PROMAL2012 SOFTWARE PACKAGE

A USER GUIDE

1. This manual is only for **VISTA, WINDOWS 7 and WINDOWS 8** users. The PROMAL2012 software and manual are available at http://www.eng.usf.edu/~kaw/promal2012/

2. If you are using **Windows XP**, you can definitely try to use the above software. It does work, but if it does not work, delete the directory where you installed PROMAL2012. Then access the older version of the software and manual from http://www.eng.usf.edu/~kaw/promal2005/ with the same userid and password. There is no difference in the two versions of the software except PROMAL2012
    a. includes elasticity micromechanical models
    b. includes Halpin-Tsai micromechanical models
    c. does not include matrix algebra module as those features are now readily available on any programmable calculator or computational systems such as MATLAB.

- *Show how to set up PROMAL2012 on a personal computer*
- *Show how to use PROMAL2012 for*
  - *developing and maintaining a database for properties of unidirectional laminas,*
  - *conducting macromechanics of a lamina,*
  - *conducting micromechanics of a lamina,*
  - *conducting macromechanics of a laminate*
- *Give examples to show how to use each of the above programs*

1. INTRODUCTION

Studying mechanics of composites requires lengthy and repetitive algebraic manipulations, such as, matrix multiplication, inversion of matrices, etc. If you want to fully understand the scope of the mechanics of composites, especially the design of laminated structures, you may need to write a computer program or use a mathematical package, such as MathCAD®, Maple®, MATLAB® or Mathematica®. I highly recommend the student to develop some of their own programs. However, it can be time consuming to build a program that is professional and efficient for all the principles taught in this book. The instructor and the student can therefore turn to the software package PROMAL2012 which is designed for classroom instruction as well as for homework assignments.

The software has five different programs.

- Lamina Properties Database - Chapter 2,
- Replacing Corrupted Lamina Properties Database - Chapter 2,
- Macromechanics Analysis of a Single Lamina - Chapter 2,
- Micromechanics Analysis of a Single Lamina - Chapter 3,
- Macromechanics Analysis of a Laminate - Chapters 4 and 5.

The software package makes you more productive by giving a tool for numerical experimentation. It provides instant, step-by-step graphical and tabular feedback. Other special features of the software include:

- systems of units switchable between the SI and USCS by a single click
- clear input and output data units
- output choices such as viewing on monitor, printing on a printer or writing to a text file.

2. SYSTEM REQUIREMENTS

- Personal computer running Windows XP, Windows VISTA, Windows 7, or Windows 8.
- Mouse or trackpad, and Keyboard
- Printer Recommended.

3. SETTING UP PROMAL

1. Read all the eligibility requirements, licensing agreement and warranty information given in the ABOUT THE SOFTWARE section of this book.
2. Save the *promal2012.zip* file to a directory of your choice. This is the directory from where you want to run the program. Extract the files using programs such as WinZip® to the same directory. To run the program, one simply opens Windows explorer (or Click on Start-> My Computer) and goes to the directory where one installed the program.

4. USING THE PROGRAM

To run the program, open Windows explorer (or Click on Start-> My Computer) and go to the directory where you installed the program. Click on the promal.exe file. (Note: A shortcut to your desktop will not work). You will be presented with two introductory screens and then the Master Menu. Figure 1 shows the Master Menu with four separate applications from which to choose. To use, click the mouse or press the ENTER key on one of the six choices. In a menu, you can also use the TAB or SHIFT+TAB key to move from one button to another.

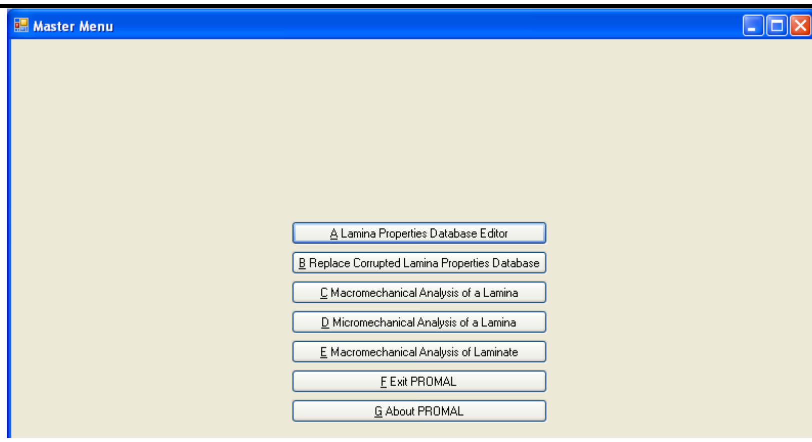


Figure 1. Master menu showing available programs in PROMAL.

4.1 COMMON BUTTONS

Some buttons are common in all the five programs. These buttons are

Send to Printer: Click on this button to print the output shown on the screen to the default printer. Each output starts on a new page. If this is not acceptable, use the Print to File button, explained in the next item.

Print to File: Click on this button to get the output shown on the screen to a text file, which would get names such as **"07-26-2012 17-02-17 PROMAL dump.txt"**. Each file name on a particular computer would be unique as it puts the date and time stamp as part of the file name. This file resides in the directory where you installed PROMAL2012. You can view, edit, cut and paste, or print this file using a word processor or a text editor. For proper formatting of the output, use Courier New font or any other scalable font (size 10).

System of Units: Click on these option buttons to select the units for input data and the units for output data. The default system of units is the SI (Système international d'unités) system for all the programs. The other system of units is the USCS (United States Customary System) system.

Return to Master Menu: Click on this button to return to the Master Menu.

Exit PROMAL: Click on this button to exit the program.

ACCESS KEYS: Access keys allow you to navigate through the program by pressing the ALT key and typing the underlined letter in the buttons. For example, you can access the *Lamina Properties Database Editor* program in the Master Menu by simultaneously pressing ALT and then the A key.

4.2 LAMINA PROPERTIES DATABASE

In the first program, you can enter the material properties and thickness of a composite lamina, update or correct the properties of an existing lamina, and simply review the properties. *You can enter properties for up to a maximum of* 100 *different lamina materials*. Properties of three typical composite systems - Graphite/Epoxy, Boron/Epoxy and Glass/Epoxy, and two typical isotropic metals - aluminum and steel are already entered for you in the database. You cannot change the values of the material properties and thickness of these five materials.

Figure 2 shows the menu for entering and editing the lamina properties and thickness. This program enters 15 items – lamina name, the 4 elastic moduli, ply thickness, the 5 strength parameters, the 2 coefficients of thermal expansion, and the 2 coefficients of moisture expansion of a specially orthotropic lamina.

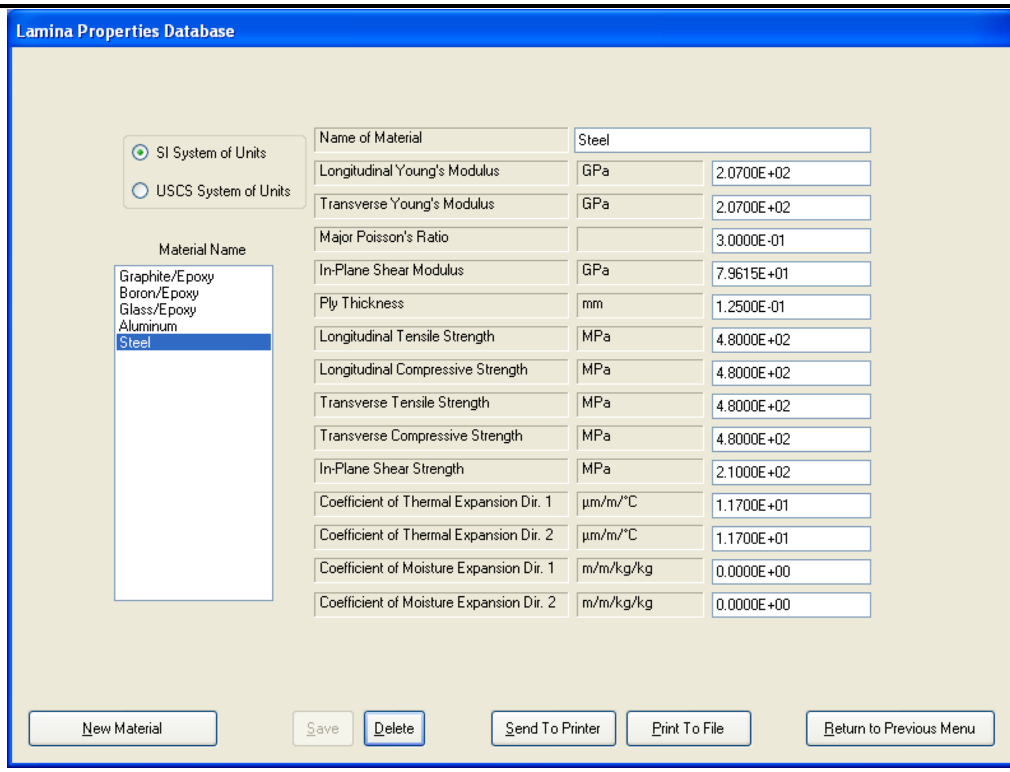


Figure 2. Menu for updating and adding lamina properties to material database.

How do I enter the properties of a new material?

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the proper system of units for the input.

3. Click on the New Material Button. *Note that PROMAL2012 disables the Save Button.* The program will enable the Save Button when you enter the material name. Put dummy non-zero numbers if a particular data is not available for elastic moduli, ply thickness or strengths. *CAUTION: However, these dummy non-zero values will accordingly affect the results obtained in the other programs of PROMAL2012.* The material name can be alphanumeric (letters and numbers). To enter the data for the material, you can use either decimal or scientific notation.
4. Click on the Save Button to save the properties of the material.

How do I delete a material?

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the material you want to delete from the Material ListBox.
3. Click on the Delete Button. You will be asked for a confirmation if you really want to delete the material.

Why can I not edit or delete the first five materials in the database?

The first five materials are reserved. You *cannot* delete or edit these five materials. This is done so that the instructor can assign homework using these common material systems.

How do I change some properties of materials I have already entered?

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the material you want to edit from the Material ListBox.
3. Make changes to the properties.
4. Click on the Save Button to save the changes in the material properties. You need to save changes before editing another material.

For a material system, I know some properties in the USCS system of units and some in the SI system of units? How do I enter the data without converting it into a single system of units?

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the system of units of your choice for the input.
3. Click on the New Material Button.
4. Enter the properties of the material. Use dummy non-zero numbers for data (elastic moduli, ply thickness and strengths) given in another system of units.

5. Click on the Save Button to save the material properties.
6. Click now on the other system of units for the input.
7. Click on the material in the Material ListBox.
8. Edit the properties given in the other system of units.
9. Click on the Save Button to save the material properties.

Example 1

Create a material record for a typical Graphite/Epoxy-2 lamina with the following properties.

Table 1 Properties of Graphite/Epoxy-2

Property Name	Symbol	Value
Longitudinal Young's Modulus	E_1	30.00 Msi
Transverse Young's Modulus	E_2	0.750 Msi
Major Poisson's Ratio	ν_{12}	0.250
In-Plane Shear Modulus	G_{12}	0.375 Msi
Ply Thickness		0.125 mm
Longitudinal Tensile Strength	$(\sigma_1^T)_{ult}$	150 Ksi
Longitudinal Compressive Strength	$(\sigma_1^C)_{ult}$	100 Ksi
Transverse Tensile Strength	$(\sigma_2^T)_{ult}$	6 Ksi
Transverse Compressive Strength	$(\sigma_2^C)_{ult}$	17 Ksi
In-Plane Shear Strength	$(\tau_{12})_{ult}$	10 Ksi
Longitudinal Coefficient of Thermal Expansion	α_1	1.8×10^{-8} m/m/^{0}C
Transverse Coefficient of Thermal Expansion	α_2	1.8×10^{-5} m/m/^{0}C
Longitudinal Coefficient of Moisture Expansion	β_1	0.0 m/m/kg/kg
Transverse Coefficient of Moisture Expansion	β_2	0.5 m/m/kg/kg

Note that you have different units for the input data. With **PROMAL2012**, you do not have to get all the data into the same system of units before data entry.

Solution

1. Click on the Lamina Properties Database Editor Button in the Master Menu.
2. Click on the USCS system of units for input.
3. Click on the New Material Button. Enter the name as Graphite/Epoxy-2, elastic moduli, strength properties.
4. Enter the name, elastic moduli, strength properties. Enter arbitrary non-zero value for the ply thickness since *PROMAL2012* will not allow you to save if you have a zero value for thickness.
5. Click on the Save Button.
6. Click on the Graphite/Epoxy-2 name in the Material List Box.
7. Click on the SI system of units for input.
8. Edit the ply thickness and enter the coefficients of thermal and moisture expansion in the SI system.
9. Click on the Save Button. Note that you did not have to convert the units manually to enter the data.
10. Click on the Return to Previous Menu Button to return to the Master Menu.

4.3 REPLACING CORRUPTED LAMINA MATERIAL DATABASE

Sometimes, the material database for the lamina may get corrupted due to power shutdown, computer lockup, accidental rebooting or other reasons. This option allows you to replace the material database with the database that you received at the setup time. Note that the database on the disk has properties for five common materials. *You do not need the setup zip file to use this option*.

How do I replace the corrupted database with the one that was on there at setup time?

1. In the Master Menu, click on Replace Corrupted Lamina Properties Database Button.
2. Click on Replace Corrupted Database with Database Which Came With the Setup Disk Button.
3. Click on the Yes Button, if you want to replace the corrupted database. Click on the No Button if you do not want to replace the corrupted database. Click on Cancel Button if you are confused.

4.4 MACROMECHANICAL ANALYSIS OF A LAMINA

The second program conducts the macromechanical analysis of a lamina discussed in Chapter 2. The input mechanical properties of a lamina are chosen from the Lamina Properties Database. You can then calculate the stiffness and the compliance matrices, the engineering constants and the strength ratios for an angle ply, and display the engineering constants and the strength ratios as a function of the ply angle in tabular or graphical form. Figure 3 shows the main menu of the *Macromechanical Analysis of a Lamina*.

How do I use this program?

1. Click on Select Lamina from Lamina Properties Database Button.
2. Select the lamina from the database by clicking on the material in the Material ListBox. Click on the Load Material Button or double click on the material in the Material List Box, and *PROMAL2012* returns you to the main menu.
3. Buttons with access keys B thru K allow you to

   a.) review the loaded data for the selected lamina,

   b.) view, print and/or dump the transformation matrices $[T]$ and $[T]^{-1}$, reduced stiffness $[Q]$ and compliance $[S]$ matrices, transformed reduced stiffness $[\bar{Q}]$ and transformed compliance $[\bar{S}]$ matrices, engineering constants for an angle ply,

   c.) tabulate and plot transformed stiffness $[\bar{Q}]$ and transformed compliance $[\bar{S}]$ matrices and engineering constants as a function of the angle of ply.

4. Click on Stresses/Strains and Strength Ratios Button to find the global and local strains and stresses, and the strength ratios from four major failure theories. Enter the components of the stress vector $(\sigma_x, \sigma_y, \tau_{xy})$ and the angle of ply. At least one of the stresses should be non-zero, and *the angle of the ply should be entered even if it is zero*.

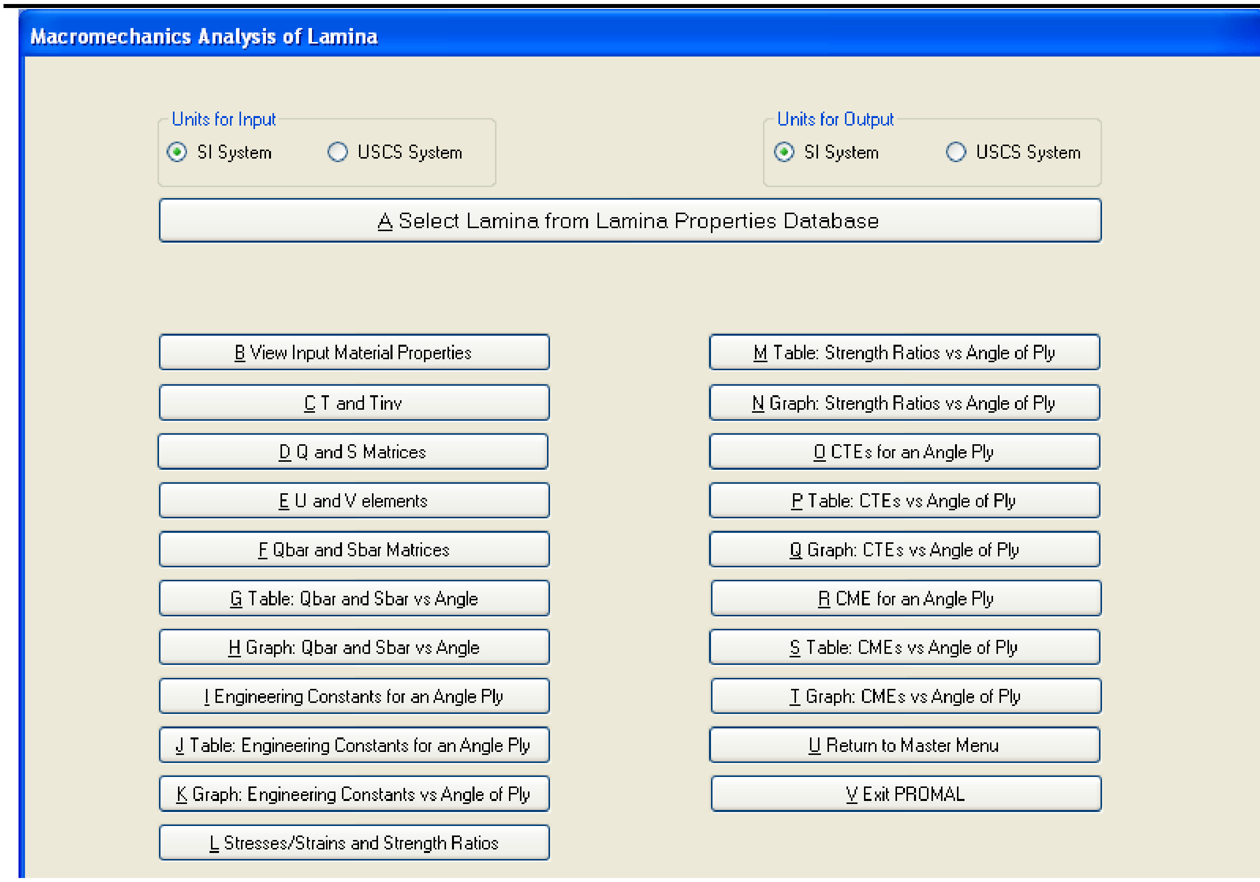


Figure 3. Main menu for macromechanical analysis of a lamina.

5. Click on Table: Strength Ratios vs. Angle of Ply or Graph Strength Ratios vs. Angle of Ply Button to tabulate or plot the strength ratios as a function of the angle of ply, respectively. Enter the components of the stress vector $(\sigma_x, \sigma_y, \tau_{xy})$. *At least one of the stresses should be non-zero*. Then you can view the strength ratios as a function of the angle of ply. *PROMAL2012* also shows results from the four failure theories in one graph to show the difference between the predictions using the four failure theories.

6. Buttons with access keys O through Q show the coefficients of thermal expansion (CTE) for a particular angle of ply, and tabulate and plot the coefficients of thermal expansion as a function of the angle of ply.

7. Buttons with access keys R through T show the coefficients of moisture expansion

(CME) for a particular angle of ply, and tabulate and plot the coefficients of moisture expansion as a function of the angle of ply.

Example 2

Consider a typical Graphite/Epoxy lamina with the mechanical properties given in Table 2.2. Find the optimum fiber angle which maximizes the safety factor for the following stress components .

Longitudinal Stress (σ_x) = 4 Ksi,

Transverse Stress (σ_y) = 2 Ksi,

Shear Stress (τ_{xy}) = 1 Ksi.

Use the Maximum Stress failure theory for your analysis. Use the properties of unidirectional Graphite/Epoxy lamina from the Lamina Properties Database.

Solution

1. Click on the Macromechanics of a Lamina Button in the Master Menu.
2. Click on the proper system of units for the input and output.
3. Click on Select Lamina from Lamina Properties Database Button to select the material properties of the Graphite/Epoxy.
4. To analyze the lamina for the optimum fiber angle for the given load, select the Graph: Strength Ratios vs. Angle of Ply Button. Enter the components of the stress vector. Once you enter these values, you are presented with the first of four graphs showing the strength ratio as a function of the angle of ply. The second graph shows the results of using the Maximum Stress failure theory. From the graph (Figure 4), the lamina will not fail (SR>1) for fiber angles between 10° and 30°.
5. Further investigations using Stresses/Strains and Strength Ratios Button shows that about 22.5° is the optimum fiber angle as it has a strength ratio of 3.784. So, one can apply 3.784 times the stresses given above before the lamina fails.

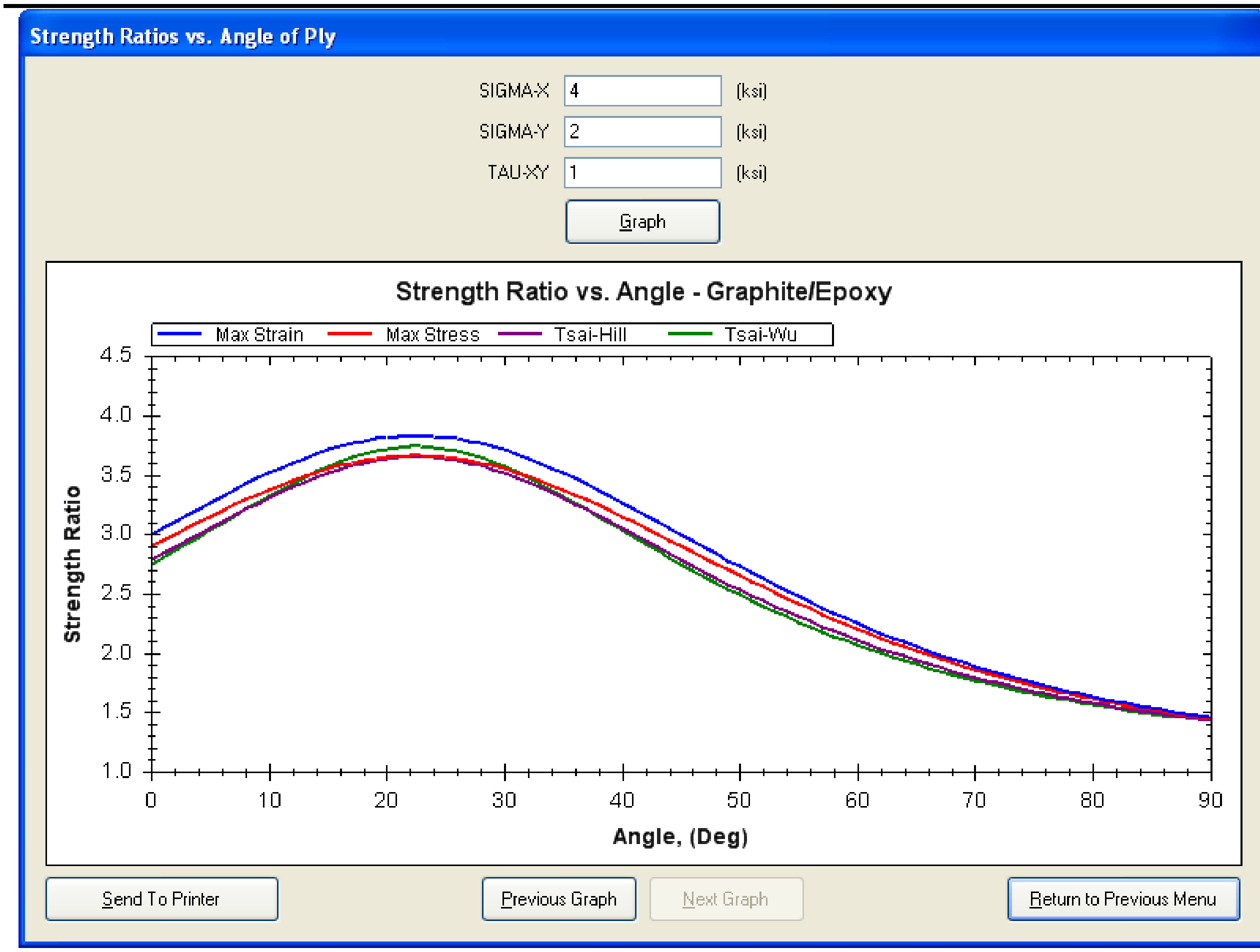


Figure 4. Strength ratio as a function of angle of ply for Example 2.

4.5. MICROMECHANICAL ANALYSIS OF A LAMINA

The third program conducts the micromechanical analysis of a lamina using formulas from the strength of materials approach. You enter the elastic moduli, coefficients of thermal and moisture expansion of the fiber and the matrix from the keyboard. You can then calculate the elastic moduli, thermal and moisture expansion coefficients of a unidirectional lamina for a particular fiber volume fraction. The program also displays these properties in a tabular/graphical form as a function of the fiber volume fraction. Figure 5 shows the main menu of the micromechanical analysis of a lamina.

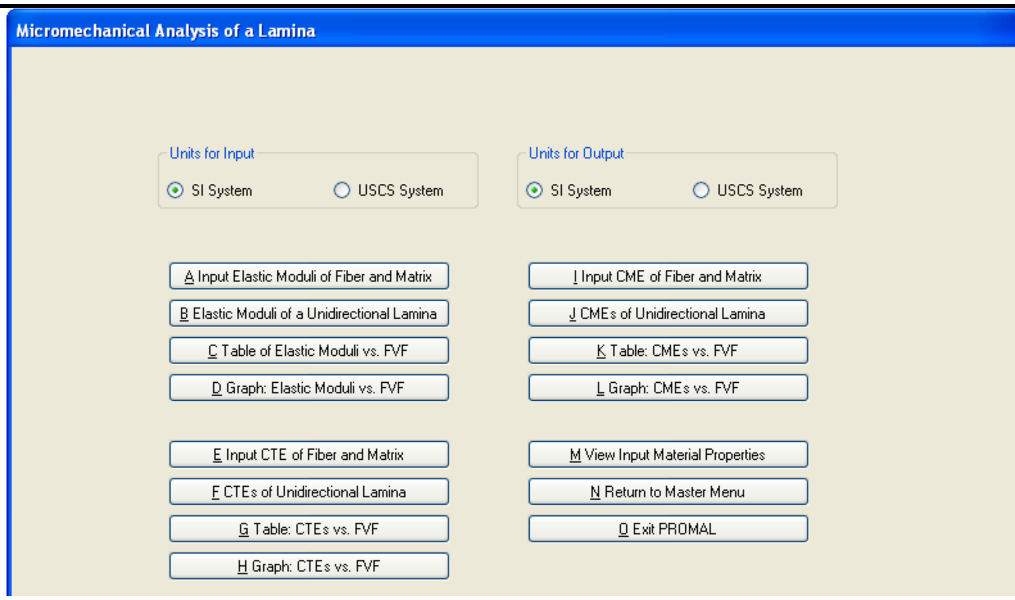


Figure 5. Main menu for the micromechanical analysis of a lamina.

How do I use this program?

1. Click on Input Elastic Moduli of Fiber and Matrix Button to enter the isotropic elastic moduli of the fiber and the matrix. Direction 1 (longitudinal) is parallel to the fibers and Direction 2 (transverse) is perpendicular to the fibers. The program does not accept null input because of a possibility of division by zero.

2. The next three Buttons with access keys B through D display the elastic moduli and the ratio of the fiber load to the composite load of a unidirectional lamina for an input value of a fiber volume fraction, tabulate and plot these parameters as a function of the fiber volume fraction.

3. Click on Input CTE of Fiber and Matrix Button to enter the coefficients of thermal expansion of the fiber and matrix. The next three buttons with access keys F through H display the longitudinal and transverse thermal expansion coefficients for an input value of a fiber volume fraction, tabulate and plot these parameters as a function of the fiber volume fraction.

4. Click on Input CME of Fiber and Matrix Button to enter the coefficients of moisture expansion and specific gravities of the fiber and matrix. The next three buttons with access keys J though L display the longitudinal and transverse moisture expansion coefficients for an input value of a fiber volume fraction, tabulate and plot these parameters as a function of the fiber volume fraction.

Example 3

The following are the mechanical properties of the constituents of a typical Glass/Epoxy lamina:

Fiber Young's modulus (E_f) = 70 GPa

Matrix Young's modulus (E_m) = 3.5 GPa

Fiber Poisson's ratio (ν_f) = 0.2

Matrix Poisson's ratio (ν_m) = 0.35

Fiber coefficient of thermal expansion $(\alpha_f) = 0.5\times10^{-5}$ m/m/^{o}C

Matrix coefficient of thermal expansion $(\alpha_m) = 6\times10^{-5}$ m/m/^{o}C

Find the fiber volume fraction for which the thermal expansion coefficient perpendicular to the fibers, (α_2) is a maximum.

Solution

1. Click on Input Elastic Moduli of Fiber and Matrix Button to enter the elastic moduli of the fiber and the matrix.
2. Click on Input CTE for Fiber and Matrix Button to enter the coefficient of thermal expansion for fiber and matrix. Note your units!
3. Click on the Graph: CTEs vs. FVF Button. From the graph, as shown in Figure 6, we see that the maximum transverse thermal expansion coefficient occurs when the fiber volume fraction is between 0.05 and 0.1. Next, using these values as the upper and lower limits, iteratively use the CTEs of Unidirectional Lamina Button to find the fiber volume fraction for which the thermal expansion coefficient is a maximum. Following this method, a fiber volume fraction of 0.071 is found to produce the maximum transverse coefficient of thermal expansion.

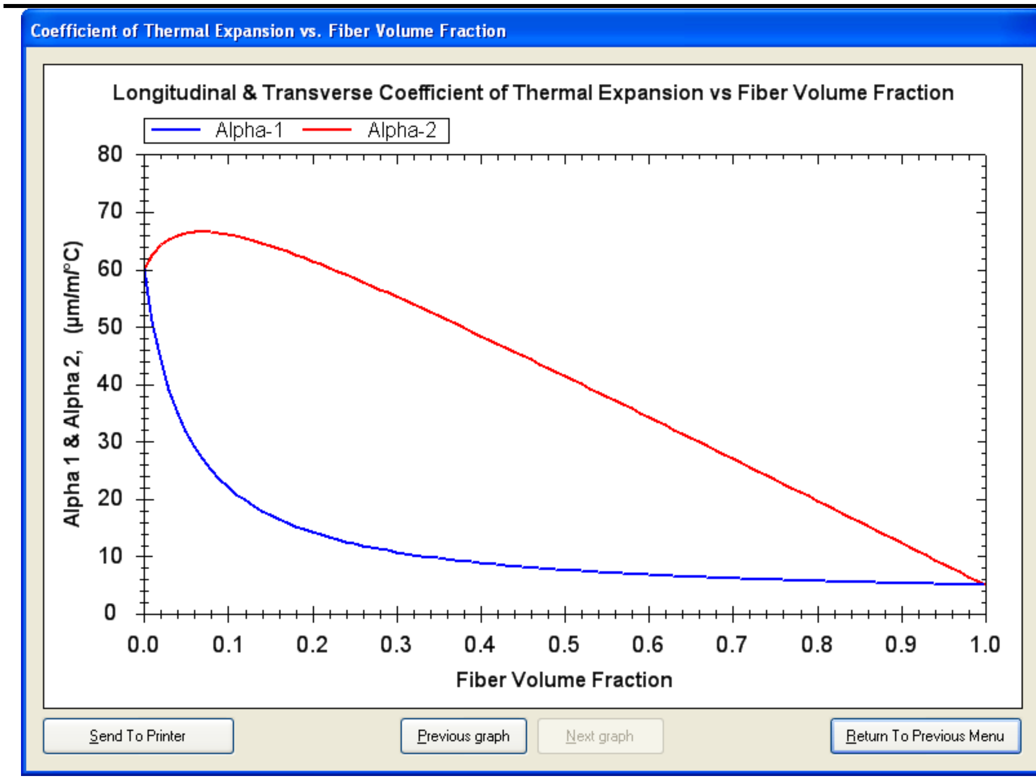


Figure 6. Coefficients of thermal expansion as a function of fiber volume fraction for Example 3.

4.6 MACROMECHANICAL ANALYSIS OF A LAMINATE

The fifth program conducts the macromechanical analysis of a laminate. The laminate can be made of a single type of lamina, hybrid laminas, and sandwich panels. The material properties for the lamina are selected from the material database of the second program. Next, you enter the orientation of the plies and the corresponding material number of each ply in the laminate. You can also read laminate stacking sequences from a data file. Now you can display the orientation and ply properties, the stiffness and the compliance matrices, and the equivalent plate properties of the laminate. Enter the mechanical and hygrothermal loads to calculate the global and local stresses and strains, strength ratios at the top, middle and bottom surface of each ply in the laminate. Figure 7 gives the main menu of the macromechanical analysis of a laminate.

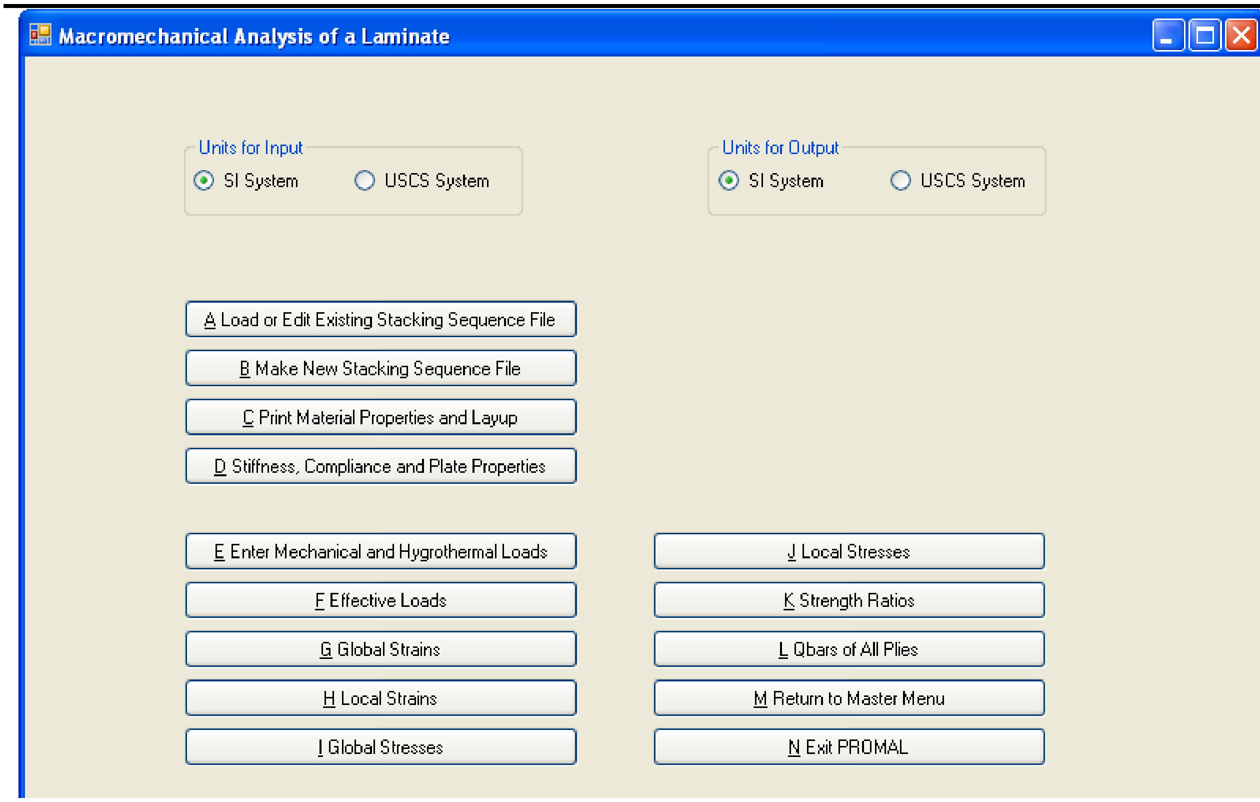


Figure 7. Main menu for macromechanical analysis of a laminate.

How do I create a new laminate sequence?

1. Click on the Macromechanical Analysis of a Laminate Button in the Master Menu.
2. Click on the Make a New Stacking Sequence File Button.
3. Starting from the top of the laminate, put the material number and ply angle in degrees for each ply in the grid separated by commas (Figure 8). For example, a symmetric graphite/epoxy laminate $[30/45]_s$ would be entered as

    1,30,1,45,1,45,1,30

4. Click on Accept Stacking Sequence Button to save the laminate stacking sequence in a file. At this point, PROMAL saves and loads the stacking sequence. Even if you do not save the laminate stacking sequence, it will still be loaded.

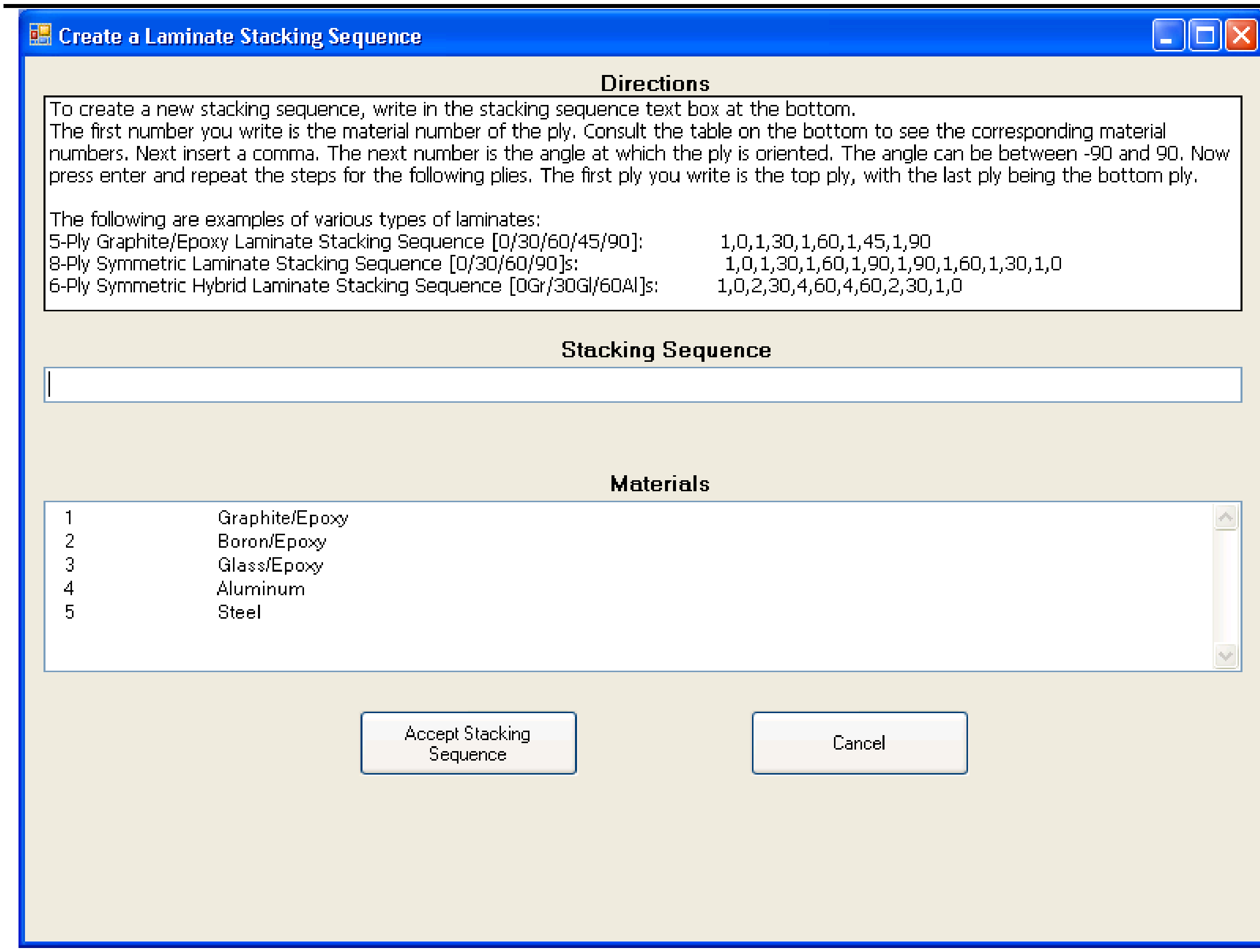


Figure 8. Menu for entering stacking sequence of a laminate

I have a large number of plies in my stacking sequence. Can I make my own laminate sequence file in notepad that I can use in PROMAL2012?

Yes, but please proceed with caution by following the proper guidelines. You can generate the text file for a stacking sequence of a laminate using your own computer program or by manually entering data in a text file via text processors such as Notepad or MS Word.

Simply put material number and angle of each ply on a separate line. The material number and ply angle should be separated by a comma.

Given below are a few examples of how to use Notepad to make stacking sequence files.

Example 4

This is an example of a total laminate. How do I make the stacking sequence file for

[0/30/-45/90/55] Glass/Epoxy laminate outside of *PROMAL2012*. Assume the properties and thickness of Glass/Epoxy lamina are same as given in the *PROMAL2012* lamina properties database.

Solution

There are 5 plies in the sequence. The laminate is unsymmetric. Five lines would then be used to show the material number and ply angles as follows

```
3,0
3,30
3,-45
3,90
3,55
```

Save it as a text file with .txt as the suffix, for example, example4.txt.

Example 5

This is an example of a symmetric laminate with even number of plies. How do I make the stacking sequence file for $[0/30/-45]_s$ Graphite/Epoxy laminate outside of PROMAL2012. Assume the properties and thickness of Graphite/Epoxy lamina are same as given in the PROMAL2012 lamina properties database.

Solution

There are 6 plies in the sequence. The laminate is symmetric. Six lines would then be used to show the material number and ply angles as follows

```
3,0
3,30
3,-45
3,-45
3,30
3,0
```

Save it as a text file with .txt as the suffix, for example, example5.txt.

Example 6

This is an example of a symmetric laminate with odd number of plies. How do I make the stacking sequence file for $[0/30/-\overline{45}]_s$ Graphite/Epoxy laminate? Assume the Graphite/Epoxy lamina properties and thickness are same as given in the PROMAL2012 lamina properties database.

Solution
There are 5 plies in the sequence. The laminate is symmetric. Five lines would then be used to show the material number and ply angles as follows

```
1, 0
1,30
1,-45
1,30
1,0
```

Save it as a text file, for example, example6.txt.

Example 7
This is an example of a hybrid laminate. How do I make the stacking sequence file for

$[10_{Gr}/\pm\overline{35}_B]_s$ laminate outside of the PROMAL2012 program. Assume the laminae properties and thicknesses of Graphite/Epoxy and Boron/Epoxy are the same as given in the PROMAL2012 lamina properties database.

Solution
The laminate consists of 6 plies where the $10°$ plies are made of Graphite/Epoxy, while the $\pm 35°$ angle plies are made of Boron/Epoxy. Note also the symmetry of the laminate. Also, the $\pm 35°$ notation indicates that the $+35°$ angle ply is followed by a $-35°$ angle ply. (Note: A notation of $\mp 35°$ would indicate the $-35°$ angle ply is followed by a $+35°$ angle ply).

There are 6 plies in the sequence. The laminate is symmetric. Six lines would then be used to show the material number and ply angles as follows

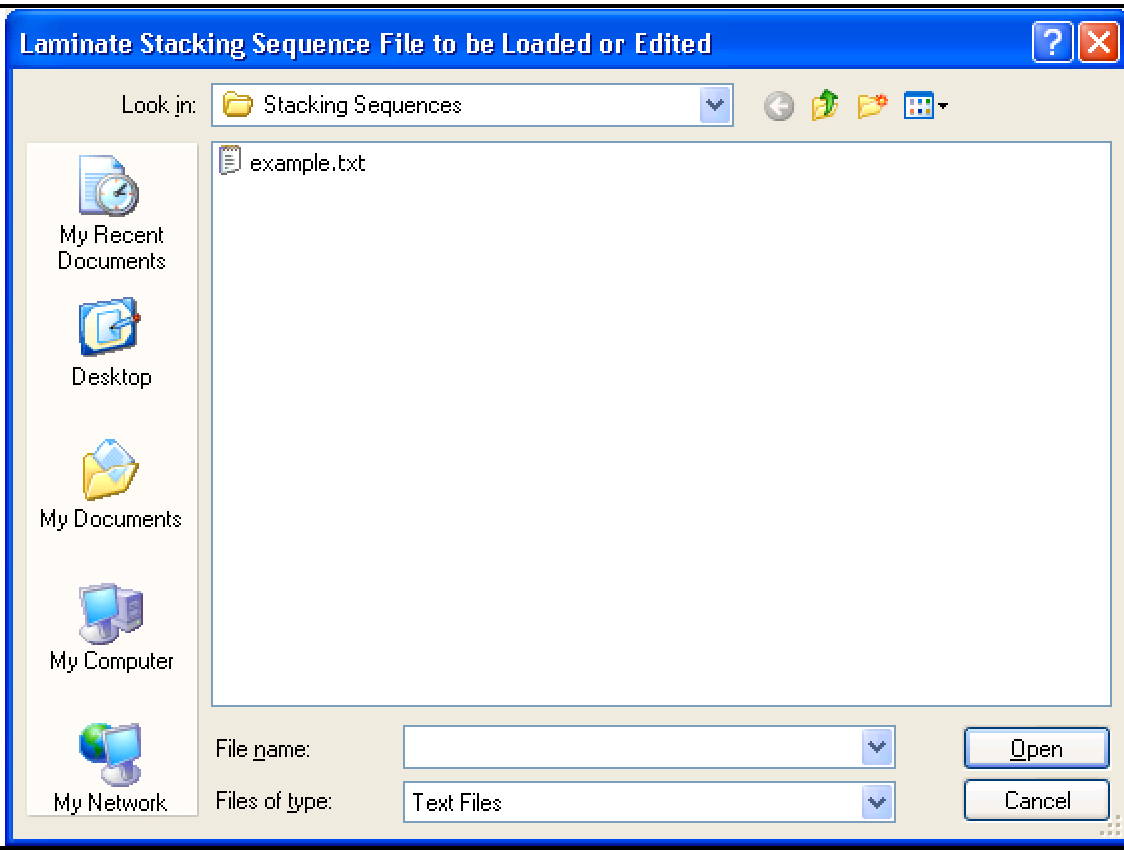
```
1,10
2,35
2,-35
2,-35
2,35
1,10
```

Save it as a text file with .txt as the suffix, for example, example7.txt.

How do I edit a previously saved laminate sequence?

Editing a laminate sequence simply involves opening a saved laminate sequence text file and making changes as desired in the stacking sequence text box (Figure 9) by following the directions given in the "How do I create a new laminate stacking sequence" question. If changes are made, the program will ask you if it is OK to save the file (cancel button cancels all changes).

Although not recommended, you can edit the laminate sequence in notepad also. However, if the data is not entered properly, the program may quit or freeze on you. If it freezes, you will need to either restart the computer or close the PROMAL.exe program in Windows Task Manager.



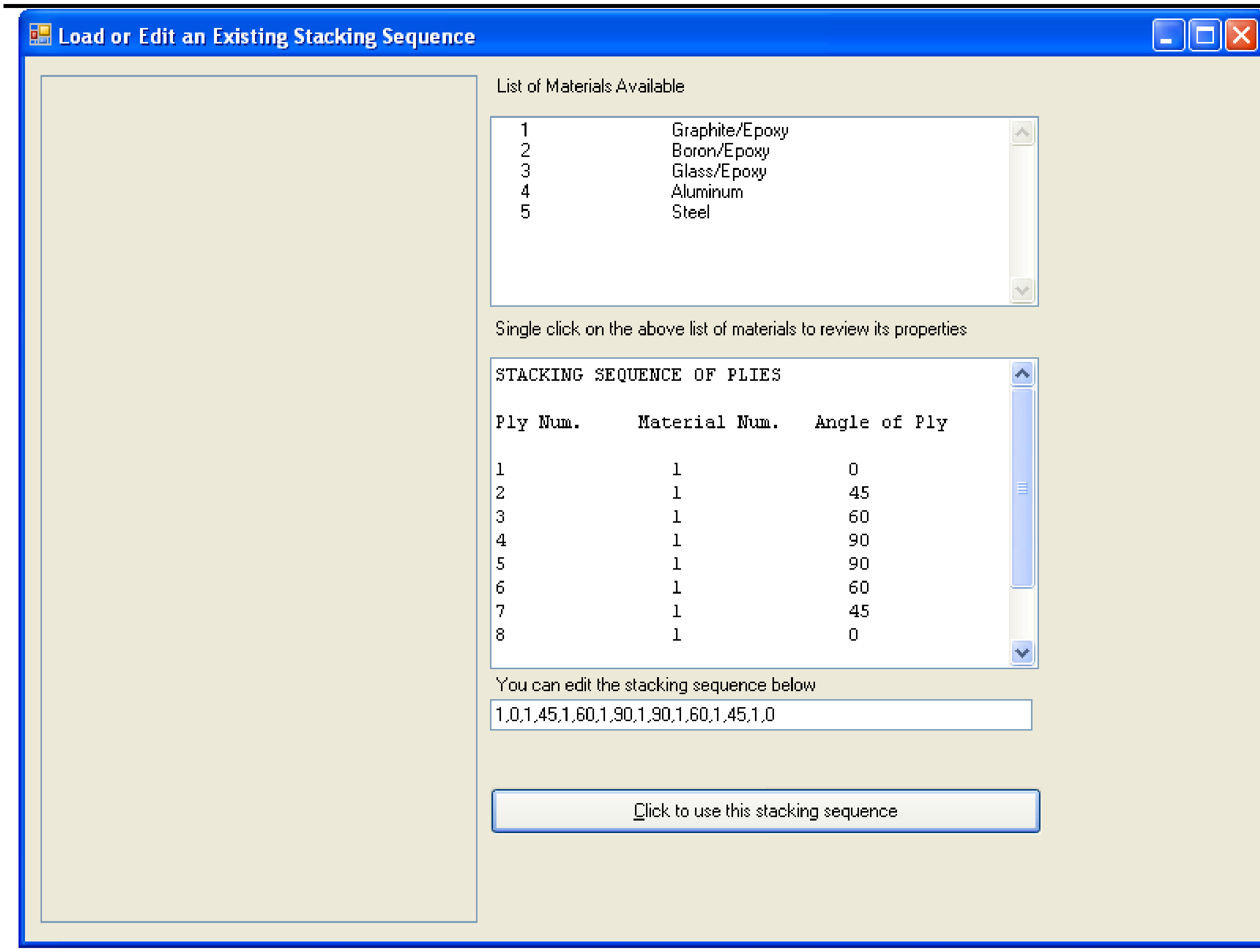


Figure 9. Menus for loading or editing a stacking sequence of a laminate.

How do I load a previously saved laminate stacking sequence?

1. Click on <u>Load/Edit Existing Stacking Sequence File</u> Button.
2. Load the laminate stacking sequence file from the dialog box.
3. You can edit the stacking sequence if you want to.
4. Click on <u>Click to use this stacking sequence</u> Button to save and/or load the laminate stacking sequence.

How do I run this program?

1. Click on <u>Load/Edit Existing Stacking Sequence File</u> Button and follow the procedure described in the previous three questions.
2. Buttons with access keys <u>C</u> through <u>D</u> allow you to view, print and/or dump to a file

the following - stacking sequence including the material names and angle of each ply; stiffness and compliance matrices including normalized matrices; equivalent plate properties such as in-plane and flexural elastic moduli, and thermal and moisture expansion coefficients.

3. Click on Applied Mechanical and Hygrothermal Loads Button to enter the mechanical loads and the hygrothermal loads. The next five buttons with access keys F through K allow you to view the effective loads, mid-plane curvatures and strains, ply by ply global and local strains and stresses, strength ratios at the top, middle and bottom of each ply, and transformed reduced stiffness matrices for each ply. *Note that if PROMAL2012 shows the strength ratio as ******, it implies that strength ratio cannot be calculated.* Typical reasons for getting ****** for strength ratios include when laminates are failing just due to hygrothermal loads, or when mechanical stresses are zero at a plane such as the mid-plane of a symmetric laminate under pure in-plane bending.

Example 8

Determine the maximum uniaxial stress you can apply in the x-direction to a $[0/45/60/90]_s$ Graphite Epoxy laminate. The x-direction is parallel to the fibers in the $0°$ ply. Use the Maximum Stress failure theory as a basis for your answer. Use the properties of unidirectional Graphite/Epoxy lamina from the Lamina Properties Database. The thickness of each ply is 0.004921 inches.

Solution

1. Click on the Macromechanics of a Laminate Button in the Master Menu.
2. Click on the Make a New Stacking Sequence File Button to make a new laminate stacking sequence. Enter the stacking sequence as

   1,0,1,45,1,60,1,90,1,90,1,60,1,45,1,0

   and click on Accept Stacking Sequence Button to save the data file.
3. The task is to find the maximum uniaxial load you can apply in the x-Direction based on the Maximum Stress failure theory. Click on Enter Mechanical and Hygrothermal Loads Button to enter a unit force per unit length in the x-direction, that is, N_x=1 lb/in.
4. Click on Strength Ratios Button to view the table of strength ratios (Figure 10).

   Minimum obtained value of strength ratio

   $= 1.279 \times 10^3$ (90^o ply)

Maximum value of uniaxial load N_x

$= \text{Load} \times \text{Strength Ratio}$

$= (1) \times (1.279 \times 10^3)$lb/in

$= 1.279 \times 10^3$ lb/in.

Thickness of the laminate

$=$ Number of plies $\times$ Thickness of one ply

$= (8) \times (4.921 \times 10^{-3})$

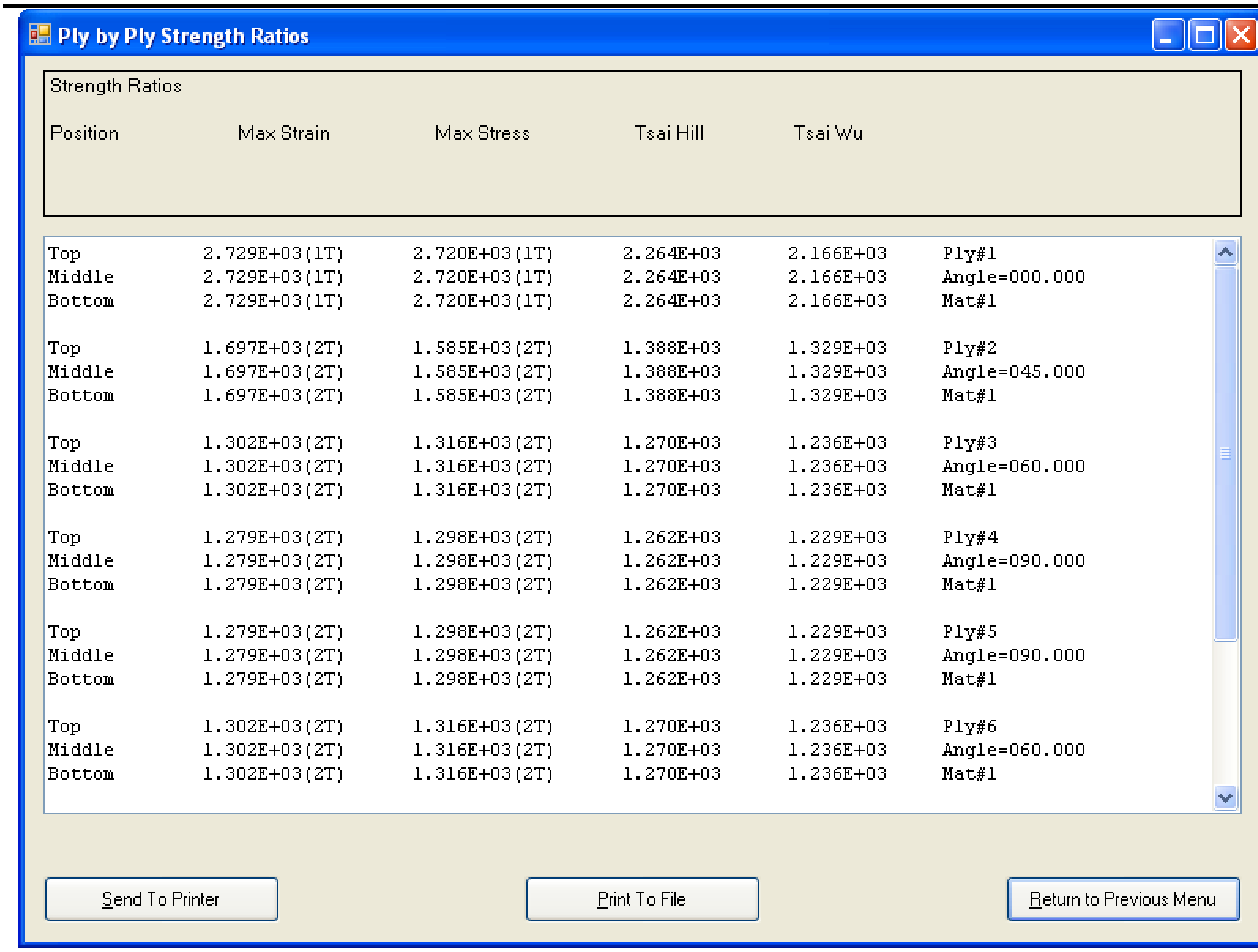
= 0.039368 inches.

Maximum allowable uniaxial stress in *x*-direction

= Maximum value of load/Thickness of laminate

$= 1.279 \times 10^3/0.039368$

= 32.488 Ksi.



Ply by Ply Strength Ratios

Strength Ratios

Position	Max Strain	Max Stress	Tsai Hill	Tsai Wu	
Top	2.729E+03(1T)	2.720E+03(1T)	2.264E+03	2.166E+03	Ply#1
Middle	2.729E+03(1T)	2.720E+03(1T)	2.264E+03	2.166E+03	Angle=000.000
Bottom	2.729E+03(1T)	2.720E+03(1T)	2.264E+03	2.166E+03	Mat#1
Top	1.697E+03(2T)	1.585E+03(2T)	1.388E+03	1.329E+03	Ply#2
Middle	1.697E+03(2T)	1.585E+03(2T)	1.388E+03	1.329E+03	Angle=045.000
Bottom	1.697E+03(2T)	1.585E+03(2T)	1.388E+03	1.329E+03	Mat#1
Top	1.302E+03(2T)	1.316E+03(2T)	1.270E+03	1.236E+03	Ply#3
Middle	1.302E+03(2T)	1.316E+03(2T)	1.270E+03	1.236E+03	Angle=060.000
Bottom	1.302E+03(2T)	1.316E+03(2T)	1.270E+03	1.236E+03	Mat#1
Top	1.279E+03(2T)	1.298E+03(2T)	1.262E+03	1.229E+03	Ply#4
Middle	1.279E+03(2T)	1.298E+03(2T)	1.262E+03	1.229E+03	Angle=090.000
Bottom	1.279E+03(2T)	1.298E+03(2T)	1.262E+03	1.229E+03	Mat#1
Top	1.279E+03(2T)	1.298E+03(2T)	1.262E+03	1.229E+03	Ply#5
Middle	1.279E+03(2T)	1.298E+03(2T)	1.262E+03	1.229E+03	Angle=090.000
Bottom	1.279E+03(2T)	1.298E+03(2T)	1.262E+03	1.229E+03	Mat#1
Top	1.302E+03(2T)	1.316E+03(2T)	1.270E+03	1.236E+03	Ply#6
Middle	1.302E+03(2T)	1.316E+03(2T)	1.270E+03	1.236E+03	Angle=060.000
Bottom	1.302E+03(2T)	1.316E+03(2T)	1.270E+03	1.236E+03	Mat#1

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Figure 10. Table showing strength ratios at top, middle and bottom of each ply in laminate in Example 8.

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