Composite Engineer’s Viewpoint

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Designing with Composite Materials
Part 4 – Detail Sizing (Computer Programs)

In the last newsletter we looked at the first sizing estimates of our composite laminate. There we considered the in-plane engineering property estimates based on carpet plots. However, we were warned not to rely on carpet plots for final strength calculations, and that we should also calculate the laminate properties fully. To do so requires the next step in the design process which is to calculate the engineering properties using a computer program.

There are several laminate computer programs available on the market. The simpler of these programs use the ‘Classical Laminate Plate Theory’ approach giving by the point stress analysis and a choice of failure criterion. The user input includes the material data base (ply engineering properties), lay-up configuration, loads and environmental conditions (operating temperature and moisture content). Such programs are relatively inexpensive ranging from about $100 to $500. You can also develop your own program on Excel, MathCAD or Matlab, etc. I personally use a rather old program (DOS based) called GENLAM as it provides a significant level of output in a simple readable file.

Using the previous newsletters example of a required stiffness ratio (E_{design}/E_{ply}) of 0.6 in an E-glass/Epoxy laminate suggested a lay-up of [50/30/20] percentage of plies in [0, ±45, 90]. If the design strain is about 4,000 μstrain (0.4%) and a configuration of the laminate is $[\pm45,0_2,90,0_2,\pm45,0_2,90]_s$ the resulting analysis gives the following:

The engineering stiffness matrices (*A*, *B*, *D*) are:

```
                          A*   B*
                          B*   D*   [GPa]

   26.689    4.401     .000      .000      .000      .000
    4.401   16.431     .000      .000      .000      .000
     .000     .000    6.360      .000      .000      .000

     .000     .000     .000    25.601     5.365      .401
     .000     .000     .000     5.365    15.592      .401
     .000     .000     .000      .401      .401     7.323
```

From this we see that with more 0 degree plies than 90 degree plies that A_{11} (26.689 GPa) is much larger that A_{22} (16.431 GPa), that the laminate is balanced in-plane that there are equal proportions of +45 and -45 degree plies since $A_{16} = A_{26} = 0$, the laminate has mid-plane symmetry since the extensorial/flexural coupling stiffness matrix $[B] = 0$. Also note that the flexural rigidity matrix [*D*] is similar in magnitude to the in-plane stiffness matrix $[A]$ and that under bending the laminate will twist only slightly since $D_{16} = D_{26} =$ 0.401 GPa is small compared with $D_{11} =$ 25.601 GPa.

These relationships are then computed as the engineering properties of in-plane moduli, Poisson's ratio, CTE, moisture expansion coefficient, and flexural rigidity moduli:

```
In-plane engineering constants

          E1o    =    25.5100       E2o    =    15.7047       E6o    =     6.3596    [GPa]
          alp1o =      9.9538       alp2o =    13.4314        alp6o =        .0000    1/[C]*1E6
          bet1o =        .0602      bet2o =        .2147      bet6o =        .0000    [kg/kg]
          nu21o =        .2679      nu12o =         .1649

 Flexural engineering constants

          E1f    =    23.7457   E2f =     14.4539   E6f =     7.3098    [GPa]
```

We note that the required stiffness, based on $E_{ply} =$ 40 GPa and thus a design stiffness $E_{design} =$ 24 GPa, has been achieved.

The design load and stress is also given in the results file as:

```
          N1 =      382.3 kN/mm                                Sigma1o    127.43 MPa
          Temperature difference =  -100.0 degC                Moisture  =  .0000
```

Whilst this would suggest that the Factor of Safety against ultimate failure (based on a ply fibre direction tensile strength of 1,060 MPa) is $FS = 8.3$. The program calculates the FS at the individual ply level against a selected failure criterion. In this case I have chosen the Quadratic Failure Criteria with the first ply and ultimate failure FS results as:

```
 Factor of Safety
          FPF                    =    .527
          Ultimate               =   5.20
```

This suggests that the laminate will start cracking in the matrix at just over half the applied load, but can sustain 5 times the load before ultimate fracture. The program also advises which plies will fail first and the progressive failure modes.

Based on these simple programs we can develop the point stress/strain and engineering properties of a laminate design. Future work will look at the detail of structural components (beams and plates) and other programs that look at structural detail.

In the next article, we will see first do a quick design review and also undertake and initial costing analysis. This will require the support of the analysis with relatively simple PC based computer programs. I also welcome questions, comments and your point of view. Feel free to contact me via r.heslehurst@adfa.edu.au. I may publish your questions and comments, and my response in future newsletter.