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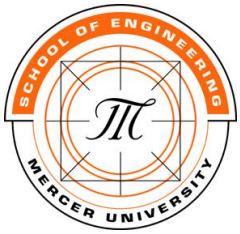

Fully Overwrapped Composite Pressure Vessels

An example

MAE 661 Laminated Composite Materials

Tank Requirements and Candidate Design

- Requirements
  - 305 mm diameter
  - Operating pressure of 20.7 MPa
  - Factor of safety of 2.0 against burst
  - Stress ratio at burst < 0.75
  - In service: ratio of operating pressure to yield pressure of 0.75
- Candidate design
  - Liner: 3.18 mm thick Al 6061-T6
    - E = 68.9 GPa, ν = 0.33, σ_y = 290 MPa
  - Overwrap: AS4-3501-6 carbon/epoxy towpreg, F_{1t} = 1830 MPa
    - Total hoop thickness t_{90} = 2.54 mm
    - Total helical thickness $t_{30} = t_{-30}$ = 1.207 mm

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Preliminary Calculations

- Since there is no bending deformation resulting from in-plane laminate loads, we want to trick CADEC into treating the laminate as symmetric; enter ply thicknesses accordingly, resulting in

$$[A]=\begin{bmatrix}483151 & 148724 & 0\\ 148724 & 659641 & 0\\ 0 & 0 & 179200\end{bmatrix} MPa\cdot mm$$

Liner + Overwrap

$$[A]=\begin{bmatrix}237273 & 67585 & 0\\ 67585 & 413762 & 0\\ 0 & 0 & 89404\end{bmatrix} MPa\cdot mm$$

Overwrap only

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Before Liner Yields

- Apply a pressure of p = 1 MPa to the tank
  - In CADEC, apply

$$N_x=\frac{pr}{2}=\frac{\left(1\frac{N}{mm^2}\right)(152.5mm)}{2}=76.25\frac{N}{mm}\quad N_y=pr=\left(1\frac{N}{mm^2}\right)(152.5mm)=152.5\frac{N}{mm}$$

    to the liner + overwrap, and calculate fiber-direction stresses
  - Results:
    - In the aluminum, σ_1 = 12.563 MPa, σ_2 = 18.628 MPa, so

$$\sigma_{eq}=\sqrt{\sigma_1^2-\sigma_1\sigma_2+\sigma_2^2}=16.456MPa$$

    - In the ±30º plies, σ_1 = 17.977 MPa
    - In the 90º plies, σ_1 = 30.266 MPa
  - Determine the pressure at which the liner yields:

$$\frac{\sigma_y}{\sigma_{eq}}=\frac{290MPa}{16.456MPa}1Mpa=17.62$$

    so the liner yields when the pressure is 17.62 MPa

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At Liner Yield

- At a pressure of 17.62 MPa, the fiber-direction stresses are:
  - In the ±30º plies, σ_1 = 17.62 x 17.977 MPa = 316.75 MPa
  - In the 90º plies, σ_1 =17.62 x 30.266 MPa = 533.29 MPa
  - Additional capability of 1830 – 533.29 = 1296.71 MPa in the hoop fibers
- As the pressure increases after the liner yields, all additional load goes into the composite
- We use CADEC to load up the composite only with additional pressure Δp (Δ denotes increment after liner yield)

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After Liner Yield

- Apply a pressure Δp = 1 MPa to the composite only

$$N_x = \frac{\Delta pr}{2} = \frac{\left(1\frac{N}{mm^2}\right)(152.5mm)}{2} = 76.25\frac{N}{mm} \qquad N_y = \Delta pr = \left(1\frac{N}{mm^2}\right)(152.5mm) = 152.5\frac{N}{mm}$$

  - Results:
    - In the ±30º plies, $\Delta\sigma_1$ = 36.98 MPa
    - In the 90º plies, $\Delta\sigma_1$ = 47.96 MPa
  - The hoop fibers will fail at an incremental pressure of

$$\Delta p = 1MPa\frac{1296.71MPa}{47.96MPa} = 27.04MPa$$

    or a total pressure of

$$p = 17.62 + 27.04 = 44.66 \text{ MPa}$$

  - The total stresses in the fibers at failure:
    - In the ±30º plies, σ_1 = 316.75 + (27.04)(36.98) = 1317 MPa
    - In the 90º plies, σ_1 = 533.79+(27.04)(47.96) = 1830 MPa

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At Burst

- Burst factor of safety = (burst pressure)/(operating pressure)

$$FS = \frac{44.66MPa}{20.7MPa} = 2.16$$

- Stress ratio at burst: (fiber direction stress in helicals)/(fiber direction stress in hoops)

$$SR = \frac{1317MPa}{1830MPa} = 0.72$$

- But the pressure at liner yield (17.62MPa) is less than the operating pressure (20.7MPa)

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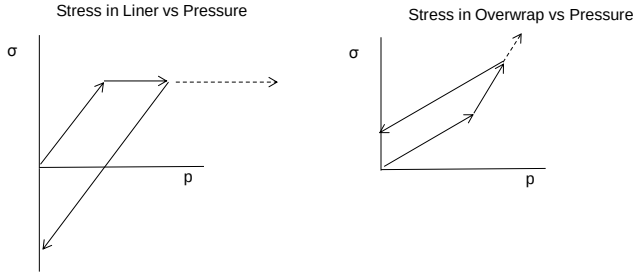
Proof Test

- To verify the quality of each tank, and to increase the liner yield pressure, the tanks are subjected to an intentional overpressure, or proof test



- Following the proof test to 4/3 of operating pressure, the liner is in compression and the overwrap is in tension.
- Upon reloading, the tank will not yield again until the proof pressure is reached.

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