# Program LAM

# 1 Introduction

The collection of Matlab command and function files in the package "lam" allows the stacking and analysis of a laminate. In fact only a representative piece of a laminate is considered, which is square and has undefined dimensions in the $xy$-plane, meaning that all loads are per unit of length.

Because a laminate consists of various layers – plies or laminas – these have to be defined : their location, thickness and material properties. From this information, the ABD-matrix can be constructed. When loading is prescribed, the deformation, being the mid-plane strains and curvatures, can be calculated. After that the strains and stresses in each ply can be calculated, both in global ($x$ and $y$) and local material (1 and 2) directions.

# 2 Installation

Installation instructions for 'lam'.

1. Save the archive tar-file in a directory, e.g. 'lam', and extract the file.
2. Set a proper path to this directory in case you run Matlab in another directory.
3. It is very convenient to make a text-file e.g. 'com.txt' to save some Matlab commands which you can copy into the Matlab shell.

# 3 Example input

As an example we consider the stacking and analysis of a 2-ply symmetric laminate.
First we clear the Matlab space and close figures.

```
clear all; close all;
```

Data on the stacking of the laminate are to be placed in the array "lam". Its first row contains the data for the upper ply, the second for the ply below it etc. When the laminate is mirrored with respect to the mid-plane ($z = 0$), we only have to give the data for the plies with $z > 0$. These data are copied later according to the mirror type, i.e. symmetric or anti-symmetric. The columns of a row in "lam" have the following data :

```
 z-   z+   ang   El    Et    Gnlt  Glt
 [mm] [mm] [deg] [GPa] [GPa] [-]   [GPa]
```

with

| | | |
|---|---|---|
| z- | [mm] | distance of lower surface of the lamina above the mid-plane |
| z+ | [mm] | distance of upper surface of the lamina above the mid-plane |
| ang | [deg] | angle of longitudinal axis w.r.t. global $x$-axis |
| El | [GPa] | longitudinal Young's modulus $E_l$ |
| Et | [GPa] | transversal Young's modulus $E_t$ |
| Gnlt | [-] | Poisson ratio $\nu_{lt}$ |
| Glt | [GPa] | shear modulus $G_{lt}$ |

For our example we have :

```
lam = ...
[  0    1   30    100   20   0.3   10
  -1    0   30    100   20   0.3   10  ];
```

Mirroring of the input data is done automatically, if needed. In that case only the top-half of the laminate must be given in "lam". Two parameters are involved. When `zm = 0`, mirroring is not done and the complete input data must be given in "lam". With `zm = 1`, the date are copied according to the value of the string parameter "ls". A symmetric laminate is made for `ls = 'sl'` and an anti-symmetric laminate for `ls = 'al'`.

In our example we do not apply mirroring, because "lam" already defines plies below and above the `z = 0` plane.

```
zm = 0;
```

Forces and moments are applied on the edges of the laminate and are given in the array "ld" in [N] and [Nm], according to :

```
ld = [ Nxx Nyy Nxy Mxx Myy Mxy ];
```

In our example we apply a tensile load in $x$-direction.

```
ld = [100 0 0 0 0 0];
```

Now the input data are complete, the laminate stacking and analysis is done by invoking the command file "runlam"

```
runlam;
```

Results can be extracted as follows :

```
disp('Laminate build-up');            disp(lam(:,1:7));
disp('Edge load');                    disp(ld);
disp('Stiffness matrix');             disp(S);
disp('Compliance matrix');            disp(C);
disp('Strains in the mid-plane');     disp(e0);
disp('Curvatures of the mid-plane'); disp(kr);
disp('Strains in each ply');          disp(rek);
disp('Stresses in each ply');         disp(str);
```

The strains in the mid-plane are as follows :

$$\text{e0}(1) = \varepsilon_{xx} \quad ; \quad \text{e0}(2) = \varepsilon_{yy} \quad ; \quad \text{e0}(3) = \varepsilon_{xy}$$

and the curvatures

$$\text{kr}(1) = \kappa_{xx} \quad ; \quad \text{kr}(2) = \kappa_{yy} \quad ; \quad \text{kr}(3) = \kappa_{xy}$$

The ply stresses and strains don't have to be uniform over the ply thickness, so in the matrices "rek" and "str", we find values at the bottom and at the top of each ply. Each ply has two rows in the matrices, going from the top to the bottom. The total number of rows is thus twice the total number of plies. Both strain and stress matrix have six columns. The first three contain the global values, the last three the local values. For the strains one row in "rek" is as follows :

$$\begin{bmatrix} \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \varepsilon_{xx} & \varepsilon_{yy} & \varepsilon_{xy} & \varepsilon_{11} & \varepsilon_{22} & \varepsilon_{12} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \end{bmatrix}$$

and for the stresses one row in "str"

$$\begin{bmatrix} \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \sigma_{xx} & \sigma_{yy} & \sigma_{xy} & \sigma_{11} & \sigma_{22} & \sigma_{12} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \end{bmatrix}$$

The local material stresses are important for failure of a ply. Both tensile and compressive stresses have to be considered. To prevent delamination, the so-called "interlaminar shear stress" must not exceed a limit value. It is calculated from the difference of shear stresses between to adjacent plies.

Maximum tensile, minimum compressive and shear stresses and strains are calculated by the function file "plystr.m", both in the material coordinate system (`Gsmc`) and the global coordinate system (`Gsgc`). Also the average values in each ply are calculated. Finally the interlaminar shear stresses (`ils`) are calculated.

```
[ Gsmc Gsgc Gsav Gemc Gegc Geav ils ] = plystr(npl,str,rek);
```

Results can also be plotted. The command file "plotlam.m" shows a deformed state of the laminate. The command file "plotstr.m" plots the stresses and the strains over the thickness. Both components in global ($x$ and $y$) directions and local material (1 and 2) directions are plotted.

```
plotlam;   plotstr;
```

Results can also be printed using the command file "prntlam.m".

It is convenient to place all input data and, if wanted, also the analysis and post processing functions in a file, which can be executed :

```
clear all; close all;
lam = ...
[  0    1   30    100   20   0.3   10
  -1    0   30    100   20   0.3   10  ];
zm = 0;
ld = [100 0 0 0 0 0];
runlam;
[ Gsmc Gsgc Gsav Gemc Gegc Geav ils ] = plystr(npl,str,rek);
disp('Laminate build-up');          disp(lam(:,1:7));
disp('Stiffness matrix');           disp(S);
disp('Compliance matrix');          disp(C);
disp('Strains in the mid-plane');   disp(e0);
disp('Curvatures of the mid-plane'); disp(kr);
```

```
disp('Strains in each ply');          disp(rek);
disp('Stresses in each ply');         disp(str);
disp('Max and min stresses');         disp(Gsmc);
disp('Interlaminar shear stresses'); disp(ils);

plotlam;
plotstr;
prntlam;
```

## 4 The package "lam"

When you look in the various files which make up the package "lam", you will notice that more options can be used than we need in our applications. It is possible to apply thermal and humidity loading. It is also possible to apply failure criteria and to see how a certain failure will affect the mechanical behavior. These options will not be used and thus not explained here.