in the plot legend. Any title is permitted, and curve titles can be duplicated between plots. If the user does not enter a curve title, a default title is assigned using the following format:

For macro X-Y plots: MACRO curve#

For micro X-Y plots: MICRO curve#

where # corresponds to the number of curves which have been generated for each X-Y plot type, starting with 1. The numbering is kept separately for each plot type. However, due to MSC/PATRAN requirements, the numbering is not reset when a new plot is created. The curve numbering is continually increased throughout **MACPOST** execution. For example, if a macro X-Y plot was created with two curves, the "default" titles of the curves if no explicit curve title was entered would be "MACRO curve1" and "MACRO curve 2". If a new macro X-Y plot were then created with one curve, its "default" title would be "MACRO curve3" NOT "MACRO curve1". If a micro X-Y plot with 2 curves were then created, their "default" curve titles would be "MICRO curve1" and "MICRO curve2".

4.2.4 Title of Plot

In this databox, which is present in both plot types, the user is to enter a title, which will be used as the title for the generated plot. Any title is permitted, and plot titles can be duplicated between plots. If the user does not enter a plot title, a default title is assigned using the following format:

For macro X-Y plots: MACRO XY Plots -#

For micro X-Y plots: MICRO XY Plots -#

where # corresponds to the number of plots which have been generated for each X-Y plot type, starting with 1. It is important to note that even if the user enters a plot title, every plot is given a "plot name" which follows the format of the default plot title. The plot name is displayed in the title bar of the window in which the plot is displayed. Furthermore, the plot name is used to identify a particular plot when the user is working with the form for displaying previously completed plots (See Section 4.3).

4.2.5 Reset Origin

In conducting a MAC/GMC analysis, often the manner in which the analysis is conducted does not facilitate an easy comparison between the computed results and either experimental or other analytical results. For example, as discussed in Section 2.2.1, if a stress-strain curve for a material with residual stresses is generated, the output strain levels would be compressive at the point where the mechanical loading begins. However, the experimentally obtained results would show zero strains at the point of mechanical load application. In order to adjust the generated plots to eliminate this difficulty, the following options are available to modify the generated curves for both plot types. These options act only on the curve that is currently being generated, and can be varied for different curves within a given plot. Note that these options only affect how the X-axis values (independent variables) are displayed. There is no method included for adjusting how the Y-axis values (dependent variables) are displayed.

The three options that are available under the "**Reset Origin**" option are "**Do not reset**", "**Reset at zero**", and "**Specify reset value**". The user must select one of these options by clicking the button next to the option, which results in a blackened center being displayed. If no option is selected, an error form like that shown in Figure 5 is displayed, and the procedures described in Section 4.2.1 must be carried out. Detailed descriptions of the three options are as follows:

Do not reset: If this option is selected, no modifications will be made to the X-axis coordinate values of the generated curve, and the values will be displayed in the plot exactly as they were computed by MAC/GMC.

Reset at zero: If this option is selected, the X-axis coordinate values computed by MAC/GMC will be modified such that the first X-coordinate is set to zero, and every proceeding X value is adjusted by the same amount as the first X value. This process shifts the entire generated curve such that it begins at zero.

Specify reset value: If this option is selected, the X-axis coordinate values of the generated curve are shifted by an amount specified by the user in the databox labeled "**Reset Value**". A positive value entered in the databox shifts the curve to the right along the X-axis, while a negative value shifts the curve to the left along the X-axis. If the user does not enter any value in the databox or enters a value of zero (0), an error form like that shown in Figure 5 is displayed, and the procedures described in Section 4.2.1 must be carried out. This option is similar to the "**Reset at zero**" option, except instead of starting the curve at X=0, the location of the start of the curve is specified by the user in terms of how much the original X-axis coordinate values are to be shifted.

4.2.6 Start Time

As a companion to the "**Reset Origin**" option discussed in Section 4.2.5, **MACPOST** offers an option that allows the user to specify the time step in the analysis at which the plotting of results will begin. This option is useful in situations such as that described in Section 4.2.5, where residual stresses are applied to a material through a temperature cool-down before mechanical loads are applied. If the user only wishes to see the results from the point at which the mechanical loads are applied, the time in the "**Start Time**" option can be set appropriately and the "**Reset at zero**" option can be selected to adjust the X-axis value at the start time to zero. An important point to note is that the "**Start Time**" entry is completely optional, and need not be activated by the user. Also, this entry only acts on the curve that is currently being generated, and can be varied for different curves in a plot.

To activate the "**Start Time**" option, the button next to the option must be selected, which results in a blackened center being displayed. If the option is selected, the user must then enter a time greater than zero, and less than the maximum time in the analysis, in the databox labeled "**Reset Value**" located underneath the option. If the option is not selected, the databox can be left blank. However, if the option is selected and the databox is left blank, an error form like that shown in Figure 5 is displayed, and the procedures described in Section 4.2.1 must be carried out. If the user enters a time that is not an exact match to one of the times saved in the results data, the closest time step will be selected as the match. For example, if the user enters a start time of 2005, and the nearest time steps present in the results data are 2000 and 2015, a time step of 2000 will be utilized in the plot generation.

If the user enters a time greater than the maximum time in the analysis (i.e. the user indicates that the plot should start at a point after the MAC/GMC analysis has concluded), an error form like that shown in Figure 6 is displayed. In this form, the nature of the error will be displayed. If the user wishes to reenter the data for the curve and continue program execution, the "**Re-enter Data**" button should be selected. In this case, the user will be returned to the original input form and the data for the curve can be reentered. If the user selects the "**Cancel**" button, on the other hand, the program execution will terminate and all displayed forms will be erased.

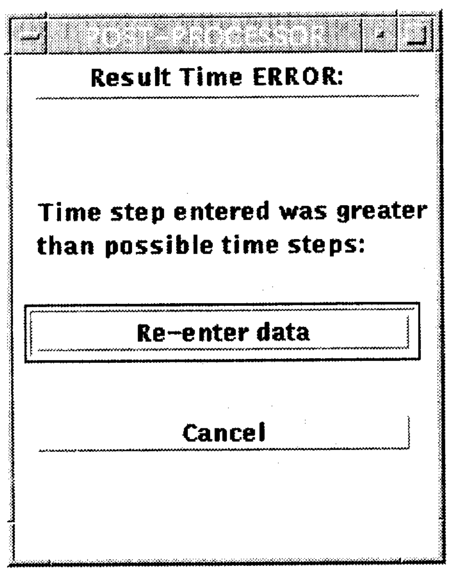

Figure 6: Value out of range error check notification form

4.2.7 Apply Button

Once the user has entered all of the required data described in Sections 4.2.1 - 4.2.6, the user then must select the "**Apply**" button to generate the desired curve. If the curve being generated is the first curve of a new X-Y plot, the X-Y plot will also be created. Note that the information such as axis titles, plot titles, etc. **cannot** be edited once a plot is generated. When a curve is generated, a text file is also generated in the directory from which MSC/PATRAN is executed. The text file lists the X and Y coordinates of each point in the curve in a two column format such that the data can be imported into an alternative spreadsheet or graphing program. The output file is given a name with the following format:

Output_XY.xyd.##

where:
= the sequential number assigned to the file, starting at 01, and progressing sequentially as 02, 03, 04, etc. The numbering is global throughout the entire program execution, and is not changed when the plot type (macro or micro) is changed. These file names are also "hard coded", and cannot be modified during **MACPOST** execution. In addition, the user must keep track of which curve corresponds to which file, as no identification is provided in the output file.

Example:

Output_XY.xyd.01 = The first curve created during **MACPOST** execution.
Output_XY.xyd.07 = The seventh curve created during **MACPOST** execution.

These files can be used by an external plotting package to generate more sophisticated X-Y plots of the data. Each file contains data for one curve from a plot. These files will reflect all of the data manipulation resulting from the use of the "**Reset Origin**", "**Reset at zero**" and "**Start Time**" options.

4.2.8 Cancel Button

The "**Cancel**" button is utilized to terminate **MACPOST** execution. When this button is selected, all of the currently displayed forms and plots will be erased from the screen. However, the user can reinitiate **MACPOST** execution at any time during the MSC/PATRAN session by once again selecting the "**RVE Post Processor**" option from the "**MAC**" option on the main MSC/PATRAN menu bar.

4.2.9 Another Curve

Selecting this button allows the user to generate another curve for the current plot. Note that if macro plots are currently being generated, the new curve must also be a plot of macro quantities. The same is true if micro plots are currently being generated. Note that currently each plot can contain a maximum of 12 curves. If the user tries to create more than twelve curves for a particular plot, an error form with a warning message will be displayed. Once this button is selected, the X-Y plot generation form of the appropriate plot type will be redisplayed, and the user can reenter the appropriate entries. As mentioned before, if a new curve is being added to a previously created plot the axis labels and the plot title cannot be changed.

Note: New curves can only be added to an X-Y plot while the current plot is being generated. Once the user leaves the current plot to generate a new plot or view previously created plots, the current plot can no longer be modified.

4.2.10 Another Plot

Selecting this button allows the user to generate another plot of the current plot type (macro or micro). Note that currently a maximum of 6 plots of each type (macro or micro) can be generated within a single MSC/PATRAN session. If a user attempts to generate more than 6 plots of a particular type, an error form with a warning message will be displayed. An important point to note is that after the first plot of a particular type is generated, whenever the user wishes to generate another plot of the same type, the user must select the "**Another Plot**" button before plot generation commences. This requirement is present even if the user returns to the appropriate plot generation form (macro or micro) after utilizing other forms, and the plot generation form appears blank. Before generating the new plot the user **MUST** select the "**Another Plot**" button.

4.2.11 Plot MACRO / Plot MICRO

Selecting this button allows the user to generate X-Y plots of the other plot type than that currently being generated. For example, if the user is currently generating macro X-Y plots, the button will be labeled "**Plot MICRO**", and selecting this button will allow the user to generate micro X-Y plots. The opposite is true if micro X-Y plots are currently being generated. Note that, as described in Section 4.2.10, once the new X-Y plot generation form is displayed, if a plot of the newly chosen X-Y plot type has been generated at any time during the current MSC/PATRAN session, the "**Another Plot**" button must be selected before plot generation is carried out.

4.2.12 Post Plots

Selecting this button allows the user to proceed to the forms that allow viewing and displaying of previously created plots. Note that if the user is currently generating macro X-Y plots, the form will be displayed which allows the user to view previously generated macro plots. The converse is true if micro X-Y plots are currently being generated. These forms are described in full detail in Section 4.3. Note that this button cannot be selected in the middle of creating a plot, or the plot data will be lost. Also, note that no additional curves can be added to the current plot once this button is selected. Furthermore, once this button is selected, the currently displayed plot is erased and can only be redisplayed using the forms described in Section 4.3. The currently displayed form is also erased.

4.2.13 Plot Contour

Selecting this button allows the user to proceed to the forms for generating and displaying contour plots over the geometry of the unit cell model. The details of this procedure are given in Section 4.4. Note that the currently displayed plots and forms will be erased once this button is selected. Also, no further curves can be added to the current plot once this button has been selected.

4.3 Display Previously Created X-Y Plots

MACPOST allows users to view previously created macroscopic and microscopic X-Y plots. The form for displaying previously created macroscopic plots is shown in Figure 7, and the form for displaying previously created microscopic plots is shown in Figure 8. Only plots of the specified type (macro or micro) can be displayed from a particular form. To display plots of the other plot type, the user must switch to the alternate form. Which form is displayed depends on which type of plot the user was generating before switching to the display forms. For example, if the user was creating macroscopic plots and selected the "**Post Plots**" button, the form to display previously created macro plots would be displayed. Note also that only one plot can be displayed at a time. When a new plot is displayed, the previously displayed plot will be erased. The format of the two forms is nearly identical, so they will be described simultaneously.

For each plot type (macro or micro), the previously created plots of that type are listed in the list box entitled "**Generated Plots**". Note that the plot names listed in the list box are **NOT** the user specified plot titles entered as described in Section 4.2.4. Instead, the "plot names", which follow the format of the default plot titles as described in Section 4.2.4 are utilized. These plot names are listed in the title bar of the window as the plot is originally generated and displayed. Consequently, it is important that the user note these plot names as they are generated so that the appropriate plot can be selected from the display list box.

To select a particular plot to be retrieved, the user must select the desired plot from the list box (resulting in a black box surrounding the selected plot name) and then select the "**Apply**" button to display the plot. When the "**Apply**" button is selected, the previously displayed plot (if any) will be erased and the selected plot will be displayed. This process can be repeated as many times as desired in the currently displayed form to display as many plots as desired.

There are several other options that are available on the display forms that will be described below.

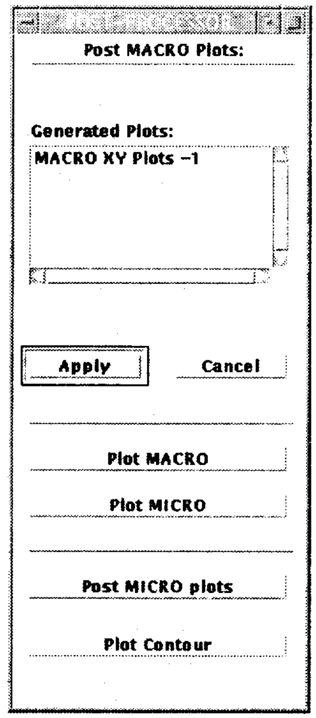

Figure 7: Display macro X-Y plot form

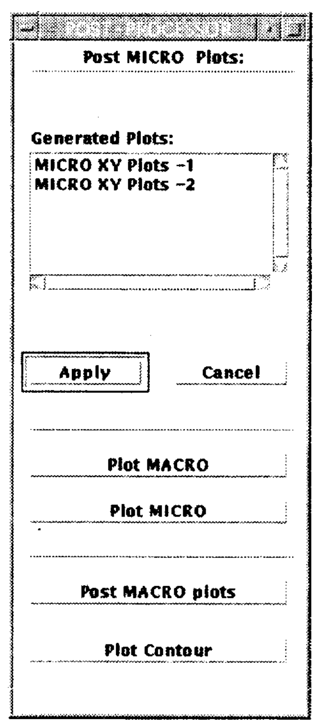

Figure 8: Display micro X-Y plot form

4.3.1 Apply Button

As described in the previous section, selecting the "**Apply**" button causes the selected plot to be displayed, and any previously displayed plots to be erased.

4.3.2 Cancel Button

The "**Cancel**" button is utilized to terminate **MACPOST** execution. Selection of this button will cause all forms and currently displayed plots to be erased from the screen. However, the user can reinitiate **MACPOST** execution at any time during the MSC/PATRAN session by once again selecting the "**RVE Post Processor**" option from the "**MAC**" option in the main MSC/PATRAN menu bar.

4.3.3 Plot MACRO

Selecting this button will display the form, described in Section 4.2, utilized for generating macro X-Y plots. All previously displayed plots and forms will be erased at this point. As a reminder, at this point, if any macro plots have been generated during the MSC/PATRAN session, the user must select the "**Another Plot**" button on the plot generation form before any further data is entered or plots generated. The "**Plot MACRO**" button is available on both macro and micro plot display forms.

4.3.4 Plot MICRO

Selecting this button will display the form, described in Section 4.2, utilized for generating micro X-Y plots. All previously displayed plots and forms will be erased at this point. As a reminder, at this point, if any micro plots have been generated during the MSC/PATRAN session, the user must select the "**Another Plot**" button on the plot generation form before any further data is entered or plots generated. The "**Plot MICRO**" button is available on both macro and micro plot display forms.

4.3.5 Post MACRO plots / Post MICRO plots

The format of this button will depend on whether macro or micro X-Y plots are currently being displayed (see Figures 7 and 8). If macro X-Y plots are currently being displayed, the format of the button will be "**Post MICRO plots**", and selecting this button will erase the currently displayed plots and forms, and display the form which allows the user to display previously created micro X-Y plots. If micro plots are currently being displayed, the format of the button will be "**Post MACRO plots**", and selecting this button will display the form which allows the user to display previously created macro X-Y plots.

4.3.6 Plot Contour

Selecting this button allows the user to proceed to the forms for generating and displaying contour plots over the geometry of the unit cell model. The details of this procedure are given in Section 4.4. Note that the currently displayed plots and forms will be erased once this button is selected.

4.4 Contour Plots

The generation of contour plots allows the user to view the variation of a single quantity, such as a particular stress component, over the geometry of the repeating unit cell at a particular point in time. Contour plot generation can be initiated either by selecting the "**Plot Contour**" option in the result type selection form described in Section 4.1, or by selecting the "**Plot Contour**" option in any of the X-Y plot generation or display forms. As mentioned in Section 2.2.2, the generation of contour plots is a two step process. First, the model geometry of the unit cell must be imported into the MSC/PATRAN database. Second, the user must specify the particular result to be displayed and the particular time step of the analysis from which the results are to be displayed. These two steps are described in detail in the following sections.

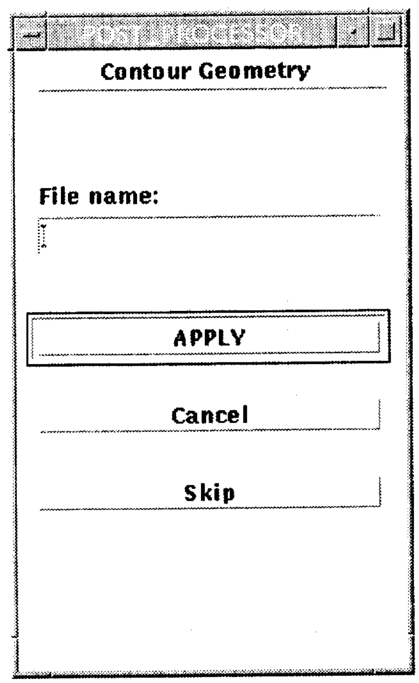

Figure 9: Model geometry import form

4.4.1 Import Model Geometry

The first step in generating a contour plot is importing the model geometry of the repeating unit cell into the MSC/PATRAN database. The "Contour Geometry" form for initiating this process is shown in Figure 9. The model geometry data for an analysis resides in a file generated during the MAC/GMC execution with a format and name as described in Sections 3.1 and 3.2 and Appendix A. To import this data into MSC/PATRAN, the user must enter the appropriate file name in the databox labeled "**File Name**". If the user neglects to enter a file name or inputs the name of a file that does not exist, an error form similar to that shown in Figure 5 is displayed, and the procedures described in Section 4.2.1 must be carried out. However, note that no checks are made to ensure that the geometry file, which is imported, is the file that is linked to the current set of results data. Also, note that the file name input is case sensitive, so the file name should be entered exactly as it appears in the user's directory and only one geometry file should be import during a single MSC/PATRAN session.

4.4.1.1 Apply Button

Once the user enters the required file name, selecting the "**Apply**" button causes the geometry to be imported and displayed and the results display input form described in Section 4.4.2 to be displayed. As mentioned in Sections 2.2.2 and 3.2, the model geometry is represented in the MSC/PATRAN database through the creation of finite element nodes and elements. Four noded elements are used for two-dimensional GMC, and eight noded elements are used for GMC-3D. Each element represents a MAC/GMC subcell, and the element numbering corresponds to the subcell numbering described in the MAC/GMC manual [5]. The nodes are used in constructing the elements that represent each subcell. The model geometry is generated in this fashion to facilitate the display of the contour plot results data.

4.4.1.2 Cancel Button

The "**Cancel**" button is utilized to terminate **MACPOST** execution. Selection of this button will cause the displayed form to be erased from the screen. However, the user can reinitiate **MACPOST** execution at any time during the MSC/PATRAN session by once again selecting "**RVE Post Processor**" from the "**MAC**" icon on the main MSC/PATRAN menu bar.

4.4.1.3 Skip Button

Once a model geometry file has been imported into the MSC/PATRAN database, this process need not be repeated during the MSC/PATRAN session. However, if the user returns to contour plot generation after generating an initial set of contour plot results and then conducting other tasks, the form is still displayed upon returning to the contour plot generation process. By selecting the "**Skip**" button, the user is immediately passed to the contour plot results display form discussed in Section 4.4.2 without any further action being taken on the model geometry. However, if the model geometry has not been imported into MSC/PATRAN, the geometry import process cannot be skipped. Furthermore, **MACPOST** does not check to ensure that model geometry is present in the database if this option is selected.

4.4.2 Display Results

With the model geometry correctly imported into the MSC/PATRAN database, the desired contour plot results can now be displayed over the geometry. The form which is displayed in Figure 10 is utilized to select both the result type which is to be displayed, and to select the time step in the analysis at which the results are to be displayed. The analysis time step can either be entered directly (as described in Section 4.4.2.1) or indirectly by the user choosing to have the results displayed at the point at which a specific macroscopic (effective) quantity occurs. For example, the user can elect to display the contour plot results at the time when the macroscopic stress in the 33-direction is equal to 200 units. This process will be described in more detail in Section 4.4.3.

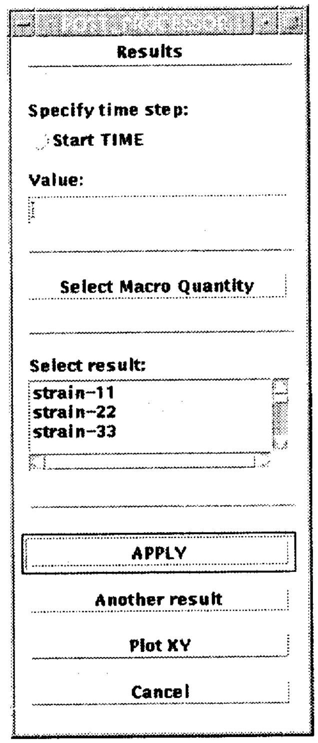

Figure 10: Contour plot generation form

4.4.2.1 Specify Time Step

If the user wishes to enter the time from the analysis at which the contour plot results are to be displayed directly, the user must select the button next to the label **"Start TIME"**, which results in a blackened center being displayed in the button. The user must then enter the time step at which the results are to be displayed in the databox labeled **"Value:"** located immediately below the **"Start TIME"** button. If the user neglects to enter a value, a time of "0" will normally be assumed. However, the user should not leave the databox blank in order to avoid difficulties in program execution.

If the user enters a time that is not an exact match to one of the times saved in the results data, the closest time step will be selected as the match. For example, if the user enters a time of 2005, and the nearest time steps present in the results data are 2000 and 2015, a time step of 2000 will be utilized in the generation of the contour plot. If the user enters a time greater than the maximum time in the analysis, an error form like that shown in Figure 6 is displayed. In this form, the nature of the error will be displayed. If the user wishes to reenter the data for the curve and continue program execution, the "**Re-enter Data**" button should be selected. In this case, the user will be returned to the contour plot generation form and the data for the plot can be reentered. If the user selects the "**Cancel**" button, on the other hand, the program execution will terminate and all displayed forms will be erased.

The user must either select this option or the option described in Sections 4.4.2.2 and 4.4.3. If the user does not select one of these two options, the program will not execute properly. However, there are currently no error checks in place to ensure that one of these options is selected.

4.4.2.2 Select Macro Quantity

If the user desires to specify the time at which the results are to be displayed as the time at which a specific macroscopic (effective) quantity, such as a particular stress component, attains a certain value, this button should be selected. At this point, the form described in Section 4.4.3 will be displayed, and the procedures specified in that section should be carried out. An important point to note is that if the time step was entered directly using the procedure specified in Section 4.4.2.1, the "**Select Macro Quantity**" button should not be selected. In most cases, if the time is entered directly, all entries made in the form described in Section 4.4.3 will be ignored, but there are currently no checks in the program to prohibit the user from selecting the "**Select Macro Quantity**" button if the time has also been entered directly. Therefore, the procedures described in this section (and revisited in Section 4.4.3) and the procedures described in Section 4.4.2.1 should be considered to be mutually exclusive.

The user must select either this option or the option described in Section 4.4.2.1. If the user does not select one of these two options, the program will not execute properly. However, there are currently no error checks in place to ensure that one of these options is selected.

4.4.2.3 Select Result

The user must select the specific result quantity that is to be displayed over the model geometry at the selected time step. To select a result quantity, the displayed list is scrolled using the scroll bar located on the right hand side of the listbox until the desired result quantity is located (see Figure 10). The desired quantity is selected by clicking on the name, which results in the area around the selected name being darkened, indicating that it has been selected. The user must select one result quantity from the listbox. If the user does not select a quantity, an error form similar to that shown in Figure 5 will be displayed, and the procedures described in Section 4.2.1 must be carried out. The result quantities which are available, and the order in which they are displayed, are shown in Section 4.2.2, with the exception of item 22 in that list, the total time, which is not available here. It should be noted that for 2-D GMC the "1" direction in MAC/GMC corresponds to the "Z" direction in the MSC/PATRAN display, the "2" direction in

MAC/GMC corresponds to the "Y" direction in the display, and the "3" direction in MAC/GMC corresponds to the "X" direction in the display. For GMC 3-D, the "1" direction in MAC/GMC corresponds to the "Y" direction in the display, the "2" direction in MAC/GMC corresponds to the "X" direction in the display, and the "3" direction in MAC/GMC corresponds to the "Z" direction in the display. This flipping and rotation of the coordinate axes has no effect on the results, it only affects how the unit cell geometry is displayed.

4.4.2.4 Apply Button

When the user has entered all of the required information described in Sections 4.4.2.1 - 4.4.2.3, the "**Apply**" button is to be selected. At this point, the requested contour plot will be generated over the model geometry, displaying the variation of the selected result quantity at the given time. A legend will be displayed on the right hand side of the screen, indicating the correlation between the displayed colors and their numerical equivalents. An important point to note is that since the results are assumed to be constant over the subcell (due to the GMC theory embedded in MAC/GMC), each subcell is displayed with one color, indicating the average value of the result quantity over the subcell. In addition, the correlation between the coordinate directions utilized in MAC/GMC and the coordinate directions utilized in MSC/PATRAN is that discussed in Section 4.4.2.3.

4.4.2.5 Another Result

If the user wishes to generate a new contour plot, the "**Another Result**" button should be selected. Selecting this button will clear all of the settings in the result generation form, and the user can enter the data required to create the new contour plot. The user should select this button whenever a new contour plot is to be created if a contour plot has been created previously at any time in the MSC/PATRAN session. The most recent contour plot which has been created remains displayed on the screen until the "**Apply**" button is once again selected, indicating that a new contour plot is to be created.

4.4.2.6 Plot XY

Once a contour plot has been generated, if the user wishes to generate new X-Y plots or display previously created X-Y plots, the "**Plot XY**" button should be selected. Selecting this button will erase the contour plot result generation form from the screen, and display the form described in Section 4.1. At this point, X-Y plots can be generated using the procedures described in Sections 4.1 and 4.2. To display previously created X-Y plots, the required forms must be accessed though the X-Y plot generation forms using the "**Post Plots**" procedures described in Section 4.2.12.

4.4.2.7 Cancel Button

The "**Cancel**" button is utilized to terminate **MACPOST** execution. Selection of this button will cause all currently displayed forms to be erased from the screen. However, the most recently generated contour plot will still be displayed. The user can reinitiate **MACPOST** execution at any time during the MSC/PATRAN session by once again selecting the "**RVE Post Processor**" option from the "**MAC**" option in the main MSC/PATRAN menu bar.

4.4.3 Select Time Step Based on Macroscopic Quantity

If the user chooses to select the time step at which contour plot results are to be displayed based on the value of a macroscopic quantity, the form shown in Figure 11 is displayed. As discussed in Section 4.4.2.2, selecting the "Select Macro Quantity" button in the Display Results form described in Section 4.4.2 accesses this form. The user first selects which macroscopic quantity is to be used for selecting the time step, the value of the macroscopic quantity which is to be searched for, and the time step in the MAC/GMC analysis at which the search is to begin. The user will then be given the five closest matches to the given search parameters. From these choices, the user selects the desired value/time pair, and the selected time step is then passed back to the Display Results form for use in generating the desired contour plots. Details of this procedure are given in the following sections.

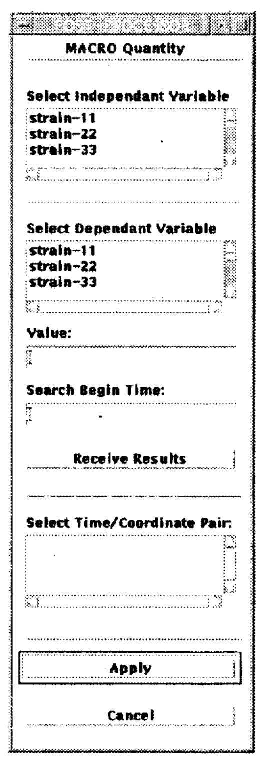

Figure 11: Form for selecting contour plot time step based on macroscopic quantity

4.4.3.1 Select Independent Variable/ Select Dependent Variable

The two listboxes shown in Figure 11 are utilized to select the macroscopic result quantity that is to be used in the time step search. The "independent" variable is the quantity that is actually used in the search. The "dependent" variable is present only to provide clarity in the displayed choices. For example, suppose a user selected a point of interest in a macroscopic stress-33 vs. strain-33 X-Y plot at which he/she desired to view a detailed contour plot, say the point where the macroscopic stress equals 200 units. Since the stress level is the value of interest, stress-33 would be selected as the "independent" variable. The user must also select a "dependent" variable, which in this case would be strain-33. **MACPOST** will display stress-33 – strain-33 point pairs to facilitate selection of the desired point for contour plot generation (see Section 4.4.3.5).

To select the desired quantities, one value must be selected from each of the listboxes. Each displayed list is scrolled using the scroll bar that is located on the right hand side of the listbox until the desired quantity is located. The desired quantity is selected by clicking on the name, which results in the area around the name being darkened, indicating that it has been selected. If the user does not select one quantity from each of the listboxes, an error form similar to that shown in Figure 5 is displayed, and the procedures described in Section 4.2.1 must be carried out. The quantities which are available in the listboxes, and the order in which they are displayed, are shown in Section 4.2.2, with the exception that item 22 in that list, the total time, is not available as an independent variable.

4.4.3.2 Select Macroscopic Value

The user should enter the value of the macroscopic quantity of interest (indicated as the "independent" variable), which is to be searched for, in the databox labeled "**Value:**". In the example described in the previous section, a value of 200 would be entered, since the point where the stress-33 equals 200 units is desired. If a value is not entered, a value of "0" is assumed. However, even if the value of interest is "0", it is recommended that the value be explicitly entered. Note that if the user enters a value that is not explicitly present in the MAC/GMC results data, the closest match will be located. If the entered value is greater than the range of values which is present in the results data, an error form similar to that shown in Figure 6 will be displayed, and the procedures described in Section 4.4.2.1 should be carried out. As a result, if the value of interest is the maximum likely to be found in the results data, the user is recommended to slightly underestimate this value, in order to ensure that a match with the results data is made. Also, note that the value which is entered is to be the exact value as present in the results data, without any "offsets" or "shifts" applied (see Section 4.2.5 for a discussion of "offsets" and "shifts" used in the generation of X-Y plots).

4.4.3.3 Search Begin Time

In this databox, the user should enter the time step of the MAC/GMC analysis at which the search for the macroscopic quantity value is to begin. This databox is useful in order to limit the range for the search. For example, if the desired macroscopic quantity occurs at more than one point in the analysis, by properly utilizing this option the correct value can be found, since the searching algorithm only locates the first occurrence of the selected value. If a value is not entered in this databox, a value of "0" is assumed. However, by entering a nonzero value, the chances of locating an undesired occurrence of the selected macroscopic quantity are significantly reduced.

Note that if the user enters a time that is not an exact match to one of the times saved in the results data, the closest time step will be selected as the match. However, if the user enters a time value which is greater than the maximum time present in the results, an error form similar to that shown in Figure 6 will be displayed, and the procedures described in Section 4.4.2.1 must be carried out.

4.4.3.4 Receive Results

Once the required data is entered, selecting the "**Receive Results**" button will cause the search for the entered macroscopic quantity value to be executed. The search will locate the time step with the closest match to the entered value, along with the two time steps preceding the closest match, and the two time steps following the closest match. The results of the search are displayed in the "**Select Time/Coordinate Pair**" listbox, which is described in greater detail in Section 4.4.3.5. Several time steps are selected in order to allow the user some flexibility in deciding which time step is actually desired.

4.4.3.5 Select Time/Coordinate Pair

The results of the search for the desired macroscopic quantity value are displayed in this listbox. The listbox has five entries in it. The time step with the closest match to the entered value is the third entry in the listbox. The two time steps preceding the closest match are listed in the first two entries in the listbox. The two time steps following the closest match are listed in the fourth and fifth entries in the listbox. In each entry in the listbox, the value of the independent variable, the value of the dependent variable, and the time step value are displayed in the following format:

Independent Variable
Dependent Variable
Time Step

There is a blank line between each of the five entries in the listbox. Listing all three values for each time step should assist the user in identifying exactly which time step should be selected. For example, using the example discussed in the previous sections, suppose stress-33 was selected as the independent variable,(with a value of 200) and strain-33 was selected as the dependent variable. Suppose when the stress in the 33 direction equaled 200 units, the strain in the 33 direction equals 0.025, and the results occurred at a time step of 5000 seconds in the analysis. The entry for this value would be displayed as follows:

2.00000E+02
2.50000E-02
5.00000E+03

It should be noted that the displayed values are the actual values as recorded in the MAC/GMC results file, with no "offsets" applied (see Section 4.2.5 for a discussion on offsets). To view all of the entries in the listbox, the scroll bar located on the right hand side of the listbox can be utilized.

To indicate the desired time step for the generation of the contour plot, one of the three lines in the entry with the desired time step should be selected. Either the independent variable value, the dependent variable value, or the time step can be selected to record the desired time step. The desired quantity is selected by clicking on the number, which results in the area around the value being darkened, indicating that it has been selected. One value must be selected from the listbox in order for the program to execute properly. If the user does not select a listbox value, an error form similar to that shown in Figure 5 will be displayed, and the procedures described in Section 4.2.1 must be carried out.

4.4.3.6 Apply Button

To pass the selected time step back to the "Display Results" form to be used in the generation of the contour plot, the "**Apply**" button is selected, and the user is returned to the "Display Results" form. The "MACRO Quantity" form will be erased from the screen at this point. At this point, the user only needs to select the result quantity of interest and select the "**Apply**" button in the "Display Results" form (see Sections 4.4.2.3 and 4.4.2.4) to generate the contour plot.

4.4.3.7 Cancel Button

Selecting the "**Cancel**" button causes the "MACRO Quantity" form to be erased from the screen. However, the "Display Results" form is not erased from the screen, so the user can enter the time step directly using the "**Specify time step**" option discussed in Section 4.4.2.1 and still generate a contour plot.

5.0 Tutorial

The following example describes the procedures involved in displaying MAC/GMC analysis results for a specific case. The procedures to be followed, the forms utilized, and the expected output will all be described. It is suggested that a new user of **MACPOST** execute the sample problem to become more familiar with the procedures. The sample problem that will be considered involves analyzing the results from a MAC/GMC analysis of a metal matrix composite composed of silicon carbide fibers in a titanium alloy matrix. A copy of the sample MAC/GMC input file that was used to generate the results used in this example is shown in Appendix B. The composite is first subjected to a thermal cool-down to impose residual stresses (simulating processing), followed by a monotonically increasing tensile load transverse to the fiber direction. The unit cell which is used for the analysis is a 26 subcell by 26 subcell two-dimensional model (676 total subcells) which simulates a circular fiber (IDP=13 in the MAC/GMC manual). For the example, the MAC/GMC analysis has been assumed to be successfully executed, and the results files required for **MACPOST** are assumed to be located in the directory from which MSC/PATRAN will be executed.

The first step in executing **MACPOST** is to initiate MSC/PATRAN execution using the procedures required for the individual user's computer system, typically setup and execution. Next, the procedures described in Section 2.1 are followed in order to create a new MSC/PATRAN database and to initialize **MACPOST** execution. Note that in most cases, only the session file "**macpost2.ses**" described in Section 2.1 needs to be executed in order to initialize **MACPOST**.

After **MACPOST** is initialized, the user should select "**RVE Post Processor**" from the "**MAC**" option in the main menu bar (see Figure 1). At this point, the initial result type selection form described in Section 4.1 and shown in Figure 2 will be displayed. For this example, the first result type which will be generated is a macroscopic X-Y plot. To begin the plot generation, the "MACRO X-Y Plot" button should be selected in the result type selection form.

The "MACRO Plots" form will now be displayed on the screen. The procedures required to complete this form are as described in Section 4.2. For this example, a plot of the 33-stress component vs. the 33-strain component will be generated. A picture of the completed form for this problem is shown in Figure 12. As shown in the figure, "strain-33" is selected in the "**Select X Axis**" databox, and "stress-33" is selected in the "**Select Y Axis**" databox. The curve which is to be generated is given a title "T=23 C" in the "**Title of Curve**" databox, and the plot is given a title "Macro Transverse Tensile Response" in the "**Title of Plot**" databox. For this problem, only the results that are computed after the thermal cool-down, during the application of the mechanical load, are plotted. Furthermore, in order to facilitate comparison to experimental results, the plotted strains are adjusted such that the strain starts at zero (0) in the generated plot. To adjust the plotted strains, the "**Reset at zero**" option is selected from the "**Reset Origin**" portion of the input form. To specify that only the results that occur during the mechanical load are to be plotted, the "**Specify start time**" option in the "**Start time**" section of the form is selected, and a time of 57600 seconds is entered in the "**Reset Value**" databox. As can be seen from the sample input file (see Appendix B), 57600 seconds is the point in the analysis where the thermal cool-down concludes and the mechanical tensile load is initiated. Therefore, only the results that occur after a time step of 57600 seconds in the analysis will be plotted. At this point, the "**Apply**" button is selected to initiate generation of the desired plot.

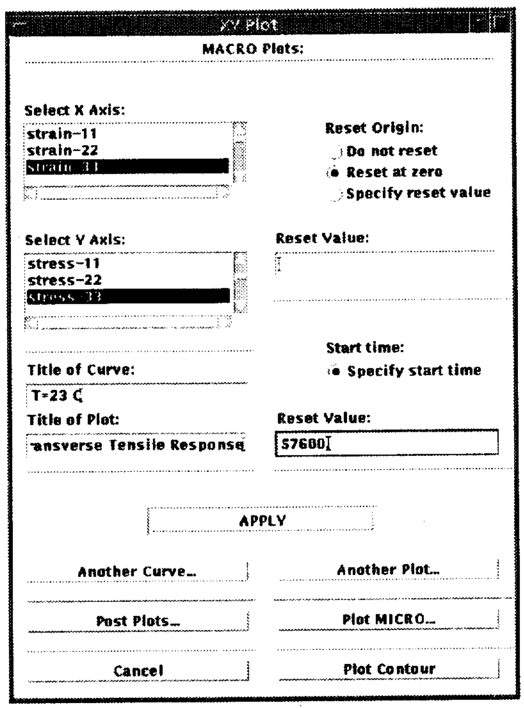

Figure 12: Macro X-Y plot generation form for sample problem

The plot that is generated by **MACPOST** is shown in Figure 13. As can be seen from the figure, the Y-Axis is labeled "Stress-33", and the X-Axis of the plot is labeled "Strain-33". These are the values that were indicated in the appropriate listboxes of the input form. The curve title that was entered is used in the plot legend to identify the curve. The plot title that was entered is used to give a title to the plot. Also, the plotted strains do indeed start at zero (0), and only the results computed during the application of the mechanical load are plotted.

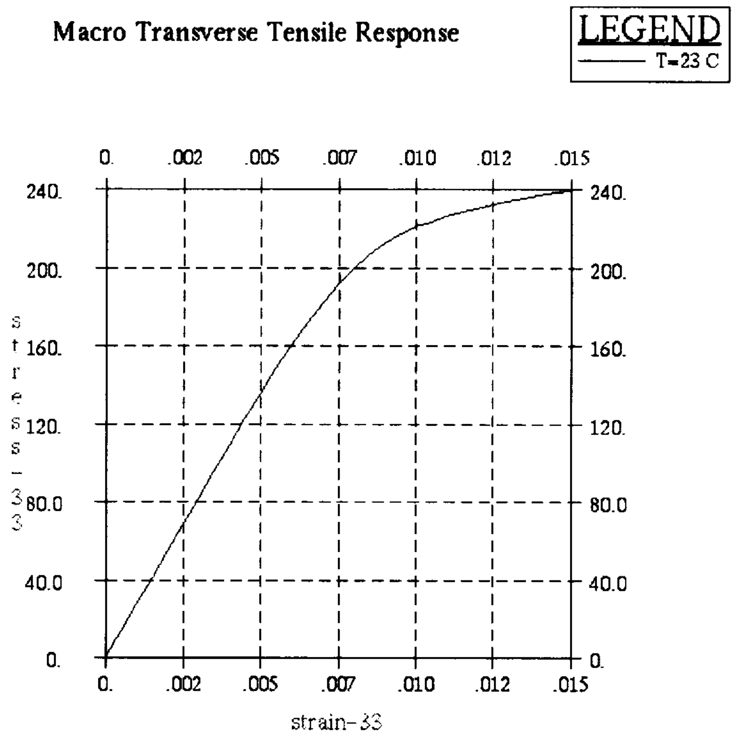

Figure 13: Macro X-Y plot for sample problem

After generation of the macroscopic X-Y plot, the next step in the example is to generate microscopic X-Y plots. To display the input form utilized to generate microscopic X-Y plots, the button "**Plot MICRO**" is selected on the "MACRO Plots" form shown in Figure 12. At this point, the macroscopic X-Y plot that was generated and the "MACRO Plots" form will be erased from the screen, and the "MICRO Plots" form will be displayed.

The first microscopic X-Y plot that will be generated is a plot of the 33-stress component vs. the 33-strain component for a subcell which is composed of fiber material and a subcell which is composed of matrix material. A picture of the completed form for generating the first curve for this step in the problem is shown in Figure 14. The procedures required to complete this form are as described in Section 4.2. First, the curve for subcell number 338 (a subcell composed of matrix material) is generated. As a reminder, the subcell numbering scheme is the same as is utilized in MAC/GMC, and is described in the MAC/GMC manual [5]. As shown in the figure, the number "338" is entered in the "**Subcell Number**" databox to indicate that the data for subcell 338 is to be plotted. To indicate which quantities are to be plotted, "strain-33" is selected in the "**Select X Axis:**" listbox, and "stress-33" is selected in the "**Select Y Axis:**" listbox. The curve that is to be generated is given a title of "Subcell 338" in the "**Title of Curve**" databox, and the plot is given a title of "Micro Transverse Tensile Response" in the "**Title of Plot**" databox. For this problem, only the results computed after the thermal cool-down, during the application of the mechanical load, are to be plotted. However, the actual strains are to be plotted, with no adjustment made so that the plotted strains start at zero (0). This allows examination of the residual strains generated by the cool-down process. To indicate that the strains are not to be adjusted, the "**Do not reset**" option is selected from the "**Reset Origin**" portion of the input form. To specify that only the results that occur during the mechanical load are to be plotted, the "**Specify start time**" option in the "**Start time**" section of the form is selected, and a time of 57600 seconds is entered in the "**Reset Value**" databox. As a reminder, 57600 seconds is the point in the MAC/GMC analysis where the thermal cool-down concludes and the mechanical tensile load is initiated. At this point, the "**Apply**" button is selected to initiate generation of a new plot with the specified curve.

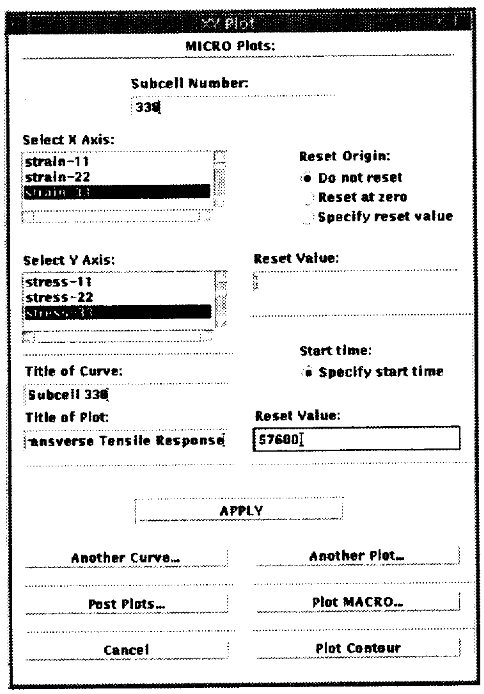

Figure 14: Micro X-Y plot generation form for sample problem

For this plot, a second curve will be added to the plot, the 33-stress component vs. the 33-strain component for subcell 169 (a fiber subcell). To add this second curve, the "**Another Curve**" button is selected on the "MICRO Plots" form. At this point, the displayed input data is cleared from the form, and the "MICRO Plots" form is redisplayed. The same procedure as described above is utilized to generate the second curve, with the following exceptions. First, the number "169" is entered in the "**Subcell Number**" databox, to indicate that the data for subcell 169 is to be plotted in this curve. The same values are selected in the "**Select X Axis**" and "**Select Y Axis**" listboxes as before, but note that even if different result quantities than those used before were selected, the axis titles in the generated plot would not change from those generated in creating the plot with the first curve. To enter the curve title for this second curve, "Subcell 169" is entered in the "**Title of Curve**" databox. No entry needs to be made in the "**Title of Plot**" databox, and even if an entry is made, it will be ignored in generating the new curve. The title of the plot must be created when generating the first curve of a plot. The same values as before are entered in the "**Reset Origin**" and "**Start Time**" portions of the input form, and the "**Apply**" button is selected to add the new curve to the plot.

The completed microscopic X-Y plot is shown in Figure 15. Note that the Y-Axis is labeled "stress-33", and the X-Axis is labeled "strain-33", the values which were entered in the appropriate listboxes of the input form when generating the first curve of the plot. The plot title that was entered in generating the first curve is used to give a title to the plot. The curve titles that were entered are used to label the two curves in the plot legend. Note that the two curves also are automatically given different line styles by **MACPOST**. Also, note that for both curves the plotted strains do not start at zero (0), but instead at the predicted strain values present at the start of the application of the simulated mechanical load. Thus, the residual strains present in the two subcells can be observed, compared and contrasted.

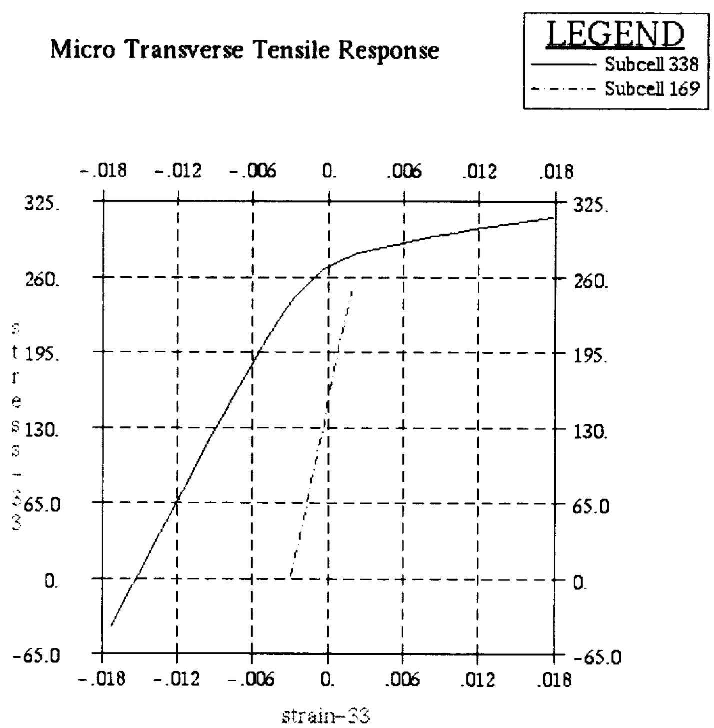

Figure 15: Micro X-Y plot for sample problem

To generate another microscopic X-Y plot, say a plot of the strain in the 22 direction vs. the strain in the 33 direction (the Poisson effect), the "**Another Plot**" button can be selected on the "MICRO Plots" form, which will cause the current X-Y plot to be erased from the screen, and the "MICRO Plots" form to be cleared and ready for the input of the data required to generate a new microscopic X-Y plot. After the second microscopic X-Y plot is generated, suppose the user wanted to review some of the plots that were generated. To view previously displayed microscopic X-Y plots, the "**Post Plots**" button on the "MICRO Plots" form is to be selected. At this point, the "MICRO Plots" form and the currently displayed X-Y plot are erased from the screen, and the "Post MICRO Plots" form shown in Figure 8 is displayed. As a reminder, the "Post MACRO Plots" form cannot be accessed directly from the "MICRO Plots" form.

In the "Post MICRO Plots" form, two microscopic plots are listed in the "**Generated Plots**" listbox. For this example, it is assumed that the user generated the microscopic plot that was described in detail above, as well as one other microscopic plot. Note that the user supplied plot titles are not displayed in the listbox. Instead, the default plot names as described in Section 4.2.4 are utilized. To display the first microscopic plot that was generated, the "MICRO XY Plots -1" entry in the "**Generated Plots**" listbox should be selected, and then the "**Apply**" button should be selected. At this point, the microscopic X-Y plot shown in Figure 15 will be redisplayed on the screen. To redisplay the macroscopic X-Y plot which was generated, the "**Post MACRO Plots**" button is to be selected, which will result in the "Post MICRO Plots" form and the currently displayed X-Y plot to be erased from the screen and the "Post MACRO Plots" form shown in Figure 7 to be displayed.

In the "Post MACRO Plots" form, the macroscopic plot that was generated is listed in the "**Generated Plots**" listbox by its default plot name, "MACRO XY Plots -1". To display this plot (shown in Figure 13), the "MACRO XY Plots -1" entry and the "**Apply**" button should be selected. At this point, the selected plot will be redisplayed on the screen.

The next step in the sample problem is the generation and display of contour plots. To begin the plot generation process, the "**Plot Contour**" button is to be selected on the "Post MACRO Plots" form. At this point, the "Post MACRO Plots" form and the currently displayed X-Y plot will be erased from the screen, and the first form required in the contour plot generation process will be displayed.

In the generation of contour plots, the first form that is displayed is the "Contour Geometry" form, which allows the user to import the model geometry data. The procedures required to utilize this form are as described in Section 4.4.1. The completed form for this example is displayed in Figure 16. For this example, the file name "APDXS.macgeo" is entered in the "**File Name**" databox, and the "**Apply**" button is selected. At this point, the model geometry will be imported into the MSC/PATRAN database and displayed on the screen. The model geometry for this problem is shown in Figure 17. As a reminder, for this problem the 26 subcell by 26 subcell two-dimensional GMC model, which simulates a circular fiber shape, was utilized. The MAC/GMC manual [5] can be consulted to gain further insight as to which subcells are composed of fiber material and which subcells are composed of matrix material in the unit cell. It should be noted that each subcell is modeled as a four noded element (for the two-dimensional GMC model used here) in MSC/PATRAN to allow for the proper generation and display of the contour plots. Once the geometry is imported, the "Contour Geometry" form will be erased from the screen and the "Results" form will be displayed.

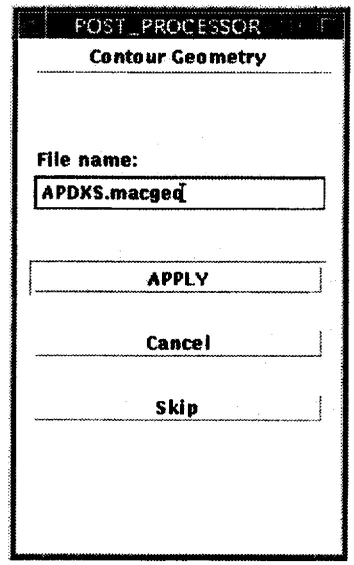

Figure 16: Model geometry input form for sample problem

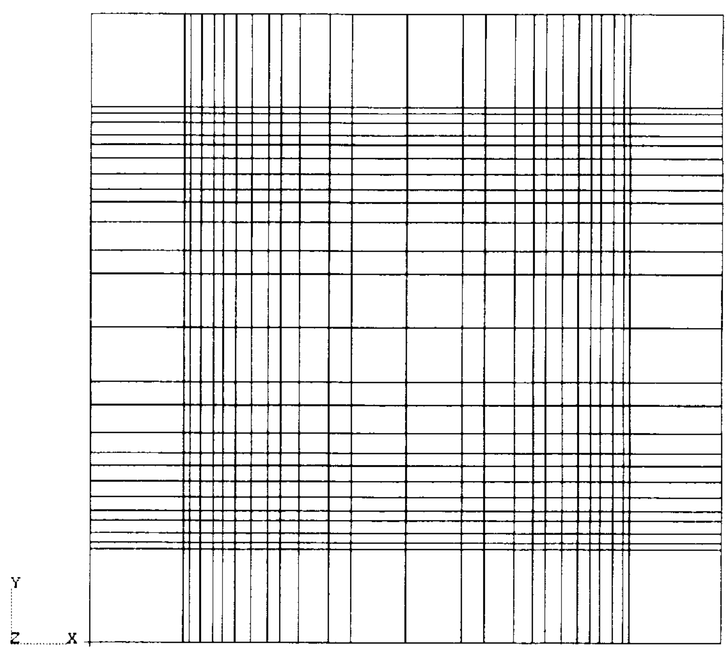

Figure 17: Model geometry for sample problem

The first contour plot to be generated is a plot of the 33-stress component at a time of 57680 seconds in the analysis. As can be seen in the MAC/GMC input file shown in

Appendix B, this time is near the end of the analysis. The "Results" form, described in Section 4.4.2, is utilized to generate the contour plot. The completed form for this problem is shown in Figure 18. As shown in the figure, since the time step at which the results are to be displayed is directly entered in this example, the "**Start TIME**" option of the "**Specify time step**" portion of the form is selected. In the "**Value**" databox, a value of 57680 seconds is entered. Since the time was entered directly, the "**Select Macro Quantity**" button is NOT selected. To indicate the type of result that is to be displayed, "stress-33" is selected in the "**Select result**" listbox. To generate the contour plot, the "**Apply**" button is selected.

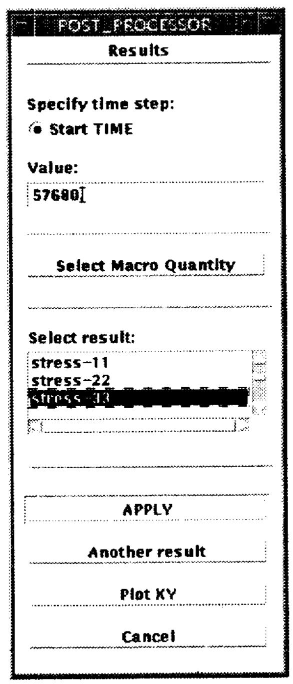

Figure 18: Contour plot generation form for first contour plot of sample problem

The generated contour plot is shown in Figure 19. Note that the 33-direction in MAC/GMC corresponds to the "X"-direction in the contour plot display. As described in Section 4.4.2.4, each subcell has one average stress value, which remains constant over the subcell, assigned to it. The stress levels in the subcells can be compared to the values shown in Figure 15 near the end of the X-Y plots. Also, note that the constant 33-stresses along each row of subcells in the 33 direction is due to the traction continuity assumptions utilized in the GMC theory.

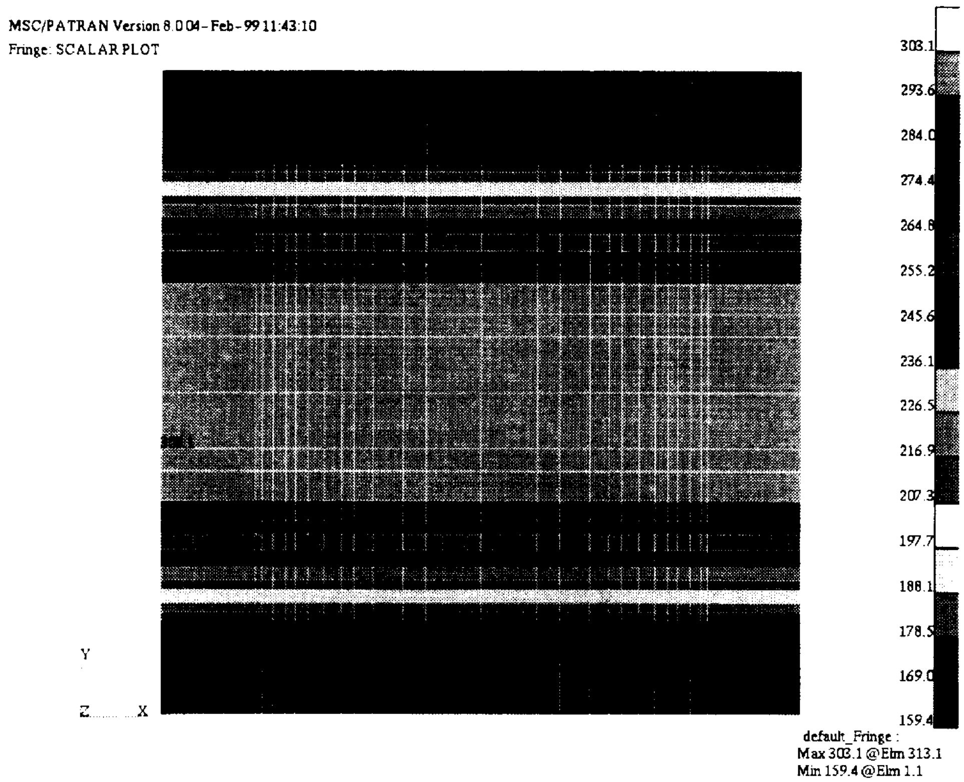

Figure 19: Contour plot of 33 stress component for sample problem

A second contour plot will also be generated, a plot of the J2 stress at the point where the macroscopic stress in the 33 direction equals 220 ksi. The first step in this process is to select the "**Another result**" button in the "Results" form. At this point, the "Results" form is cleared and prepared to receive new input. Note, however, that the current contour plot remains displayed on the screen until a new contour plot is generated.

The completed "Results" form for this portion of the example is shown in Figure 20. Note that since the time at which the results are to be displayed is not entered directly by the user, the "**Specify time step**" portion of the form is left blank. Instead, the first step in entering the input data is to select the "**Select Macro Quantity**" button. At this point, the "MACRO Quantity" form described in Section 4.4.3 will be displayed. The completed "MACRO Quantity" form for this example is shown in Figure 21.

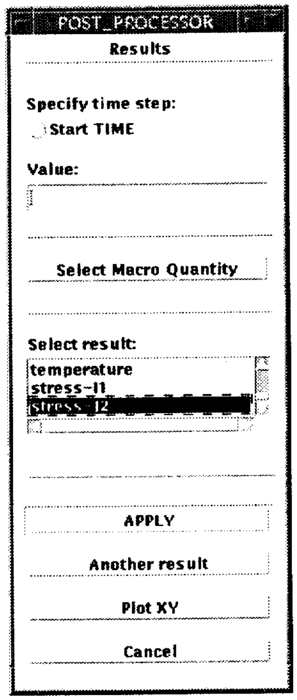

Figure 20: Contour plot generation form for second contour plot of sample problem

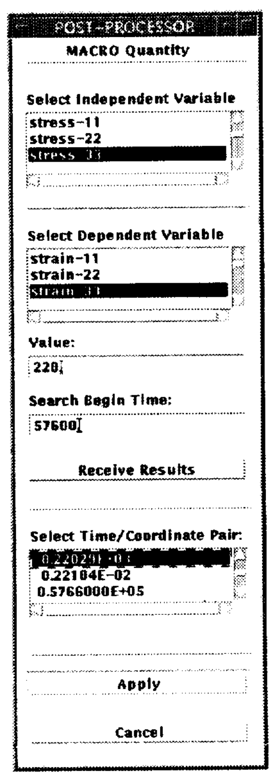

Figure 21: Select time step form for second contour plot of sample problem

For this example, since the contour plot results are to be displayed at the point where the macroscopic 33-stress component equals 220 ksi, the "stress-33" entry is selected in the "**Select Independent Variable**" listbox. Since stress-strain macroscopic X-Y plots were generated, strain-33 is selected in the "**Select Dependent Variable**". Since the macroscopic quantity selected as the time step basis will often be chosen as a result of behaviors observed in the macroscopic X-Y plots, this selection is reasonable. The value of the stress to be searched for, 220, is entered into the "**Value**" databox. Note that no units for the value are entered in the databox. Since the value of interest occurred during the mechanical load portion of the analysis, the search is specified to start at 57600 seconds, the point of the MAC/GMC analysis at which the thermal cool-down is concluded and the mechanical loading begins. By specifying a start time, the time required to execute the search is reduced, and the probability is increased that the located time step is the time step of interest. To indicate the analysis time step at which the search is to begin, a value of 57600 is entered in the "**Search Begin Time**" databox.

To execute the time step search, the "**Receive Results**" button is now selected. After the search is concluded, the closest match to the indicated stress value, along with the results from the two preceding and two following time steps, will be displayed in the "**Select Time/Coordiante Pair**" listbox. The entry with the closest match is the portion of the listbox which is shown in Figure 21, where the 33-stress component equals 220.29 ksi, the 33-strain component equals 0.0022104, and the time equals 57660 seconds. Note that the strain value displayed will not correspond to the strain value seen in the macroscopic X-Y plot shown in Figure 13, since the strains in that figure were offset so that the plot would start at a strain value of zero. For contour plots, no offsets are applied to any of the values. To indicate that this time should be utilized in generating the contour plot, any of the three values shown in the entry can be selected. For the example shown in Figure 21, the stress value of 220.29 was selected. Once the selection is made, the "**Apply**" button is chosen in order to record the time step and pass the information back to the "Results" form. At this point, the "MACRO Quantity" form is erased from the screen, and the user is returned to the "Results" form.

Once the time step has been selected using the "MACRO Quantity" form, as shown in Figure 20 the result quantity to be plotted, the J2 stress, is indicated by selecting the "stress-J2" entry in the "**Select result**" databox. At this point, the user needs only to select the "**Apply**" button and the contour plot will be generated. The generated contour plot is shown in Figure 22. Again, note that each subcell has one constant J2 stress value assigned to it.

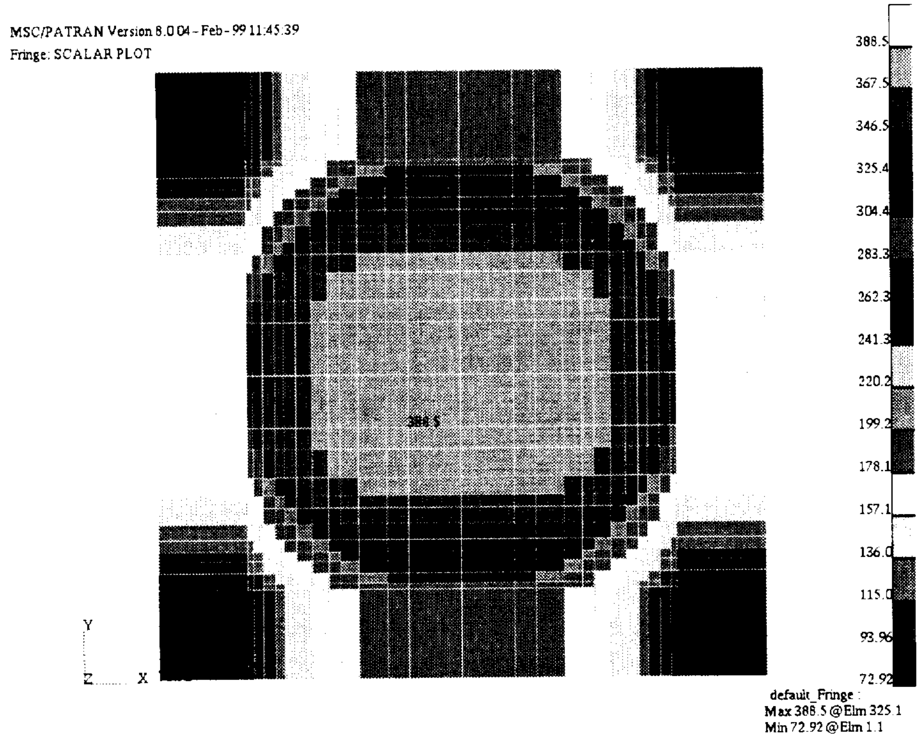

Figure 22: Contour plot of J2 stress invariant for sample problem

At this point, since the example is completed, the user may select the "**Cancel**" button to erase the "Results" form from the screen and terminate **MACPOST** execution. The most recent contour plot will remain plotted on the screen. However, note that the user could have generated another contour plot result by selecting the "**Another result**" button, or returned to the X-Y plot generation process by selecting the "**Plot XY**" button. Also, note that even once **MACPOST** is terminated, it can be restarted at any time during the MSC/PATRAN session by selecting the "**MAC**" option from the main menu bar.

6.0 References

1. Aboudi, J.: Mechanics of Composite Materials: A Unified Micromechanical Approach. Elsevier, Amsterdam, 1991.

2. Aboudi, J.: "Micromechanical Analysis of Thermo-Inelastic Multiphase Short-Fiber Composites", Composites Engineering, Vol. 5, pp. 839-850, 1995.

3. Pindera, M-J.; and Bednarcyk, B.A.: "An Efficient Implementation of the Generalized Method of Cells for Unidirectional, Multi-Phased Composites with Complex Microstructures", Composites: Part B, Vol. 30, pp. 87-105, 1999 (also NASA CR-202350).

4. Bendnarcyk, B.A.; and Pindera, M.-J.: "Micromechanical Modeling of Woven Metal Matrix Composites", NASA CR-204153, 1998.

5. Arnold, S.M.; Bednarcyk, B.A.; Wilt, T.E.; and Trowbridge, D.: "Micromechanics Analysis Code with Generalized Method of Cells (MAC/GMC) User Guide: Version 3.0", NASA TM-1999-209070.

6. MSC/PATRAN User Manual, Version 8.0. MacNeal-Schwendler Corporation, Los Angeles, CA, 1998.

Appendix A: File Formats

Geometry ".macgeo" file

The "*.macgeo" file contains the model geometry data required for the contour plots. There are five sections to the file: Summary data, node ID's, nodal coordinates, element ID's, and element connectivity. For each section, the variables written, and the FORTRAN format utilized to write the data to the file, are given below.

1) Summary Data: One line with the following summary data for the model:

JMAX,NST,ITOPOL,INUM (5X,I6,1X,I6,1X,I6,1X,I6)

where:

JMAX = Total number of nodes for the model
NST = Total number of elements (subcells) in the model
ITOPOL = Topology code required for MSC/PATRAN model generation
4 for 2-D models, 28 for 3-D models
INUM = Number of nodes associated with an element
4 for 2-D models, 8 for 3-D models

2) Nodal ID's: This line is repeated the number of times equal to the number of nodes divided by ten. If the number of nodes is not evenly divisible by ten, a final line will be written with the remaining nodes. Only the nodal ID's are listed here, with no information about the coordinates associated with each node. Note that the nodal information is required by MSC/PATRAN in order to construct the subcell elements. The format for the nodal ID's is as follows:

INOD,INOD,INOD,INOD,INOD,INOD,INOD,INOD,INOD,INOD (5X,10(I6,1X))

where:

INOD = Node identification number

3) Nodal Coordinates: This line is repeated the number of times equal to the number of nodes in the model. The nodal coordinates are given in the MSC/PATRAN X-Y-Z coordinate system. Note that a constant Z coordinate of zero (0) is given for 2-D GMC. The format of the nodal coordinate data is as follows:

GRIDX,GRIDY,GRIDZ (5X,E16.9,1X,E16.9,1X,E16.9)

where:

GRIDX = X-coordinate of node
GRIDY = Y-coordinate of node
GRIDZ = Z-coordinate of node

4) Element ID's: This line is repeated the number of times equal to the number of elements (subcells) divided by ten. If the number of elements is not evenly divisible by ten, a final line will be written with the remaining elements. Only the element ID's are listed here, with no information about the nodal connectivity of the element. The format for the element ID's is as follows:

IELM,IELM,IELM,IELM,IELM,IELM,IELM,IELM,IELM,IELM (5X,10(I6,1X))

where:

IELM = Element identification number

5) Element Connectivity: This line is repeated the number of times equal to the number of elements (subcells) in the model. The nodes that are used to construct each element are listed in this line, in the order required by MSC/PATRAN in order to appropriately construct the element. Note that 2-D GMC will have four nodes per element, while GMC 3-D will have eight nodes per element. The format of the element connectivity data is as follows, where the values in brackets are only used for GMC 3-D:

NCON1,NCON2,NCON3,NCON4[,NCON5,NCON6,NCON7,NCON8]
(5X,4(I6,1X)[,4(I6,1X)])

where:

NCONn = The nth nodal ID of the element

Macroscopic X-Y Plot Compatible Results Files (macro*_pat.data)

The results data utilized to generate the macroscopic X-Y plots are contained in the files "macro1_pat.data", "macro2_pat.data", "macro3_pat.data" and "macro4_pat.data". Each file contains the number of lines equal to the number of time steps for which the results are printed out (determined from the MAC/GMC input file). Each line of the results file contains the data for a particular time step. The contents, FORTRAN format, and description of each of the results files are given below.

macro1_pat.data: This file contains data for the six total strain components. The format for each line of output is as follows:

t,e11,e22,e33,e23,e13,e12 (5X,E14.7,3X,6(E12.5,3X))

where:

t = current time
e11 = 11-strain component
e22 = 22-strain component
e33 = 33-strain component
e23 = 23-engineering shear strain component
e13 = 13-engineering shear strain component
e12 = 12-engineering shear strain component

macro2_pat.data: This file contains data for the six stress components. The format for each line of output is as follows:

t,s11,s22,s33,s23,s13,s12 (5X,E14.7,3X,6(E12.5,3X))

where:

t = current time
s11 = 11-stress component
s22 = 22-stress component
s33 = 33-stress component
s23 = 23-stress component
s13 = 13-stress component
s12 = 12-stress component

macro3_pat.data: This file contains data for the six inelastic strain components. The format for each line of output is as follows:

t,ie11,ie22,ie33,ie23,ie13,ie12 (5X,E14.7,3X,6(E12.5,3X))

where:

t = current time

ie11 = 11-inelastic strain component
ie22 = 22-inelastic strain component
ie33 = 33-inelastic strain component
ie23 = 23-inelastic engineering shear strain component
ie13 = 13-inelastic engineering shear strain component
ie12 = 12-inelastic engineering shear strain component

macro4_pat.data: This file contains the thermal strain data, creep time, temperature, and I1 and J2 stress invariants for each time step. The format for each line of output is as follows:

t,te11,te22,te33,ct,temp,sI1,sJ2 (5X,E14.7,EX,7(E12.5,3X))

where:

t = current time
te11 = 11-thermal strain component
te22 = 22-thermal strain component
te33 = 33-thermal strain component
ct = creep time
temp = current temperature
sI1 = I1 stress invariant
sJ2 = J2 stress invariant

Microscopic X-Y Plot Compatible Files (micro*_pat.data)

The results data utilized to generate the microscopic (subcell) X-Y plots are contained in the files "micro1_pat.data", "micro2_pat.data", "micro3_pat.data", and "micro4_pat.data". The format for each of these files is similar to that used for the macroscopic X-Y plot results files. However, for these files the data for every subcell are included. The file lists all of the data for every time step for the first subcell, then the data for every time step for the second subcell, and so on, until the data for all of the subcells has been output. The subcell number is included as the first entry in the data for the first time step listed for the particular subcell. The contents, FORTRAN format, and description of each of the results files are given below.

micro1_pat.data: This file contains data for the six total strain components. The format for the first line of output for each subcell is as follows:

n,t,e11,e22,e33,e23,e13,e12 (1X,I4,E14.7,3X,6(E12.5,3X))

while the format for the remaining lines of output for each subcell is as follows:

t,e11,e22,e33,e23,e13,e12 (5X,E14.7,3X,6(E12.5,3X))

where:

n = subcell number
t = current time
e11 = 11-strain component
e22 = 22-strain component
e33 = 33-strain component
e23 = 23-engineering shear strain component
e13 = 13-engineering shear strain component
e12 = 12-engineering shear strain component

micro2_pat.data: This file contains data for the six stress components. The format for the first line of output for each subcell is as follows:

n,t,s11,s22,s33,s23,s13,s12 (1X,I4,E14.7,3X,6(E12.5,3X))

while the format for the remaining lines of output for each subcell is as follows:

t,s11,s22,s33,s23,s13,s12 (5X,E14.7,3X,6(E12.5,3X))

where:

n = subcell number
t = current time
s11 = 11-stress component

s22 = 22-stress component
s33 = 33-stress component
s23 = 23-stress component
s13 = 13-stress component
s12 = 12-stress component

micro3_pat.data: This file contains data for the six inelastic strain components. The format for the first line of output for each subcell is as follows:

n,t,ie11,ie22,ie33,ie23,ie13,ie12 (1X,I4,E14.7,3X,6(E12.5,3X))

while the format for the remaining lines of output for each subcell is as follows:

t,ie11,ie22,ie33,ie23,ie13,ie12 (5X,E14.7,3X,6(E12.5,3X))

where:

n = subcell number
t = current time
ie11 = 11-inelastic strain component
ie22 = 22-inelastic strain component
ie33 = 33-inelastic strain component
ie23 = 23-inelastic engineering shear strain component
ie13 = 13-inelastic engineering shear strain component
ie12 = 12-inelastic engineering shear strain component

micro4_pat.data: This file contains the thermal strain data, creep time, temperature, and I1 and J2 stress invariants for each time step. The format for the first line of output for each subcell is as follows:

n,t,te11,te22,te33,ct,temp,sI1,sJ2 (1X,I4,E14.7,3X,7(E12.5,3X))

while the format for the remaining lines of output for each subcell is as follows:

t,te11,te22,te33,ct,temp,sI1,sJ2 (5X,E14.7,3X,7(E12.5,3X))

where:

n = subcell number
t = current time
te11 = 11-thermal strain component
te22 = 22-thermal strain component
te33 = 33-thermal strain component
ct = creep time
temp = current temperature
sI1 = I1 stress invariant
sJ2 = J2 stress invariant

Microscopic Contour Plot Compatible Files (micro*_pat.contour)

The results data utilized to generate the contour plots are contained in the files "micro1_pat.contour", "micro2_pat.contour", "micro3_pat.contour", and "micro4_pat.contour". The format for each of these files is similar to that used for the microscopic X-Y plot results files. However, instead of organizing the data first by subcell, the data is organized first by time step. The time value is included as the first entry in the data for each time step. The data for each subcell for that time step is then output. The contents, FORTRAN format, and description of each of the results files are given below.

micro1_pat.contour: This file contains data for the six total strain components. The format for the first line of output for each time step is as follows:

t (1X,E14.7)

while the format for the remaining lines of output for each time step is as follows:

n,e11,e22,e33,e23,e13,e12 (15X,I6,6(E12.5,3X))

where:

n=subcell number
t=current time
e11 = 11-strain component
e22 = 22-strain component
e33 = 33-strain component
e23 = 23-engineering shear strain component
e13 = 13-engineering shear strain component
e12 = 12-engineering shear strain component

micro2_pat.contour: This file contains data for the six stress components. The format for the first line of output for each time step is as follows:

t (1X,E14.7)

while the format for the remaining lines of output for each time step is as follows:

n,s11,s22,s33,s23,s13,s12 (15X,I6,6(E12.5,3X))

where:

n = subcell number
t = current time
s11 = 11-stress component
s22 = 22-stress component
s33 = 33-stress component

s23 = 23-stress component
s13 = 13-stress component
s12 = 12-stress component

micro3_pat.contour: This file contains data for the six inelastic strain. The format for the first line of output for each time step is as follows:

t (1X,E14.7)

while the format for the remaining lines of output for each time step is as follows:

n,ie11,ie22,ie33,ie23,ie13,ie12 (15X,I6,6(E12.5,3X))

where:

n = subcell number
t = current time
ie11 = 11-inelastic strain component
ie22 = 22-inelastic strain component
ie33 = 33-inelastic strain component
ie23 = 23-inelastic engineering shear strain component
ie13 = 13-inelastic engineering shear strain component
ie12 = 12-inelastic engineering shear strain component

micro4_pat.contour: This file contains the thermal strain data, creep time, temperature, and I1 and J2 stress invariants for each subcell. The format for the first line of output for each time step is as follows:

t (1X,E14.7)

while the format for the remaining lines of output for each time step is as follows:

n,te11,te22,te33,ct,temp,sI1,sJ2 (15X,I6,7(E12.5,3X))

where:

n = subcell number
t = current time
te11 = 11-thermal strain component
te22 = 22-thermal strain component
te33 = 33-thermal strain component
ct = creep time
temp = current temperature
sI1 = I1 stress invariant
sJ2 = J2 stress invariant

Total Quantity Data

The file "total_pat.data" contains information regarding the total number of time steps output and the total number of subcells in the unit cell in the following format:

NPC1,NST (1X,I5,2X,I5)

where:

NPC1 = total number of time steps included in results files
NST = total number of subcells in analysis unit cell

This file is utilized by **MACPOST** to control the processing of the results data.

Appendix B: MAC/GMC Input File Utilized for Sample Problem

```
test of PATRAN output
*PRINT
  NPL=1 %
*LOAD
  LCON=3 LOP=3 LSS=1 %
*MECH
  NPTW=3 TI=0.,57600.,57690. LO=0.,0.,0.015 %
*THERM
  NPTT=3 TI=0.,57600.,57690. TE=900.,23.,23. %
*MODEL
  MOD=1 %
*PATRAN
  FN=apdxs TPRE=57600 STP=30  %
*SOLVER
  NTF=1 NPTS=3 TIM=0.,57600.,57690. STP=100,0.1 %
*FIBER
  NFIBS=1
  NF=1 MF=6 NDPT=2 MAT=E %
*MATRIX
  NMATX=1
  NM=1 MM=4 NDPT=2 MAT=A %
*MRVE
  IDP=13 VF=0.4 R=1
*CURVE
  NP=2 %
*MACRO
  NT=1
  NC=1 X=3 Y=9 NAM=apdxs
*END
```

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13. ABSTRACT *(Maximum 200 words)*

As advanced composite materials have gained wider usage, the need for analytical models and computer codes to predict the thermomechanical deformation response of these materials has increased significantly. Recently, a micromechanics technique called the generalized method of cells (GMC) has been developed, which has the capability to fulfill this goal. To provide a framework for GMC, the Micromechanics Analysis Code with Generalized Method of Cells (MAC/GMC) has been developed. As MAC/GMC has been updated, significant improvements have been made to the post-processing capabilities of the code. Through the MACPOST program, which operates directly within the MSC/PATRAN graphical pre- and post-processing package, a direct link between the analysis capabilities of MAC/GMC and the post-processing capabilities of MSC/PATRAN has been established. MACPOST has simplified the production, printing, and exportation of results for unit cells analyzed by MAC/GMC. MACPOST allows different micro-level quantities to be plotted quickly and easily in contour plots. In addition, meaningful data for X-Y plots can be examined. MACPOST thus serves as an important analysis and visualization tool for the macro- and micro-level data generated by MAC/GMC. This report serves as the user's manual for the MACPOST program.

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