

Macromechanical Analysis of Laminates

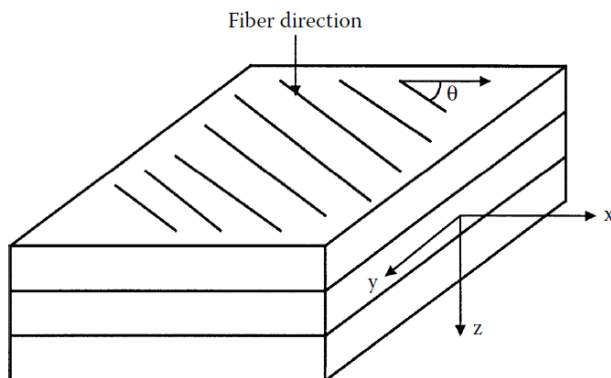
So far we have looked at macromechanical analysis of a single LAMINA, however a real structure will consist on several lamina stacked together for the following reasons;

1. A single lamina is $\sim 0.1\text{-}0.2\text{mm}$ thick, so to get a structure of meaningful strength and stiffness several lamina must be combined.
2. A single lamina is significantly weaker/more flexible transverse to the fibres, so by stacking several plys at varying orientations then this problem can be overcome

The above poses a significant problem to the Engineer. How many plys should you use, what orientation do those plys need and what about stacking sequence. This also gives the engineer significant opportunities if OPTIMISATION is used.

Laminate Code

A laminate is made of a group of single lamina bonded together;



The following notations are used to describe laminates;

0
-45
90
60
30

$$[0/-45/90/60/30]$$

(note that this implies that each ply is of the same material/thickness)

0
-45
90
90
60
0

$$[0/-45/90_2/60/0]$$

(note that two 90 degree plies are next to each other)

0
-45
60
60
-45
0

$$[0/-45/60]_s$$

(This is a SYMMETRIC laminate)

0
-45
60
-45
0

$$\left[0/-45/\overline{60}\right]_s$$

(This laminate is symmetrical but consists of an odd number of plies)

Graphite/epoxy	0
Boron/epoxy	45
Boron/epoxy	-45
Boron/epoxy	-45
Boron/epoxy	45
Graphite/epoxy	0

$$\left[0^{Gr}/\pm 45^B\right]_s$$

(This laminate is made of different materials, the +45 is followed by a -45 and is symmetric)

Other 'special' laminates

In addition to the above the following are notable ways of laying up a laminate.

0
90
90
0
90

[0/90₂0/90]

(laminates that contain only 0 or 90 plies are CROSS-PLY laminates)

-40
40
-40
40

[-40/40/-40/40]

(laminates that are only oriented a plus/minus theta are called ANGLE PLY laminates)

45
60
-60
-45

[45/60/-60-45]

(laminates that are symmetrical about the midplane except for sign are called ANTISYMMETRIC laminates)

30
40
-30
30
-30
-40

[30/40/-30/30/-30/-40]

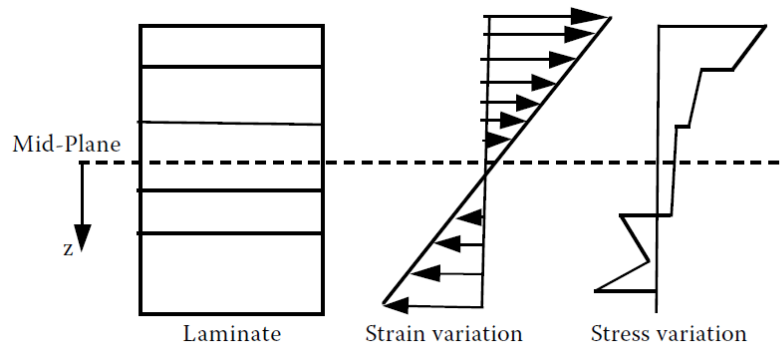
(laminates where plies are in plus/minus pairs are called BALANCED laminates – note that the pairs do not need to be adjacent to each other)

Hygrothermal Stresses and Strains

Composites are generally processed at high temperatures and then cooled down to room temperature, due to the differing thermal expansion coefficients of the reinforcement agent and the matrix residual stresses and strains will result at a micromechanical level when the composite is cooled down. In addition, most composites absorb moisture which leads to swelling stresses and strains similar to those caused by thermal expansion. These are obviously different in longitudinal and transverse directions depending on the structure of the lamina. If the lamina is free to expand then no residual stress would develop at the macromechanical level, however if the lamina is part of a laminate, so that it is not free to expand or contract then residual stresses and strains can exist in the laminate. This can be minimised by using symmetric laminates

Stresses and strains through a Laminate

It can be shown that strains vary as a function of the distance from the neutral axis (just as with isotropic materials), however because each ply has a different stiffness, although the stresses vary linearly within each ply, the stresses may jump from lamina to lamina;



In order to show the above the following assumptions are made;

1. Each lamina is orthotropic
2. Each lamina is homogeneous
3. A line straight and perpendicular to the middle surface remains straight and perpendicular during deformation ($\gamma_{xz} = \gamma_{yz} = 0$)
4. The laminate is thin and loaded in plane only
5. Displacements are continuous and small
6. Each lamina is elastic
7. No slip occurs between the lamina interfaces