Homework 4

Due Date: March 5th, 2021

1. What is the mechanical process that causes delamination? Provide a loading case that can cause delamination and what you would expect to observe. Describe one method for preventing delamination. (**20 points**)

2. Why is the stress at the edge of a laminate different than what would be predicted in the center of the laminate by classic lamination theory? What components of stress arise near the edges? Why would you not expect this edge stress to arise for a [±60º] laminate in uniaxial tension? (**20 points**)

3. Why can the toughness of a composite exceed the toughness of its constituent materials? Describe three different mechanisms that contribute to composite toughness and the materials systems in which we would expect them to occur. (**20 points**)

4. Silicon/PDMS composites are used as flexible solar cells. A given Si/PDMS composite has Si fibers that are $6\mu m$ in diameter, a fiber volume fraction $V_f = 40\%$, an interface toughness of $G_{ic} = 50 J/m^2$ and an interfacial shear strength of $\tau_{i*} = 3\ MPa$. Plot the energy dissipated during fracture from both interface debonding (G_{cd}) and fiber pullout (G_{cp}) as a function of pullout aspect ratio from $s = 1 - 25$. At what aspect ratio is there a transition between the dominant mechanism? What is the increase in energy dissipated from an aspect ratio of $s = 1$ to $s = 25$? (**20 points**)

5. Calculate the bending coupling (B) matrices for a [0/90] and a [0/90]$_s$ laminate made of glass fiber reinforced epoxy. Each lamina has a stiffness $\underline{C} = \begin{bmatrix} 36.5 & 2.1 & 0 \\ 2.1 & 6.6 & 0 \\ 0 & 0 & 1.8 \end{bmatrix} GPa$ and a thickness of 0.5mm. If these plates are bent to have a curvature of $\underline{\kappa} = \begin{bmatrix} 0.02 \\ 0 \\ 0 \end{bmatrix} mm^{-1}$, what is the corresponding average axial load in the plate? (**20 points**)

Coding

6. (a) Write a function to predict the first ply failure in a laminate. The inputs should be the global applied stress $\underline{\sigma}_g$, the ply layup angles, thicknesses and stiffness tensor $\underline{C}$ and the composite strengths (σ_{1*}, σ_{2*} and τ_{12*}). It should use a Tsai-Hill criterion to predict failure. The function should output which if any ply has failed and the corresponding stresses in that ply.

   (b) Now take a CFRP composite with fiber properties $E_f = 350\ GPa$, $\nu_f = 0.21$, matrix properties of $E_m = 3.4$, $\nu_m = 0.42$ and a volume fraction $V_f = 65\%$. This is made into lamina and stacked in a [0º/30º/45º/60º/90º]$_s$ layup. The thickness of the 0º, 45º and 90º plies is 0.5mm and the thickness of the 30º and 60º plies is 1mm. The failure strengths of the plies are $\sigma_{1*} = 2.1\ GPa$, $\sigma_{2*} = 75\ MPa$ and $\tau_{12*} = 160\ MPa$. If a global stress is applied with a ratio of $\underline{\sigma}_g = \begin{bmatrix} 3 \\ 1 \\ 2 \end{bmatrix} \sigma_o$, find the σ_o at which the laminate will fail to the nearest MPa and indicate which ply has failed and at what ply stress.

   Hint: To check your code, take a [0º/±45º/90º]$_s$ laminate with ply thicknesses of 0.5mm for the 0º and 90º plies and 1.0mm for the ±45º plies. The first ply to fail will be the -45°, which will fail at $\sigma_o = 96\ MPa$ *with a ply stress of* $\sigma_{-45°} = \begin{bmatrix} -171.6 \\ 74.0 \\ -22.1 \end{bmatrix} MPa$.

   Hint: see the last widget in the DoITPoMS module on failure of laminates. (*20+30=50 points*)

Total value of this homework = 12.5% of the course grade (150 points)