AME 486

Project 4 & 5

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#1

- Composite world article
  - https://www.compositesworld.com/articles/pultruded-cfrp-chassis-enables-36-payload-increase-for-specialized-commercial-vehicles
  - A German company, developed a pultruded carbon fiber-reinforced polymer chassis for a 3.5-ton commercial vehicle
  - Reduces weight by 185 kg but increases 36% in payload capacity
  - The CRFP chassis utilizes a quadriaxial non-crimp fabric architecture and a specialized pultrusion process
  - New improvements on rigidity, durability, and service life
  - Could offer advancements for other commercial type vehicles
    - Weight savings
    - Fuel/cost savings
    - Regulations
    - Greater payload capacity
    - Efficiency

#2

- There are 15 unknowns and 15 coupled equations that are in structural analysis. The 15 unknowns are 6 stress, 6 strain, and 3 displacement relationships. The 15 governing equations consist of 3 stress equilibrium equations, 6 strain-displacement relationships, and 6 stress-strain relationships.
- Stress components (6) – internal forces per unit area
  - σ_{xx}: Normal stress in the X- direction
  - σ_{yy}: Normal stress in the Y- direction
  - σ_{zz}: Normal stress in the Z- direction
  - σ_{xy}: Shear stress on the plane normal to the z-axis
  - σ_{yz}: Shear stress on the plane normal to the x-axis
  - σ_{zx}: Shear stress on the plane normal to the y-axis
- Strain components (6) – deformation of material
  - ε_{xx}: Normal strain in the X- direction
  - ε_{yy}: Normal strain in the Y- direction
  - ε_{zz}: Normal strain in the Z- direction
  - ε_{xy}: Shear strain in the xy-plane
  - ε_{yz}: Shear strain in the yz-plane
  - ε_{zx}: Shear strain in the zx-plane
- Displacements (3 unknowns) - movement of points due to applied load
  - u = x-direction displacement
  - v = y-direction displacement
  - w = z-direction displacement

#2 Cont.

- Considerations in elasticity to derive common equations
  - 3 equilibrium equations also known as the “governing equations”

$$\frac{\partial \sigma_{xx}}{\partial x}+\frac{\partial \sigma_{xy}}{\partial y}+\frac{\partial \sigma_{xz}}{\partial z}+b_x=0$$
$$\frac{\partial \sigma_{xy}}{\partial x}+\frac{\partial \sigma_{yy}}{\partial y}+\frac{\partial \sigma_{yz}}{\partial z}+b_y=0$$
$$\frac{\partial \sigma_{xz}}{\partial x}+\frac{\partial \sigma_{yz}}{\partial y}+\frac{\partial \sigma_{zz}}{\partial z}+b_z=0$$

  - Strain – displacement relation
    - Based on Geometric considerations, 6 equations

$$\varepsilon_{xx}=\frac{\partial u}{\partial x},\ \varepsilon_{yy}=\frac{\partial v}{\partial y},\ \varepsilon_{zz}=\frac{\partial w}{\partial z} \qquad \gamma_{xy}=\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x},\quad \gamma_{yz}=\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y},\quad \gamma_{zx}=\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}$$

#2 Cont.

- Stress – strain relationship
- Using the constitutive law, the stress tensor depends on the strain tensor

$$\sigma_{ij} = F_{ij}(\varepsilon_{11}, \varepsilon_{22}, \varepsilon_{33}, \ldots)$$

- This is expanded using the Taylor Series expansion. Only the linear term is retained

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}, \qquad i, j, k, l = 1,2,3$$

- Due to material symmetry, we can express the stress-strain relationship using shorthand notation

$$\begin{bmatrix} \sigma_{11} = \sigma_1 \\ \sigma_{22} = \sigma_2 \\ \sigma_{33} = \sigma_3 \\ \sigma_{23} = \sigma_4 \\ \sigma_{13} = \sigma_5 \\ \sigma_{12} = \sigma_6 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ & & C_{33} & C_{34} & C_{35} & C_{36} \\ & \text{Sym} & & C_{44} & C_{45} & C_{46} \\ & & & & C_{55} & C_{56} \\ & & & & & C_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_{11} = \varepsilon_1 \\ \varepsilon_{22} = \varepsilon_2 \\ \varepsilon_{33} = \varepsilon_3 \\ 2\varepsilon_{23} = \varepsilon_4 \\ 2\varepsilon_{13} = \varepsilon_5 \\ 2\varepsilon_{12} = \varepsilon_6 \end{bmatrix}$$

- The standard form yields the following 6 strain relationships

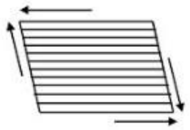
$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$$

#3

- An orthotropic material has three mutually perpendicular planes of symmetry with different mechanical properties along the three orthogonal directions
- To derive the constitutive law, the uniaxial tension test approach establishes the relationship between the normal stresses and strains as well as the shear stress and strains
- Shear stress for orthotropic lamina are typically zero under pure normal stresses

$$\gamma_{12} = \gamma_{13} = \gamma_{23} = 0$$

- Normal strains are zero under pure shear stress



$$\gamma_{12} = \frac{\tau_{12}}{G_{12}} \qquad \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \gamma_{13} = \gamma_{23} = 0$$

$$\gamma_{13} = \frac{\tau_{13}}{G_{13}} \qquad \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \gamma_{12} = \gamma_{23} = 0$$

$$\gamma_{23} = \frac{\tau_{23}}{G_{23}} \qquad \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \gamma_{13} = \gamma_{12} = 0$$

#3

- The uniaxial tension test is a virtual test that displays how the constitutive law is derived
- The axial stress along the 1-direction causes 3 strains
  - Strains in the 1-direction is directly proportional the applied stress
  - Strains in the 2-direction are due to the Poisson's ratio effect

Strain 1-direction

$$\varepsilon_{11} = \frac{\sigma_{11}}{E_1}$$

Strain 2-direction

$$\varepsilon_{22} = -\nu_{12}\,\varepsilon_{11}$$

$$\varepsilon_{22} = -\nu_{12}\,\frac{\sigma_{11}}{E_1}$$

Strain 3-direction

$$\varepsilon_{33} = -\nu_{13}\,\varepsilon_{11}$$

$$\varepsilon_{33} = -\nu_{13}\,\frac{\sigma_{11}}{E_1}$$

#3

- The virtual uniaxial test in the 2 and 3 directions are repeated
  - The strains are calculated for all the directions and are superimposed to determine the overall strain response of the material
  - This allows for calculation of the total strain response of the material when applied stresses are in any principal direction
  - The chart below shows the stress calculations for each principal direction

Total Strain	Stress in 1 –Direction		Stress in 2 –Direction		Stress in 3 –Direction
$\varepsilon_{11} =$	$\varepsilon^{1}_{11} = \dfrac{\sigma_{11}}{E_1}$	$+$	$\varepsilon^{2}_{11} = -\nu_{21}\dfrac{\sigma_{22}}{E_2}$	$+$	$\varepsilon^{3}_{11} = -\nu_{31}\dfrac{\sigma_{33}}{E_3}$
$\varepsilon_{22} =$	$\varepsilon^{1}_{22} = -\nu_{12}\dfrac{\sigma_{11}}{E_1}$	$+$	$\varepsilon^{2}_{22} = \dfrac{\sigma_{22}}{E_2}$	$+$	$\varepsilon^{3}_{22} = -\nu_{32}\dfrac{\sigma_{33}}{E_3}$
$\varepsilon_{33} =$	$\varepsilon^{1}_{33} = -\nu_{13}\dfrac{\sigma_{11}}{E_1}$	$+$	$\varepsilon^{2}_{33} = -\nu_{31}\dfrac{\sigma_{22}}{E_2}$	$+$	$\varepsilon^{3}_{33} = \dfrac{\sigma_{33}}{E_3}$

#3

- Super position was used – need to find how the strain responds to the system

$$
\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix} =
\begin{bmatrix}
\frac{1}{E_1} & -\frac{\upsilon_{21}}{E_2} & -\frac{\upsilon_{31}}{E_3} & 0 & 0 & 0 \\
-\frac{\upsilon_{12}}{E_1} & \frac{1}{E_2} & -\frac{\upsilon_{32}}{E_3} & 0 & 0 & 0 \\
-\frac{\upsilon_{13}}{E_1} & -\frac{\upsilon_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}}
\end{bmatrix}
\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix}
$$

Due to Symmetry:

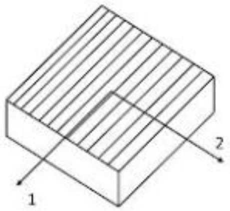
$$\frac{\nu_{ij}}{E_i} = \frac{\nu_{ji}}{E_j}$$

- E = Youngs modulus in the principle directions
- V = Poisson’s ratio
- G = Shear modulus in the planes of material symmetry

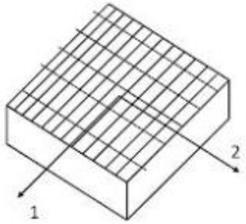
#3

- After being fully derived and super imposed, the 3D orthotropic properties are shown below.
- For specific materials, the mechanical behaviors are determined under various loading conditions

- Unidirectional lamina:
  - $E_{11}, E_{22}, E_{33}, \nu_{12}, \nu_{13}, \nu_{23}, G_{12}, G_{13}, G_{23}$
  - Typically need to specify 6 properties
    - E_{11} , $E_{22} = E_{33}$
    - $\nu_{12} = \nu_{13}, \nu_{23}$
    - $G_{12} = G_{13}, G_{23}$



- Plain weave:
  - $E_{11}, E_{22}, E_{33}, \nu_{12}, \nu_{13}, \nu_{23}, G_{12}, G_{13}, G_{23}$
  - Typically need to specify 6 properties
    - $E_{11} = E_{22}, E_{33}$
    - ν_{12} , $\nu_{13} = \nu_{23}$
    - $G_{12}, G_{13} = G_{23}$



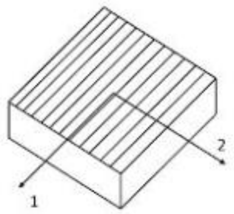
- Isotropic (need to specify two properties: E and ν)
  - $E_{11} = E_{22} = E_{33} = E$; $\nu_{12} = \nu_{13} = \nu_{23} = \nu$; $G_{12} = G_{13} = G_{23} = G = E/(2(1+\nu))$

#4

- Part A
  - Unidirectional lamina – we just derived and explained how this works. Follow the specific material property response of an orthotropic material

Unidirectional lamina:

- $E_{11}, E_{22}, E_{33}, \nu_{12}, \nu_{13}, \nu_{23}, G_{12}, G_{13}, G_{23}$
- Typically need to specify 6 properties
  - $E_{11}, E_{22} = E_{33}$
  - $\nu_{12} = \nu_{13}, \nu_{23}$
  - $G_{12} = G_{13}, G_{23}$



- $E_{11} = 28.15\ Msi$
- $E_{22} = E_{33} = 2.21\ Msi$
- $v_{12} = v_{13} = 0.356\ Msi$
- $v_{23} = 0.545\ Msi$
- $G_{12} = G_{13} = 0.774\ Msi$
- $G_{23} = 0.715\ Msi$

A)

orthotropic lamina = 70%
Void content = 4%
$V_f = 0.70$
$V_v = 0.04$

$\nu_m = 0.43$
$E_m = 0.6$ Msi
$E_f = 40$ Msi
$\nu_f = 0.35$

Volume fraction $\Rightarrow V_m = 1 - 0.7 - 0.04 = 0.26$

$$E_{11} = V_f E_f + V_m E_m + V_v E_v$$
$$= 0.7(40) + 0.26(0.6) + 0.04(0) = 28.15\ \text{Msi}$$

$$E_{22} = \frac{E_f E_m}{V_f E_e + V_e E_f} = \frac{40(.6)}{(0.7)(0.6) + (0.26)(40)}$$

$$E_{22} = 2.21\ \text{Msi} = E_{33}$$

$$\nu_{12} = V_f \nu_f + V_m \nu_m = 0.70(0.35) + (0.26)(0.43)$$

$$\nu_{12} = 0.356\ \text{Msi} = \nu_{13}$$

$$G_{12} = \frac{G_f G_m}{V_f G_m + V_m G_f}$$

$$G_f = \frac{E_f}{2(1+\nu_f)} = \frac{40}{2.7} = 14.8$$

$$G_m = \frac{E_m}{2(1+\nu_m)} = \frac{0.6}{2.86} = 0.209$$

$$G_{12} = \frac{(14.8)(0.209)}{(0.7)(.209) + (0.26)(14.8)}$$

$$G_{12} = 0.774\ \text{Msi}$$

$$\nu_{23} = \frac{-E_{22}\left[E_{11}\left((1/2) - \nu_{12}\right) + 2G_{12}\nu_{12}^2\right] + A}{2E_{11}G_{12}}$$

$$A = E_{22}^2\left[E_m\left(\tfrac{1}{2} - \nu_{12}\right) + 2G_{12}\nu_{12}^2\right] - 4E_{11}G_{12}\left[E_{11}E_{22}\left(\tfrac{1}{2} - \nu_{12}\right) - G_{12}\left(E_{11} - 2E_{22}\nu_{12}^2\right)\right]$$

$A = 33.18$

$$\nu_{23} = 0.545\ \text{Msi}$$

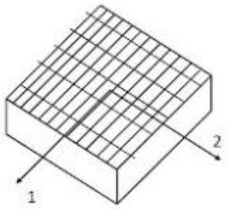
$$G_{23} = \frac{E_{22}}{2(1+\nu_{23})} = 0.715\ \text{Msi}$$

#4

- Part B
  - Plain weave
  - Note: we will see that v_{23} will be close in value to the Poisson ratio of the resin and the G_{23} is near the shear modulus of the resin

Plain weave:

- E_{11}, E_{22}, E_{33}, ν_{12}, ν_{13}, ν_{23}, G_{12}, G_{13}, G_{23}
- Typically need to specify 6 properties
  - $E_{11} = E_{22}$, E_{33}
  - ν_{12} , $\nu_{13} = \nu_{23}$
  - G_{12}, $G_{13} = G_{23}$



- $E_{11} = E_{22} = 15.18\ Msi$
- $E_{33} = 2.21\ Msi$
- $v_{12} = 0.356\ Msi$
- $v_{13} = v_{23} = 0.545\ Msi$
- $G_{12} = G_{13} = 0.774\ Msi$
- $G_{13} = G_{23} = 0.715\ Msi$

B) $E_{11} = \frac{E_{11,UD} + E_{22}\,UD}{2} = 15.18$

$E_{22} = E_{11} = 15.18$

$E_{33} = E_{33}UD = 2.21$

$V_{12} = V_{12}\,UD = 0.356$

$V_{13} = V_{23} = 0.545$

$G_{12} = 0.774$

$G_{23} = G_{13} = 0.715$

#4

- Part C
  - Most relationships are switched for A and B
  - Both unidirectional and plain weave IM7 have similar characteristics but void content, fiber and matrix volume fractions, and specific material properties differ
    - For example, E_{11} for unidirectional weave is larger that in the plain weave
      - This makes sense, unidirectional lamina exhibits stronger mechanical properties because of fiber orientation
    - If we look online at the database, we see that a 0° tensile modulus of IM7/8552 epoxy system should exhibit a tensile modulus around 23.8 Msi
      - Our estimations were close at 28 Msi
    - For plain weave, a tensile modulus between 10-13 is normal
      - Our estimations were close here as well at 15 Msi

- Source:

https://www.hexcel.com/Products/Resources/1664/hextow-laminate-properties-in-hexply-8552

#4

- Part B
  - S compliance matrix

a)

$$[S] = \begin{bmatrix} 1/E_{11} & -\nu_{21}/E_{22} & -\nu_{31}/E_{33} & 0 & 0 & 0 \\ -\nu_{12}/E_{11} & 1/E_{22} & -\nu_{32}/E_{33} & 0 & 0 & 0 \\ -\nu_{13}/E_{11} & -\nu_{23}/E_{22} & 1/E_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{31} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_{12} \end{bmatrix}$$

$$[S]_a = \begin{bmatrix} 0.035524 & -0.012647 & -0.012647 & 0 & 0 & 0 \\ -0.012647 & 0.452489 & -0.246606 & 0 & 0 & 0 \\ -0.012647 & -0.246606 & 0.452489 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.3986 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1.29199 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1.29199 \end{bmatrix}$$

$$[S]_b = \begin{bmatrix} 0.065876 & -0.02345 & -0.035903 & 0 & 0 & 0 \\ -0.023452 & 0.065876 & -0.035903 & 0 & 0 & 0 \\ -0.035903 & -0.035903 & 0.452489 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.3986 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1.29199 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1.29199 \end{bmatrix}$$

#5

- Global orientation
  - $\sigma_1 = 0.212\ Msi$
  - $\sigma_1 = 0.009\ Msi$
  - $\sigma_1 = 0.0092\ Msi$
- At 20° orientation
  - $\sigma_x' = 0.194\ Msi$
  - $\sigma_y' = 0.0268\ Msi$
  - $\tau_{xy}' = 0.0723\ Msi$

5)

$E_{11} = 20 \quad V_{12} = .3 \quad G_{12} = 0.9$

$E_{22} = 1 \quad V_{13} = 0.4 \quad G_{13} = 0.9$

$E_{33} = 1 \quad V_{23} = 0.4 \quad G_{23} = 0.5$

Single lamina

$$\begin{bmatrix} E_{11} & V_{12} & G_{13} \\ V_{12} & E_{22} & G_{23} \\ G_{31} & G_{32} & E_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \end{bmatrix}$$

$$\begin{bmatrix} 20 & .3 & .9 \\ .3 & 1 & .5 \\ .9 & .5 & 1 \end{bmatrix} \begin{bmatrix} .01 \\ .005 \\ .003 \end{bmatrix} = \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \end{bmatrix}$$

$\sigma_1 = 0.212$

$\sigma_2 = 0.009$

$\sigma_3 = .0092$

Orientation angles

$$\sigma_x = \sigma_{11}\cos^2\theta + \sigma_{22}\sin^2\theta + 2\sigma_{12}\sin\theta\cos\theta$$

$$\sigma_y = \sigma_{11}\sin^2\theta + \sigma_{22}\cos^2\theta - 2\sigma_{12}\sin\theta\cos\theta$$

$$\tau_{xy} = -(\sigma_{11} - \sigma_{22})\sin\theta\cos\theta + \sigma_{12}(\cos^2\theta - \sin^2\theta)$$

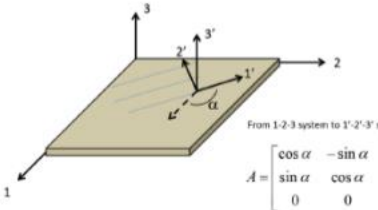
$\sigma_x' = 0.194 \quad \sigma_y' = 0.0268 \quad \tau_{xy}' = .0723$

#6

- Proving the transformation

Can use transformation to show that the stress tensor due to rotation θ about z is:

$$\sigma_{x'} = \sigma_x \cos^2\theta + \sigma_y \sin^2\theta + 2\tau_{xy}\sin\theta\cos\theta$$
$$\sigma_{y'} = \sigma_x \sin^2\theta + \sigma_y \cos^2\theta - 2\tau_{xy}\sin\theta\cos\theta$$
$$\tau_{x'y'} = (\sigma_y - \sigma_x)\sin\theta\cos\theta + \tau_{xy}(\cos^2\theta - \sin^2\theta)$$



From 1-2-3 system to 1'-2'-3' system

$$A = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Hint Use:

$$\sigma'_{ij} = A_{mi}A_{nj}\sigma_{mn}$$

$$\sigma_{22} = \sum_m\sum_n A_{m2}A_{n2}\sigma_{mn}$$
$$= A_{12}A_{12}\sigma_{11} + A_{22}A_{12}\sigma_{21} + \cancel{A_{32}A_{12}\sigma_{31}}$$
$$+ A_{12}A_{22}\sigma_{12} + A_{22}A_{22}\sigma_{22} + \cancel{A_{12}A_{32}\sigma_{13}}$$
$$+ \cancel{A_{32}A_{32}\sigma_{33}} + \cancel{A_{32}A_{22}\sigma_{32}} + \cancel{A_{22}A_{32}\sigma_{23}}$$
$$= \sin^2\alpha\,\sigma_x - \sin\alpha\cos\alpha\,\tau_{xy} + (-\sin\alpha)(\cos\alpha)\tau_{xy} + \cos^2\alpha\,\sigma_y$$

$$\boxed{\sigma_{22} = \sigma_x\sin^2\alpha + \sigma_y\cos^2\alpha - 2\tau_{xy}\sin\alpha\cos\alpha}$$

$$\sigma_{12} = \sum_m\sum_n A_{m1}A_{n2}\sigma_{mn}$$
$$= A_{11}A_{12}\sigma_{11} + A_{21}A_{12}\sigma_{21} + \cancel{A_{31}A_{12}\sigma_{31}}$$
$$+ A_{11}A_{22}\sigma_{12} + A_{21}A_{22}\sigma_{22} + \cancel{A_{11}A_{32}\sigma_{13}}$$
$$+ \cancel{A_{31}A_{32}\sigma_{33}} + \cancel{A_{31}A_{22}\sigma_{32}} + \cancel{A_{21}A_{32}\sigma_{23}}$$
$$= \cos\alpha\sin\alpha\,\sigma_x + \sin^2\alpha\,\tau_{xy} + \cos^2\alpha\,\tau_{xy} + \sin\alpha\cos\alpha\,\sigma_x$$

$$\boxed{\tau_{12} = (\sigma_y - \sigma_x)\sin\alpha\cos\alpha + \tau_{xy}(\cos^2\alpha - \sin^2\alpha)}$$

$$\sigma'_{ij} = A_{mi}A_{nj}\sigma_{mn} \qquad A = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\sigma_{11} = \sigma_{x'}, \quad \sigma_{22} = \sigma_{y'}$$

$$\sigma_{12} = \tau_{xy}$$

$$\sigma_{11} = \sum_m\sum_n A_{m1}A_{n1}\sigma_{mn}$$
$$= A_{11}A_{11}\sigma_{11} + A_{21}A_{11}\sigma_{21} + \cancel{A_{31}A_{11}\sigma_{31}}$$
$$+ A_{11}A_{21}\sigma_{12} + A_{21}A_{21}\sigma_{22} + \cancel{A_{11}A_{31}\sigma_{13}}$$
$$+ \cancel{A_{31}A_{31}\sigma_{33}} + \cancel{A_{31}A_{21}\sigma_{32}} + \cancel{A_{21}A_{31}\sigma_{23}}$$
$$= \cos\alpha^2\sigma_x + \sin\alpha\cos\alpha\,\tau_{xy} + \cos\alpha\sin\alpha\,\tau_{xy} + \sin^2\alpha\,\sigma_y$$

$$\boxed{\sigma_{11} = \sigma_x\cos^2\alpha + \sigma_y\sin\alpha^2 + 2\tau_{xy}\sin\alpha\cos\alpha}$$

#7

- Since we were given strain data in problem 5, I used the material properties to compute stresses. Shown below. THIS IS THE CORRECT SOLUTION

7) $d = 30\text{ in}$, $p = 100\text{ psi}$, $\alpha = 30^\circ$

material properties (Pr. 5)

[orthotropic lamina]

$E_{11} = 20\text{ Msi}$ $\quad \varepsilon_1 = 1\%$

$E_{22} = E_{33} = 1\text{ Msi}$ $\quad \varepsilon_2 = 0.5\%$

$\nu_{12} = 0.3$ $\quad \varepsilon_3 = 0.3\%$

$\nu_{13} = \nu_{23} = 0.4$

$G_{12} = G_{13} = 0.9$

$G_{23} = 0.5\text{ Msi}$

$$\begin{bmatrix} E_{11} & \nu_{12}E_{12} & 0 \\ \nu_{12}E_{11} & E_{22} & 0 \\ 0 & 0 & G_{12} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{12} \end{bmatrix}$$

$\sigma_{11} = 0.2024\text{ Msi}$

$\sigma_{22} = 0.00804\text{ Msi}$

$\sigma_{12} = 0.0027\text{ Msi}$

$N_n = \sigma_{11}\cos\alpha + \sigma_{12}\sin\alpha$ Normal

$0.2024\cos(30) + 0.0027\sin(30) = \boxed{0.176\text{ Msi}}$

$N_s = \sigma_{11}\sin\alpha - \sigma_{12}\cos\alpha$ shear

$0.2024\sin(30) - 0.0027\cos(30) = \boxed{0.0988\text{ Msi}}$

- Without the strain data, you can also solve using the internal pressure and vessel diameter to calculate stress. We were never given a thickness of the vessel. It said to use problem 6 material properties, it doesn't exist. Because we don't have thickness our estimation is going to be all over the place.

Using Problem 6

$\sigma_{11} = \sigma_z\cos^2\alpha + \sigma_\theta\sin^2\alpha$ $\qquad \sigma_\theta = \frac{Pr}{t}$

$\sigma_{22} = \sigma_z\sin^2\alpha + \sigma_\theta\cos^2\alpha$ $\qquad \sigma_z = \frac{Pr}{2t}$

$\sigma_{12} = (\sigma_\theta - \sigma_z)\sin\alpha\cos\alpha$

we don't know t

$\sigma_{11} = \left(\frac{Pr}{2t}\right)\cos^2\alpha + \frac{Pr}{t}\sin^2\alpha$

$\sigma_{22} = \frac{Pr}{2t}\sin^2\alpha + \frac{Pr}{t}\cos^2\alpha$

$\sigma_{12} = \left(\frac{Pr}{t} - \frac{Pr}{2t}\right)\sin\alpha\cos\alpha$

$\downarrow$

$\sigma_{11} = \frac{Pr}{t}\left(\frac{1}{2}\cos^2\alpha + \sin^2\alpha\right) = \frac{0.0009375}{t}\text{ Msi}$

$\sigma_{22} = \frac{Pr}{t}\left(\frac{1}{2}\sin^2\alpha + \cos^2\alpha\right) = \frac{0.0013125}{t}\text{ Msi}$

$\sigma_{12} = \frac{Pr}{t}\left(\frac{1}{2}\sin 2\alpha\right) = \frac{0.00064\,95}{t}\text{ Msi}$

$\sigma_{11} = 0.000938\text{ Msi}$

$\sigma_{12} = 0.00065\text{ Msi}$

$N_n = \sigma_{11}\cos\alpha + \sigma_{12}\sin\alpha$ $\qquad N_n = \sigma_{11}t$

$N_s = \sigma_{11}\sin\alpha - \sigma_{12}\cos\alpha$ $\qquad N_s = \sigma_{12}t$

$$\boxed{\begin{array}{l} N_n = 0.00137\text{ Msi} \\ N_s = -94.4\text{ Msi} \end{array}}$$

#8

- Used material properties from Problem 5. Again, problem 6 did not have any material properties attached to it.

8) $L = 8in$

$w = 2in$

$t = 0.005in$

$G_{axial} = 1000\ lbs$

Material properties from Problem 5

$\varepsilon_i = 0.005$

$\varepsilon_1 = 0.01$

$E_{11} = 20\ msi$

$E_{22} = 1\ msi$

$\nu_{12} = 0.3$

$$\text{transverse strain } (\varepsilon) = -\nu_{12}\frac{\varepsilon_1}{E_{11}}E_{22} + \varepsilon_i$$

$$\varepsilon = -(0.3)\frac{0.01}{20}(1) + 0.005$$

$$\boxed{\varepsilon = 0.00485}$$

PRJ #5, Problem #1

- Tensile Tests
  - The purpose of this test is to determine the Young's Moduli (E_1, E_2, E_3) and Poisson's ratio (ν_{12}, ν_{23}, ν_{31})
  - This test consists of performing uniaxial tensile tests along each principal material direction that being 1,2 and 3.
  - The measurements from this test are:
    - Axial strain: which is used to determine Young's modulus
    - Transverse strain: used to determine Poisson's ratio
- Shear Tests
  - The purpose of this test is to determine the Shear Moduli (G_{12}, G_{23}, G_{31})
  - The test is performed by applying pure shear loads in the following planes: 1-2, 2-3, and 3-1.
  - From this test, we can measure shear stress and shear strain that will help compute the shear modulus, G

PRJ #5, Problem #2

- The off-axis 45 degree test is a method that estimate shear strength by applying a tensile load at an angle to the principal material directions
  - This however overpredicts the shear strength due to:
    - The specimen also experiencing normal stresses in the principal material directions
      - These normal stresses contribute to failure in a way that leads to a higher apparent strength than the correct and true shear strength
    - Composites are strong in tension along fiber directions, but in a off-axis test the fibers carry part of load
      - That leads to a failure mode that is not shear dominated and can lead to an overestimation of the material's shear properties
    - The involvement of normal and shear stresses makes the test not purely uniformly shear and make it hard to get accurate measurements for pure shear properties of the material.
- Losipescu Shear Test
  - Acceptable method of directly measuring the shear properties of materials, it provides pure shear stress conditions, resulting in more accurate measurements for shear modulus (G) and shear strength
  - The setup can be described as a rectangular specimen with a V-notch cut, where it is clamped in a special fixture that applied a pure shear force across (perpendicular) the notched area; to measure shear strain, strain gauges are placed in the notched area
  - Advantages:
    - Pure shear loading; avoiding normal stresses
    - Direct measurement of shear properties: shear modulus and strength
    - Works for fiber-reinforced composites and anisotropic materials
    - Specimen size is small; efficient and cost effective for testing

PRJ #5, Problem #3

- **Potential pitfalls short beam shear test**
  - Difficult to get a uniform shear in test specimen
  - Some tests adequately determine shear strength but not shear modulus
  - Does not obtain a pure/uniform shear stress state
  - Less than ideal stress state present on the test specimen
  - Applied loading creates high local stress concentrations
  - Short length of the beam does not permit large zones of uniform shear stress

- **Benefits of short beam shear test**
  - Very simple, low cost, very efficient
  - Excellent for material screening and quality control test, particularly for unidirectional composites
  - Good indicator of the quality of a fiber matrix interfacial bond
  - Requires a small test specimen
  - Focuses on primarily on three-point loading – this is advantages and spreads out the applied load better

- Despite the disadvantages of the short beam shear test, the test offers simplicity and effectiveness in assessing quality of a material

PRJ #5, Problem #4

- Interlaminar strength in composite materials refers to the ability of the layers to resist separation under various loading conditions
- From the paper, it expresses the need of improving the modeling techniques used to predict delamination in composite materials
- By using Sun's failure criterion, which accounts for the interaction between shear and normal stresses at the interface, the authors enhance the interfacial constitutive law
  - This improvement can allow for a more accurate prediction of delamination initiation and growth under different ranges of loading conditions
- Types of Testing that can be performed to obtain a failure criteria for interlaminar strength:

  - Short Beam Shear (SBS) Test:
    - Measures the interlaminar shear strength by applying a load to a short beam specimen until failure occurs. This test is usually more useful for materials that have brittle matrices.

  - Interlaminar Tensile Strength Test:
    - Evaluates the tensile strength between layers by subjecting a specimen to tensile loading perpendicular to the laminate plane.

  - Curved Beam Test:
    - Assesses the interlaminar tensile strength by applying tensile loads to a "curved composite specimen", which induces stress concentrations that can lead to delamination.

PRJ #5, Problem #5

- From lecture, we learned that A- Basis and B-Basis value represent statistical lower-bound estimates of material properties, with A-Basis being our first percentile value and B-Basis being our 10^{th} percentile value
- **Why selection matters:**
  - Regulatory compliance:
    - Industries such as aviation and NASA require A-Basis for flight-critical components
    - B-Basis may be used for more cost-effective performance such as automotive and general manufacturing
  - Structural Safety:
    - A-Basis used for critical components, can prevent catastrophic failures in aircraft, spacecraft, and medical devices/equipment
    - B-Basis can serve an adequate approximate for applications with lower risk
  - Weight and Cost Efficiency:
    - Since A-Basis is very conservative and critical, this leads to heavier and costlier designs, and budget is very important to companies and those who put up an RFP

- **Why documenting pictures of samples that were tested matters?**
  - Analysis of Failure Mode:
    - Serves as a tool to identify failure mechanisms (ex. Brittle fracture, delamination, etc.)
    - Can be used for diagnosing unexpected results or some deviation from your expected behavior
  - Test Conditions can be validated
    - Documentation can confirm whether or not the test was conducted properly and according to standards
      - Ex. Loading conditions, test fixture setup, alignment of specimen
  - Detection of Manufacturing
    - Helps identify voids, cracks, and fiber misalignment

PRJ #5, Problem #5 cont.

- **Why screening for outliers matters?**
  - Outliers can distort statistical analysis, which can lead to incorrect design values and skew property data, making it inaccurate and not dependable
  - Key reasons for screen outliers:
    - Ensures true material behavior is reflected in its design values
    - Detects testing errors from misalignment, improper test setups, or equipment malfunctions
    - Can indicate material defects or inconsistencies
    - Ensures regulatory compliance within many standards
    - Overall ensures engineers reliable and accurate data

PRJ #5, Problem #6

- This chapter mainly focuses on the design of composite material, in which it provides very detailed and extensive guidelines for effective application in structural components.
- The ten lessons from reading this document are (in no particular order):
  - **Composite Behavior:** Recognizing the unique anisotropic properties of composites that are crucial for having an accurate and reliable analysis and design

  - **Material Selection Criteria:** Knowing how to select appropriate matrix and fiber combinations based on requirements of performance and environmental conditions to ensure optimal composite performance without failure or environmental degradation.

  - **Load Transfer Mechanism:** Designing an effective specimen or apparatus load transfer between adjoining structures and composite components to prevent stress concentrations (voids) and potential failures.

  - **Design Allowable:** Essentially setting a standard that is based on statistics for design allowable through many variations of testing and analysis to ensure reliable structural performance

  - **Manufacturing Process Integration:** The incorporation of manufacturing considerations in the design process to help select suitable fabrication methods, tooling, to produce consistent and quality composites.

PRJ #5, Problem #6 cont.

- **Environmental Considerations:** Depending on the material's application or location in which it will be used, factors such as temperature, humidity, and UV exposure are put into consideration during the design phased to ensure a greater life cycle and durability of the composite structure.

- **Damage Tolerance and Repairability:** Accounting for damage tolerance and considering methodologies for repair to further enhance the lifespan and structure of these composites.

- **Cost Benefit Analysis:** The balancing between the manufacturing costs of the material and the performance benefits to investigate the economic side of composite applications.

- **Quality Assurance:** The implementation of quality control measures during material selection, fabrication and the assembly processes to ensure the quality and reliability of the final product.

- **Regulatory Compliance:** Respecting and adhering to industry standards; standards can change based on the type of industry (critical components, etc.)

PRJ #5, Problem #7

- In early stages of society, builders found that mud dwellings lack in structure but when combined with straw, it increased its resistance to tearing and squeezing, resulting in a better dwelling
- But since then, we have used composites because of weight reduction and increase in strength has been developed for flight critical components
- The type of material that the CCM is made of carbon graphite epoxy resin system, it's a fabric that was hand laid up on a male tool then put into a pressurized oven, called an autoclave, which gets cook
  - Afterwards, aluminum honeycomb is added, gluing the honeycomb to the skin, cure it then lay another skin, then back into the autoclave and cure it
- The shape of the CCM, was first built around the backbone, in which they designed the flooring to be connected with the backbone and then designed to take advantage of the shape of the backbone.
- Factor of safety should always be considered for your design requirements, just so if there is little variation in the composite, the behavior should be within requirements/limits due to factor of safety

PRJ #5, Problem #7 cont.

- Shell buckling is one of the primary failure modes in launch vehicles structures
- The buckling phenomena is when you are applying a compressive load to a structure, and it can no longer withstand that load and causing the structure's cross section to crush inward
- DIC is used a visual aid but also to analyze the buckling effect on these spacecraft structures, to see even the littlest of movements in the dots spattered on the structure
- Especially in the automotive industry, it is really hard to move the world to more fuel-efficient cars as the key to make them lighter is composites, however composites are not cheap (carbon fiber), and people don’t want to sacrifice certain aspects of the regular cars (e.g. AC) to make them more fuel efficient

PRJ #5, Problem #8

- To establish the material properties for composites, the NCAMP conducted a series of standardized tests that include:
    - **Tensile Testing:** evaluates the material's response to uniaxial tensile stress, which therefore determines the following properties: tensile strength, modulus, and elongation at the breakpoint.
    - **Compressive Testing:** Under compressive loads, assesses the behavior of composites, which can produce data on modulus and compressive strength.
    - **Shear Testing:** this test measures the material's ability to resist shear forces, whilst yielding interlaminar shear strength and in-plane shear properties
    - **Fatigue Testing:** assesses the durability of the composite to be able to predict lifespan and performance over time which can have a great impact on the design process
    - **Flexural Testing:** determine the flexural strength and modulus when subjected to bending forces
    - **Fracture Toughness Testing:** assesses the composite's resistance to crack and propagate to understand its failure mechanism.

PRJ #5, Problem #9

- **Tensile testing** was conducted to determine properties such as tensile strength, modulus, and elongation
  - Were conducted to follow ASTM D3039 standard s
- **Shear testing**: measure the material's ability to resist shear forces, which resulted in finding interlaminar shear strength and in-plane shear properties
  - Aligns with the ASTM D5379
- **Compressive Testing:** Behavior under compressive loads is analyzed that provides compressive strength and modulus
  - Tests conducted to consist with ASTM D3410 standards
- **Thermal Analysis:** thermal properties are evaluated, including glass transition T_g and thermal expansion coefficients using TMA
- **Flexural Testing:** as stated previously, this test determines the flexural strength and modulus by subjecting the composite to bending forces.
  - This test follows ASTM D790 standards.

PRJ #5, Problem #10

- Based on the text, the thermomechanical analyzer (TMA) measures the dimensional changes in a sample with high precision.
- This method is valuable for characterizing composites, as to provide insights into their thermal and mechanical behavior under varying conditions
  - Can detect transitions such as glass transitions, softening points, and other phase changes
- As we know the coefficient of thermal expansions (CTE) quantifies the rate at which a material expands or contracts with temperature changes
- With TMA, the sample is subjected to a controlled temperature program and its dimensional changes are recorded
- TMA and CTE evaluations help in monitoring the consistency of composite materials during manufacturing, to make sure that they meet specific mechanical performance and thermal criteria.
- Knowing of the CTE, is vital as a mismatch in CTEs, can lead to internal stresses, warping, or delamination
- In addition, TMA and knowing of your CTE will help in monitoring the consistency of composite materials during manufacturing to meet quality, thermal, and mechanical performance criteria.

PRJ #5, Problem #11

- A statistical process control plays a key role in a composite test program as it ensures consistency, quality and reliability in material manufacturing and testing
- There are many variables during the 5 stages of curing, fiber orientation, resin content, etc. that can affect the performance and quality of the composite
  - Statistical process control provides a structured approach to control and monitor these variations
- Reasons to implement statistical process control:
  - Ensure consistency in material properties
  - Can detect process variability in the early stages
  - Test data had that extra cushion of reliability
  - Minimizes the risk of producing defective composite parts
    - Leads to cost savings for testing and production
  - Can serve as documented evidence of process control for aerospace and automotive industries as they are required to be in strict compliance with ASTM, FAA, etc.

PRJ #5, Problem #12

- “Laminate bearing/bypass interaction test methods
- Mechanically fastened joints are often used in structures, including composite structures
  - To transfer load from portion of the structure to another
    - This load is transferred by bearing (contact) forces that develop between the fastener and the side of the hole in the structure it occupies
- If a fastener fails, the mode is typically transverse shear
  - This shear strength is readily measured
- The challenge is to design the joint so that each fastener carries only an allowable portion of the total applied load so that neither it nor the hole in the composite structure fails prematurely.
  - Each individual fastener transfers a portion of the total load via a bearing force

PRJ #5, Problem #12 cont.

- The ideal test apparatus would be capable of independently applying specified amounts of bearing and bypass load to a composite laminate specimen that incorporates a single fastener
    - But such equipment is expensive, somewhat cumbersome but they are not impractical
- Very simple tests using multiple fasteners to achieve bearing with bypass is possible, but albeit with limited control of the ratio
    - Approach was taken by ASTM for a new standard
- A bypass failure is achieved if the specimen fails somewhere between the two fasteners
    - A failure at the lower fastener indicated a laminate bearing failure
- Buckling is a concern when the unsupported specimen is loaded in compression, therefore an anti-buckling fixture would have to be used
    - Not a problem for tensile loading
    - Fixtures can be used or not, but the test report should clearly indicate if it was used
- Looks like these methods are still being researched and looked into right now, but definitely something to keep an eye for

PRJ #5, Problem #13

- **Issues that could arise in a test program:**
  - Material variability
    - Differences in resin distribution, void content, curing cycle, and fiber alignment can give inconsistent results
  - Defects in test coupons
    - Issues of delamination, porosity, fiber waviness and incomplete curing can all lead to incorrect material properties and values
  - Small samples size can’t capture the full range of the material variability
  - Variation in the testing environment
  - Improper test set up and alignment can cause unintended stress concentrations
- **To minimize these issues:**
  - Implement non-destructive evaluation (NDE) of test coupons
    - Through ultrasonic testing, X-ray or thermography, we can inspect the coupons before testing, which can identify internal defects, ensuring that the data is valid and reliable
  - Increase the sample size and implement statistical process control to monitor trends and variability
  - Control the curing cycles, fiber placement and resin mixing
  - Conduct tests in a controlled environment

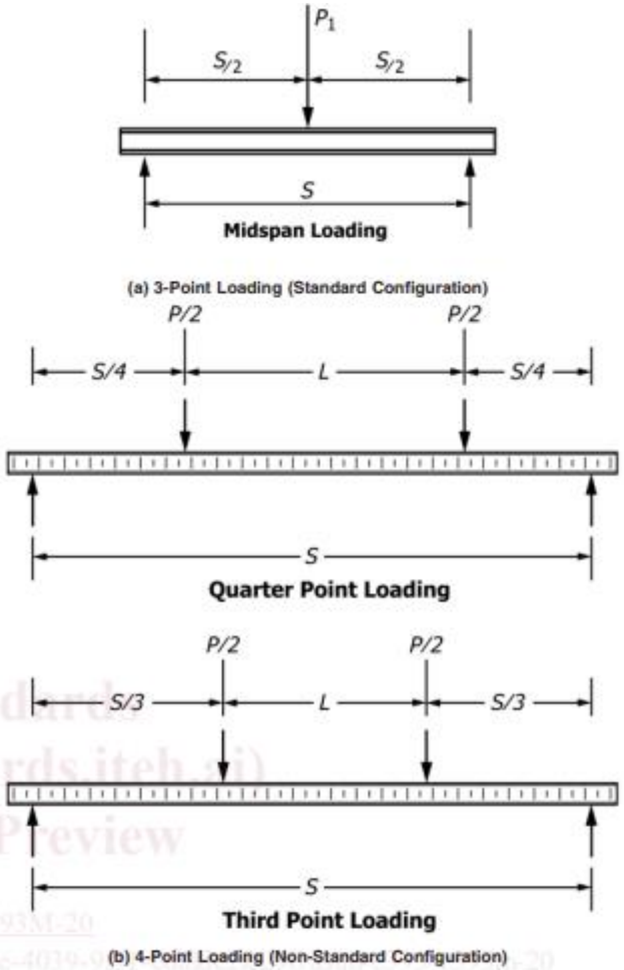
PRJ #5, Problem #13 cont.

- Implication of a bad test program on the design?
  - Over or under prediction of strength
    - Defective coupons, if not detected, can provide strength values that may be overestimated
    - If material properties are underestimated, then it shows a overly conservative design
  - Incorrect data can lead to unnecessary changes in design, meaning wasted effort and cost with more material waste
  - Incorrect data can cause delays and problems if material qualification is rejected by FAA, ASTM, etc.

PRJ #5, Problem #14 (A)

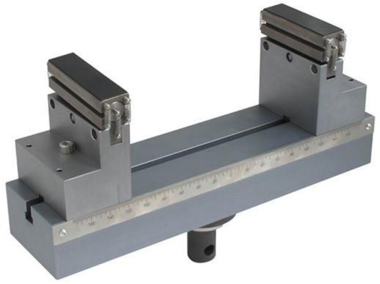
- ASTM C393
  - Flexure test for composites
  - Determines sandwich structure flexural stiffness, core shear strength, core shear modulus, and facial compressive/tensile strengths
  - Can evaluate core-to-facing bond strength
  - Provides load-deflection data for stiffness calculations per the D7250 and D7250M standards
  - Applicable to sandwich panels with continuous and discontinuous bonding surfaces

  - Bend fixture
    - Two rubber pads
    - 4-point or 3-point bend fixture
    - Adjustable length
    - Controlled speed on test bench



	Configuration	Support Span (S)	Load Span (L)
Standard	3-Point (Mid-Span)	150 mm [6.0 in.]	0.0
Non-Standard	4-Point (Quarter-Span)	S	S/2
	4-Point (Third-Span)	S	S/3

FIG. 1 Loading Configurations



The support span length shall satisfy:

$$S \leq \frac{2k\sigma t}{F_s} + L \qquad (1)$$

or, the core shear strength shall satisfy:

$$F_s \leq \frac{2k\sigma t}{(S - L)} \qquad (2)$$

The core compression strength shall satisfy:

$$F_c \geq \frac{2(c+t)\sigma t}{(S - L)l_{pad}} \quad \text{(4-point loading)} \qquad (3)$$

$$F_c \geq \frac{4(c + t)\sigma t}{S l_{pad}} \quad \text{(3-point loading)}$$

where:

S = support span length, mm [in.],
L = loading span length, mm [in.] (L = 0 for 3-point loading),
σ = expected facing ultimate strength, MPa [psi],
t = facing thickness, mm [in.],
c = core thickness,
F_s = estimated core shear strength, MPa [psi],
k = facing strength factor to ensure core failure (recommend k = 0.75),
l_{pad} = dimension of loading pad in specimen lengthwise direction, mm [in.], and
F_c = core compression allowable strength, MPa [psi].

Source:
https://www.youtube.com/watch?v=LwH23xs87QE
https://www.astm.org/c0393_c0393m-20.html
https://cdn.standards.iteh.ai/samples/107575/67ba0e7192a048628bc69339503cb687/ASTM-C393-C393M-20.pdf

PRJ #5, Problem #14 (A)

- ASTM C393 basic equations

Flexural Modulus (E)

$E = (F/d) * (l^3/4bh^3)$

Where:

- E = Flexural Modulus (GPa)
- F = Applied force at fracture (N)
- d = Displacement at the loading point (mm)
- L = Span length between supports (mm)
- b = Width of the specimen (mm)
- h = Height of the specimen (mm)

Flexural Strength (σf)

$\sigma f = (3F*L) / (2b*d^2)$

Where:

- σf = Flexural Strength (MPa)
- F = Applied force at fracture (N)
- L = Span length between supports (mm)
- b = Width of the specimen (mm)
- d = Thickness of the specimen (mm)

Strain (ε)

$\varepsilon = (6d / L) * (F / (b\,h^3))$

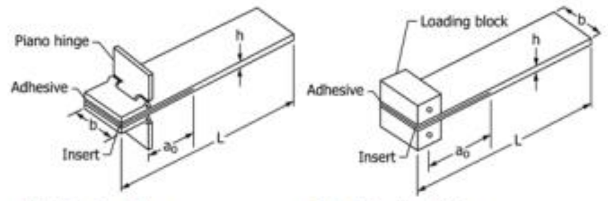
Where:

- ε = Strain (unitless)
- d = Displacement at the loading point (mm)
- L = Span length between supports (mm)
- F = Applied force at fracture (N)
- b = Width of the specimen (mm)
- h = Height of the specimen (mm)

Source:
https://www.youtube.com/watch?v=LwH23xs87QE
https://www.astm.org/c0393_c0393m-20.html
https://cdn.standards.iteh.ai/samples/107575/67ba0e7192a048628bc69339503cb687/ASTM-C393-C393M-20.pdf

PRJ #5, Problem #14 (B)

- ASTM D5528
  - Mode 1 fracture toughness – evaluates the susceptibility to delamination in laminated composite structures
  - Measures resistance to interlaminar fracture using a double cantilever beam test
  - Assess fiber surface treatment, fiber volume fraction variations, and environmental effects
  - Good for comparing fracture toughness between different composites or different batches of the same material
  - Helps develop delamination failure criteria for damage tolerance and durability analysis
  - Good for materials with unidirectional carbon fiber and glass fiber tape laminates with polymer matrices



(a) with piano hinges (b) with loading blocks

FIG. 1 Double Cantilever Beam Specimen

3.2.3 *strain energy release rate, G [M/T²]*—the loss of energy, dU, in the test specimen per unit of specimen width for an infinitesimal increase in delamination length, *da*, for a delamination growing self-similarly under a constant displacement. In mathematical form,

$$G = -\frac{1}{b}\frac{dU}{da} \quad (1)$$

where:

U = total elastic energy in the test specimen,
b = specimen width, and
a = delamination length.

Mode I Interlaminar Fracture Toughness (G_IC)

G_IC = (P_c * a) / (B * h) * (1/2 * [1 - (a/w)²])

Where:

- G_IC = Mode I interlaminar fracture toughness (J/m²)
- P_c = Critical load at delamination initiation (N)
- B = Specimen width (m)
- h = Specimen thickness (m)
- a = Crack length (m)
- w = Specimen width (m)

Source:
https://www.astm.org/d5528-13.html
https://www.youtube.com/watch?v=aqNph-UURGc
https://www.testresources.net/applications/standards/astm/astm-d5528-interlaminar-fracture-toughness-of-fiber-reinforced-polymer-matrix-composites
https://cdn.standards.iteh.ai/samples/86343/06b41848b1704c4889afc8ccdd9159b9/ASTM-D5528-13.pdf

PRJ #5, Problem #14 (C)

- ASTM D3532
  - Determines the gel time of resin squeezed from prepreg tape or sheet material for material acceptance
  - Gel time varies with test temperature
  - Gel time does not measure out-time
  - Applicable to carbon fiber epoxy tape and sheet for high and low viscosity systems

2. Summary of Test Method

2.1 A specimen of prepreg material approximately 5 mm [0.25 in.] square is placed between microscope cover glasses on a hot plate preheated to either of two test temperatures, 120 or 175°C [250 or 350°F]. Pressure is applied to the specimen through the coverglass with a wood pick to form a bead of resin at the edge of the cover glass. The time from the application of heat until the resin ceases to form strings by contact with the pick is noted and reported as the gel time.

Source: https://www.astm.org/d3532_d3532m-19.html
https://www.youtube.com/watch?v=BJhnKrEszYw
https://www.coesfeld.com/en/products/detail/surfaces-and-coatings/gel-time/gt-gel-time-measurement-16-20-auto.html
https://cdn.standards.iteh.ai/samples/80757/c76c6c27ec65459eb64b7fefe900de7f/ASTM-D3532-D3532M-12.pdf

PRJ #5, Problem #14 (D)

- ASTM D2734
  - Void content test
  - High void content reduces fatigue resistance, increases water penetration, and weathering susceptibility, and causes greater variability in mechanical strength properties
  - Measuring void content can help assess composite material quality
  - Note: Not applicable to composites where ignition effects on materials are unknown
  - No YouTube video was found

8.1 *Calculation*—Using the values determined in 7.1, 7.2, and 7.3, calculate theoretical density of a composite as follows:

$$T_d = 100/(R/D + r/d) \qquad (1)$$

where:

T_d = theoretical composite density,
R = resin in composite, weight %,
D = density of resin,
r = reinforcement in composite, weight %, and
d = density of reinforcement.

8.2 *Examples:*
From 7.1:

$$D = 1.230 \text{ g/cm}^3 \qquad (2)$$

From 7.2:

$$d = 2.540 \text{ g/cm}^3 \qquad (3)$$

From 7.3:

$$R = 28.55 \text{ weight}\%, \qquad (4)$$

Source:
https://cdn.standards.iteh.ai/samples/95184/b26277b5e1964070bffd22168c604a16/ASTM-D2734-16.pdf
https://www.astm.org/d2734-16.html

PRJ #5, Problem #14 (E)

- ASTM D6272
  - Flexural properties of unreinforced and reinforced plastics and electrical insulating materials by four-point bending
    - Four-point bending – stress is uniformly distributed
    - Three-point bending – stress occurs directly under the loading nose
  - Specimen depth, temperature, atmospheric conditions, strain rate all affect flexural properties
  - Applies to rigid and semi-rigid materials but not to materials that do not break or fail in the outer fibers
  - Specification of the material is referenced before performing this test
  - Similar to C393 test but different in the material they test and the enforcement of their fibers

Source:
https://www.astm.org/d6272-17e01.html
https://cdn.standards.iteh.ai/samples/96729/fb95e03e6aae418bb32e7c7b64dff430/ASTM-D6272-17.pdf
https://www.youtube.com/watch?v=qK1qxPYk5TY

Flexural Strength (σf)

$\sigma f = (3F*L) / (2b*d^2)$

Where:

- σf = Flexural Strength (MPa)
- F = Applied force at fracture (N)
- L = Span length between supports (mm)
- b = Width of the specimen (mm)
- d = Thickness of the specimen (mm)

Flexural Modulus (E)

$E = (F/d) * (l^3/4bh^3)$

Where:

- E = Flexural Modulus (GPa)
- F = Applied force at fracture (N)
- d = Displacement at the loading point (mm)
- L = Span length between supports (mm)
- b = Width of the specimen (mm)
- h = Height of the specimen (mm)

Strain (ε)

$\varepsilon = (6d / L) * (F / (b h^3))$

Where:

- ε = Strain (unitless)
- d = Displacement at the loading point (mm)
- L = Span length between supports (mm)
- F = Applied force at fracture (N)
- b = Width of the specimen (mm)
- h = Height of the specimen (mm)

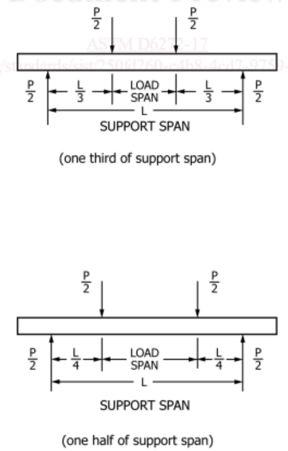


FIG. 1 Loading Diagram

PRJ #5, Problem #14 (F)

- ASTM D3530
    - Test method for volatile content of composite material prepreg
    - Useful in developing optimum manufacturing process
    - Applies to thermosetting resin composites, which lose mass when heated due to water loss and volatilization of low molecular weight matrix components
    - Max test temp = 300˚ C
    - Not applicable at temperatures where the matrix flows from the reinforcement

12. Procedure

12.1 Weigh each of the three specimens on an analytical balance to 0.1 mg. Record the mass of each specimen as M_i.

12.2 Coat any surfaces of the rack or clip that may contact the specimen with a suitable release agent to prevent loss of specimen mass due to resin adherence.

12.3 Place the samples on the rack or suspended from the rack (braids, ribbons, and fabric) as quickly as possible, place the rack into a preheated oven, and set at the nominal cure or consolidation temperature as recommended by the manufacturer or controlling specification. The specimens should be placed so that the maximum surface area is exposed to the circulating heat.

12.4 Set the timer for 15 min or as specified by manufacturer or controlling specification.

NOTE 1—Different exposure time may be used. Exposure time shall be studied to verify that at least 90 % of the maximum volatiles content is obtained at the recommended time.

12.5 Remove the specimens from the rack and place them in a desiccator.

- ASTM D3530
    - No YouTube video was found
    - No formulas required - just measurement of weight before and after cure temp

Source:
https://www.astm.org/d3530-20.html
https://cdn.standards.iteh.ai/samples/107635/8c539138a645485f9a158be04c4de085/ASTM-D3530-20.pdf

PRJ #5, Problem #14 (G)

- ASTM D6484
  - Open-hole compressive strength of polymer matrix composite laminates
  - Measures notched compressive strength for structural design allowables, material specification, R&D, and quality assurance
  - Key influencing factors
    - Material, fabrication method, lay-up accuracy, stacking sequence, specimen geometry, hole preparation, conditioning, testing environment, alignment, gripping, loading procedure, speed, time at temperature, void content, and reinforcement volume
  - Applies to multidirectional polymer matrix composites reinforced by high-modulus fibers
  - Covers continuous and discontinuous fiber composites with balanced and symmetric laminates in the test direction

Source:
https://www.astm.org/d6484_d6484m-20.html
https://cdn.standards.iteh.ai/samples/107475/58551ab4402a4deeb76a0e978538f01a/ASTM-D6484-D6484M-20.pdf
https://www.youtube.com/watch?v=u1gHxCt-qv0

D6484/D6484M – 20

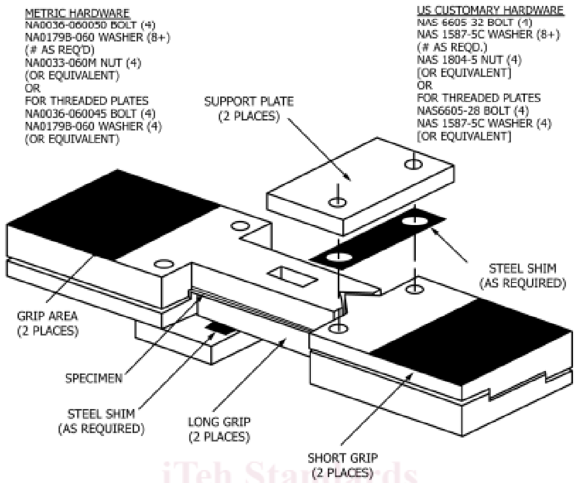


FIG. 1 Support Fixture Assembly

Open-Hole Compressive Strength Formula

σ_OH = P_max / A_0

Where:

- σ_OH = Open-hole compressive strength (MPa)
- P_max = Maximum load applied during the test (N)
- A_0 = Original cross-sectional area of the specimen (mm^2)

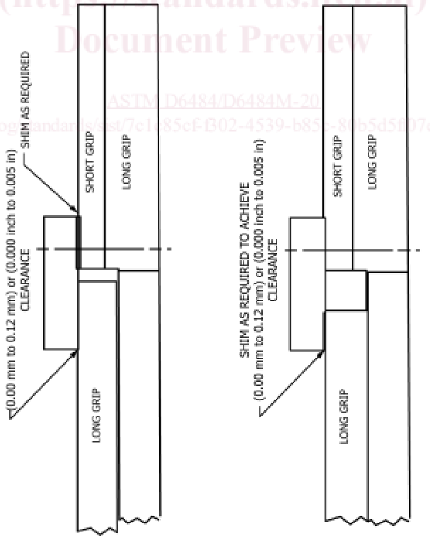


FIG. 2 Support Fixture—Shim Requirements

PRJ #5, Problem #14 (H)

- ASTM D3039
    - Standard test method for tensile properties of a polymer matrix
    - Applies to polymer matrix composites reinforced with high-modulus fibers
    - Key influencing factors
        - Material, preparation method, lay-up, stacking sequence, conditioning, testing environment, alignment, gripping, speed, time at temp, void content, and reinforcement volume
    - Measured properties
        - Ultimate tensile strength
        - Ultimate tensile strain
        - Tensile chord modulus of elasticity
        - Poisson's ratio
        - Transition strain

Source:
https://www.astm.org/d3039_d3039m-08.html
https://cdn.standards.iteh.ai/samples/98550/1ea65d99fa0843b69e4fd81d6a0b55c1/ASTM-D3039-D3039M-17.pdf
https://www.youtube.com/watch?v=q_Px6xZX2nk
https://www.instron.com/en/testing-solutions/astm-standards/astm-d3039

Tensile Strength (σ_{max})

$\sigma_{max} = P_{max} / A_0$

Where:

- σ_{max} = Tensile Strength (MPa)
- P_{max} = Maximum load applied during the test (N)
- A_0 = Original cross-sectional area of the specimen (mm^2)

Tensile Modulus (E)

$E = P / (A * \varepsilon)$

Where:

- E = Tensile Modulus (GPa)
- P = Load applied during the test (N)
- A = Cross-sectional area of the specimen (mm^2)
- ε = Engineering strain (unitless)

Strain-to-Failure ($\varepsilon_{failure}$)

$\varepsilon_{failure} = (\Delta L / L_0) \times 100$

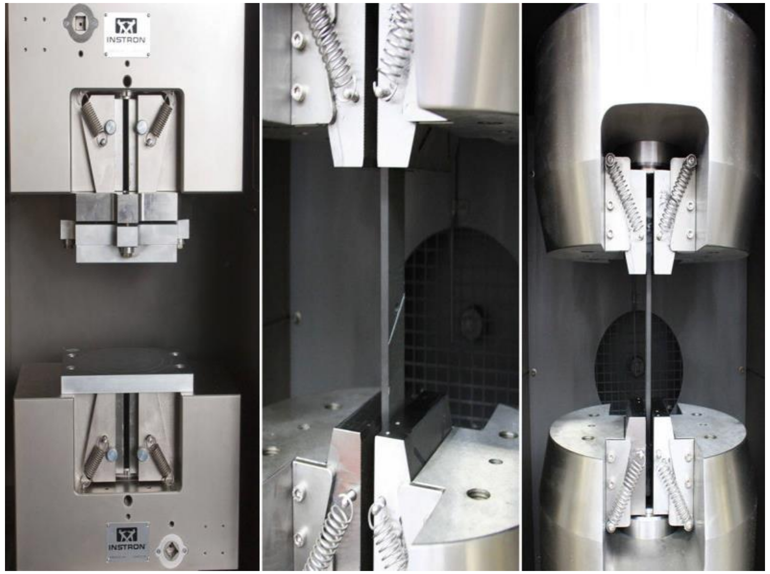
Where:

- $\varepsilon_{failure}$ = Strain-to-Failure (%)
- ΔL = Change in length of the specimen at failure (mm)
- L_0 = Original length of the specimen (mm)

TABLE 1 Tensile Specimen Geometry Requirements

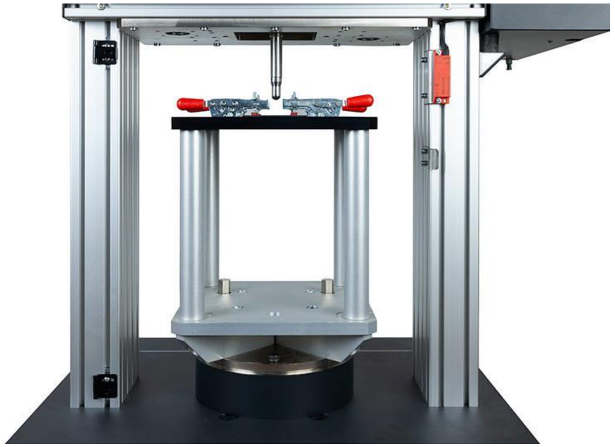
Parameter	Requirement
Coupon Requirements:	
shape	constant rectangular cross-section
minimum length	gripping + 2 times width + gage length
specimen width	as needed[A]
specimen width tolerance	±1 % of width
specimen thickness	as needed
specimen thickness tolerance	±4 % of thickness
specimen flatness	flat with light finger pressure
Tab Requirements (if used):	
tab material	as needed
fiber orientation (composite tabs)	as needed
tab thickness	as needed
tab thickness variation between tabs	±1 % tab thickness
tab bevel angle	5 to 90°, inclusive
tab step at bevel to specimen	feathered without damaging specimen

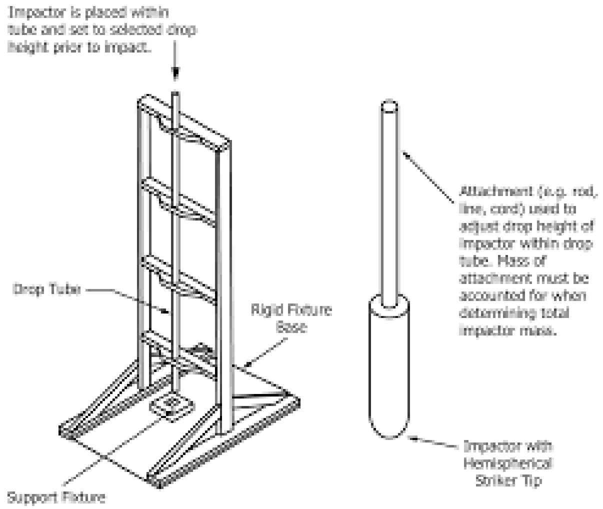
[A] See 8.2.2 or Table 2 for recommendations.



PRJ #5, Problem #14 (I)

- ASTM D7136
  - Standard test method for measuring the damage resistance of fiber-reinforced polymer matrix composite to a drop weight impact event
  - Tests multidirectional polymer matrix composite laminates using drop-weight impact with hemispherical impactor
  - Analyzes stacking sequence, fiber treatment, fiber volume fraction, and environmental effects on damage resistance
  - Compare damage parameters across different composite materials
  - Induces damage for other tolerance testing (D7137 and D7137M)
  - Impact resistance depends on geometry, thickness, stiffness mass, and boundary conditions
  - Impact energy is normalized by thickness for comparison, multiple impact levels can be tested for damage correlation





Key Measured Properties

Property	Formula/Method	Units
Impact Energy (E)	E = m g h	Joules (J)
Impact Velocity (v)	v = sqrt(2 g h)	m/s
Peak Force (F_max)	Directly measured from impact force-time curve	Newtons (N)
Absorbed Energy (E_a)	E_a = E - E_r	Joules (J)
Dent Depth (d)	Direct measurement (micrometer, profilometer)	mm
Damage Area (A_d)	A_d = π a b	mm^2
Stiffness Reduction	(E_before - E_after) / E_before × 100%	%

Source:
https://www.astm.org/d7136_d7136m-15.html
https://cdn.standards.iteh.ai/samples/80560/b06efe91cc274ae48af0ff589b763599/ASTM-D7136-D7136M-12.pdf
https://www.youtube.com/watch?v=ygjtNMbmqAM

PRJ #5, Problem #14 (J)

- ASTM D5229
  - Standard test method for moisture absorption properties and equilibrium conditioning of polymer matrix composite materials
    - (A) Measure **moisture diffusivity** constant and **moisture equilibrium** content at specific humidity and temp
    - Used to estimate exposure times for conditioning, input for moisture prediction models, and qualitative material selection
    - (B-E) Condition test coupons to specific equilibrium or environmental states
    - (Y-Z) Assess moisture loss when a test coupon is removed from conditioning or exposed to heat before or after mechanical testing
    - Moisture diffusion model assumes single-phase Fickian diffusion for uniform moisture absorption through thickness
      - Materials with toughened epoxies or multi-phase matrices may need different models
  - Applies to laminated polymer matrix composites and other materials that follow Fickian diffusion
  - Used for conditioning specimens to moisture-free state, equilibrium or external environments
  - Evaluates moisture loss due to heating or strain gauge bonding

Source:
https://www.astm.org/d5229_d5229m-20.html
https://cdn.standards.iteh.ai/samples/105785/f1fca087b1fb4ad8b8de434940484b3f/ASTM-D5229-D5229M-20.pdf
https://www.youtube.com/watch?v=ikZ2k-FBR6Q

3.2.3 *average moisture content, M (%), n*—the average amount of absorbed moisture in a material, taken as the ratio of the mass of the moisture in the material to the mass of the oven-dry material and expressed as a percentage, as follows:

$$M, \% = \frac{W_i - W_o}{W_o} \times 100 \quad (1)$$

where:

W_i = current specimen mass, g, and
W_o = oven-dry specimen mass, g.

(See also *oven-dry*.)

3.2.4 *Fickian diffusion, n*—a model of material moisture absorption and desorption that follows Fick's second law, as follows in one-dimension:

$$\frac{\partial c}{\partial t} = D_z \frac{\partial^2 c}{\partial z^2}$$

(see Note 25). This criteria for change in moisture content over a reference time period can be expressed in several equivalent ways; four equivalent expressions are shown below:

$$|M_i - M_{i-1}| < 0.020\% \quad (3)$$

or

$$\left|\frac{W_i - W_b}{W_b} - \frac{W_{i-1} - W_b}{W_b}\right| \times 100 < 0.020\% \quad (4)$$

or

$$\left|\frac{W_i - W_b}{W_b} - \frac{W_{i-1} - W_b}{W_b}\right| < 0.00020 \quad (5)$$

or

$$\left|\frac{W_i - W_{i-1}}{W_b}\right| < 0.00020 \quad (6)$$

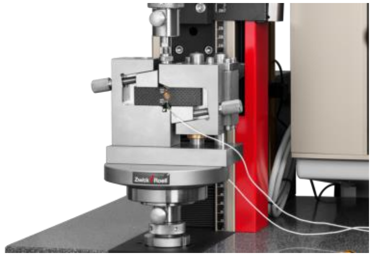
where:

M = specimen average moisture content, %,
W = specimen mass, g, and the subscripts indicate:
i = value at current time,
$i-1$ = value at previous time, and
b = value at baseline time.

- Calculated mass change at equilibrium: Mass Change = (Wi – Wb) / Wb * 100
- No good specific YouTube video
- Different procedure for doing this A-Z but, this is a gravimetric test that measured change over time to the average moisture content of a material
  - Done by measuring the total mass change of coupons that are exposed on two sides to a specified environment

PRJ #5, Problem #14 (K-1)

- ASTM D5379
  - Measures shear properties of composite materials by the V-Notched beam method
  - Tests in-plane or interlaminar shear properties depending on material orientation
  - Can measure shear properties in any of the 6 possible hear planes, but only one per specimen
  - Measured properties
    - Shear strain-stress response
    - Ultimate shear strength
    - Ultimate shear strain
    - Shear chord modulus of elasticity
  - Applies to high modulus fiber reinforced composites
    - Unidirectional lamina
    - Woven fabric laminates
    - Balanced and symmetric 0/90-degree laminates
    - Short fiber composites with randomly distributed fibers



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https://www.astm.org/d5379_d5379m-19e01.html
https://cdn.standards.iteh.ai/samples/104367/5da6a5598ed34bc6b4ad40a9a8e5c4d0/ASTM-D5379-D5379M-19.pdf
https://www.zwickroell.com/industries/composites/v-notched-shear-test/
https://www.youtube.com/watch?v=TdUlcdmtV-k

Shear Stress (τ)

$\tau = F / A$

Where:

- τ = Shear stress (MPa)
- F = Applied force (N)
- A = Shear area of the specimen (mm^2)

Ultimate Shear Strength (τ_max)

$\tau_{max} = F_{max} / A$

Where:

- τ_{max} = Ultimate shear strength (MPa)
- F_{max} = Maximum force applied before failure (N)
- A = Shear area of the specimen (mm^2)

Ultimate Shear Strain (γ_max)

$\gamma_{max} = \Delta x / h$

Where:

- γ_{max} = Ultimate shear strain (unitless)
- Δx = Lateral displacement due to shear (mm)
- h = Specimen thickness (mm)

Shear Chord Modulus of Elasticity (G)

$G = \Delta\tau / \Delta\gamma$

Where:

- G = Shear chord modulus of elasticity (GPa)
- $\Delta\tau$ = Change in shear stress (MPa)
- $\Delta\gamma$ = Change in shear strain (unitless)

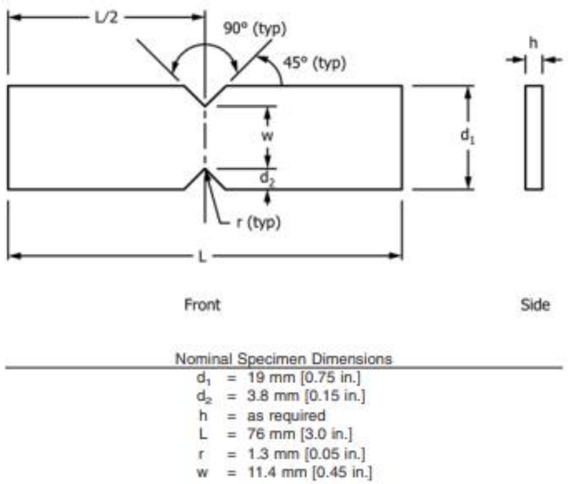


FIG. 2 V-Notched Beam Test Coupon Schematic

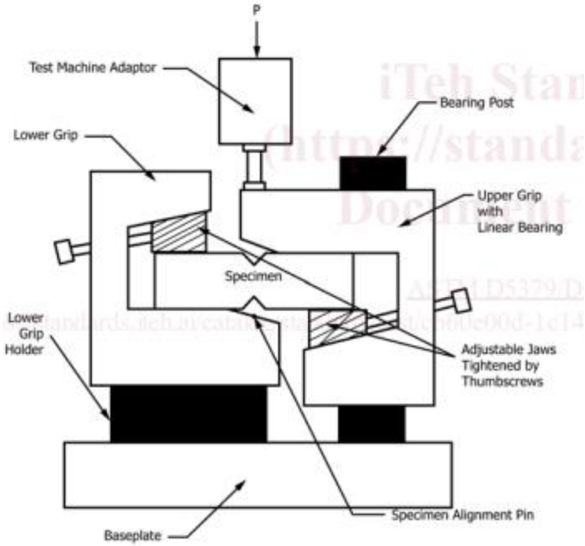


FIG. 3 V-Notched Beam Test Fixture Schematic

PRJ #5, Problem #14 (K-2)

- ASTM D695
  - Standard test method for compressive properties of rigid plastics
    - Compressive properties include
      - Modulus of elasticity
      - Yield stress
      - Deformation beyond yield point
      - Compressive strength
      - Flattening behavior
  - Used for R&D, quality control, material acceptance/rejection
  - Not suitable for engineering design in impact, creep, or fatigue applications
  - Need to look at material specification over general test conditions
  - Covers unreinforced and reinforced rigid plastics, including high modulus composites
  - Applies to materials with a modulus less than 41,370 MPa

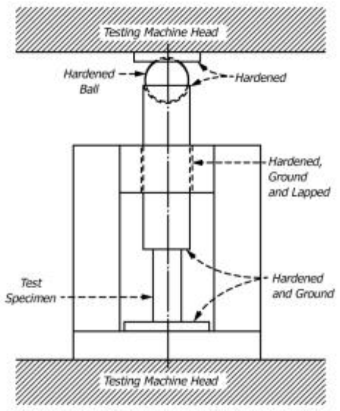


FIG. 2 Compression Tool

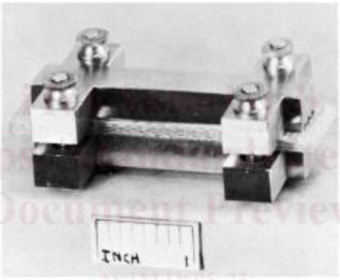


FIG. 3 Support Jig for Thin Specimen

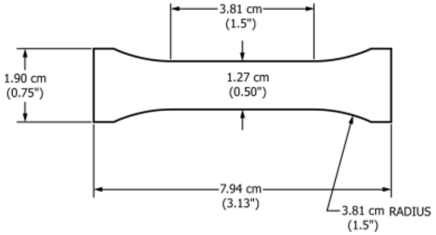
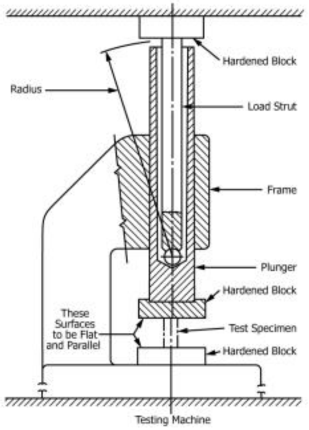


FIG. 5 Compression Test Specimen for Materials Less than 3.2 mm Thick



Source:
https://www.astm.org/d0695-23.html
https://cdn.standards.iteh.ai/samples/115935/85b6719005d347f68a20f07d4864d26c/ASTM-D695-23.pdf
https://www.intertek.com/polymers-plastics/testlopedia/compression-properties-astm-d695/
https://www.youtube.com/watch?v=wkSXiZokPwc
https://www.instron.com/en/testing-solutions/astm-standards/astm-d695-plastics

- Compressive strength = maximum compressive load / minimum cross-sectional area
- Compressive modulus = change in stress / change in strain

PRJ #5, Problem #14 (K-2) (Cont.)

- General formulas

Ultimate Compressive Strength ($\sigma_{c,max}$)

$\sigma_{c,max} = F_{max} / A$

Where:

- $\sigma_{c,max}$ = Ultimate compressive strength (MPa)
- F_{max} = Maximum applied force before failure (N)
- A = Original cross-sectional area (mm^2)

Compressive Stress (σ_c)

$\sigma_c = F / A$

Where:

- σ_c = Compressive stress (MPa)
- F = Applied compressive force (N)
- A = Original cross-sectional area of the specimen (mm^2)

Compressive Strain (ε_c)

$\varepsilon_c = \Delta L / L_0$

Where:

- ε_c = Compressive strain (unitless or %)
- ΔL = Change in length under compression (mm)
- L_0 = Original specimen length (mm)

Compressive Modulus (E_c)

$E_c = \Delta\sigma_c / \Delta\varepsilon_c$

Where:

- E_c = Compressive modulus (MPa or GPa)
- $\Delta\sigma_c$ = Change in compressive stress (MPa)
- $\Delta\varepsilon_c$ = Change in compressive strain (unitless)

Compressive Yield Strength (σ_{cy})

$\sigma_{cy} = F_y / A$

Where:

- σ_{cy} = Compressive yield strength (MPa)
- F_y = Force at yield point (N)
- A = Original cross-sectional area (mm^2)

PRJ #5, Problem #14 (K-3)

- ASTM D271
  - Standard test method for density of sandwich core materials
  - Measurements of density using Length, width, thickness, and weight
  - Influencing factors
    - Core material and fabrication method
    - Core geometry
    - Specimen geometry and preparation
    - Measurement methods
    - Specimen conditioning and moisture content
  - Applies to sandwich core materials with both continuous and discontinuous bonding surfaces

4. Summary of Test Method

4.1 This test method consists of environmentally conditioning a sandwich core specimen, weighing the specimen, measuring the length, width and thickness of the specimen, and calculating the density.

$$d_{IP} = \frac{1728\,W}{lwt} \qquad (2)$$

where:

d_{IP} = density, lbm/ft^3,
W = final mass after conditioning, lbm,
l = final length after conditioning, in.,
w = final width after conditioning, in., and
t = final thickness after conditioning, in.

13.3 *Statistics*—For each series of tests calculate the average value, standard deviation, and coefficient of variation (in percent) for density:

$$\bar{x} = \left(\sum_{i=1}^{n} x_i\right)/n \qquad (5)$$

$$S_{n-1} = \sqrt{\left(\sum_{i=1}^{n} x_i^2 - n\,\bar{x}^2\right)/(n-1)} \qquad (6)$$

$$CV = 100 \times S_{n-1}/\bar{x} \qquad (7)$$

where:

$\bar{x}$ = sample mean (average),
S_{n-1} = sample standard deviation,
CV = sample coefficient of variation, %,
n = number of specimens, and
x_i = measured or derived property.

Source:
https://www.astm.org/c0271_c0271m-16r22e01.html
https://cdn.standards.iteh.ai/samples/112326/41593f9cee464028be17f82def869895/ASTM-C271-C271M-16-2022-e1.pdf
https://www.youtube.com/watch?v=os0zeUuf_50

PRJ #5, Problem #14 (K-4)

- ASTM FTIR E168
  - Standard practice for general techniques of infrared quantitate analysis
  - Guidelines for Infrared spectroscopy
    - Preparation, operation, and calculation techniques
  - Covers commonly used IR quantitative analysis techniques
    - Including, computer assisted and manual data collection/analysis
  - Does not cover all concerns in developing new quantitative methods

8.1 Quantitative spectrometry is based on the Beer-Bouguer-Lambert (henceforth referred to as Beer's) law, which is expressed for the one component case as:

$$A = abc \tag{1}$$

where:

A = absorbance of the sample at a specified wavenumber,
a = absorptivity of the component at this wavenumber,
b = sample path length, and
c = concentration of the component.

Since spectrometers measure transmittance, T, of the radiation through a sample, it is necessary to convert T to A as follows:

$$A = -\log T = -\log \frac{P}{P_0} \tag{2}$$

where:

P_0 = input radiant power at the sample, and
P = radiant power transmitted through the sample.

independent equations containing n absorbance measurements at n wavenumbers are necessary. This is expressed for constant path length as follows:

$$\begin{aligned} A_1 &= a_{11}bc_1 + a_{12}bc_2 + \cdots + a_{1n}bc_n \\ A_2 &= a_{21}bc_1 + a_{22}bc_2 + \cdots + a_{2n}bc_n \\ &\cdots \\ &\cdots \\ &\cdots \\ A_i &= a_{i1}bc_1 + a_{i2}bc_2 + \cdots + a_{in}bc_n \end{aligned} \tag{4}$$

where:

A_i = total absorbance at wavenumber i,
a_{in} = absorptivity at the wavenumber i of component n,
b = path length of the cell in which the mixture is sampled, and
c_n = concentration of component n in the mixture.

Source:
https://www.astm.org/e0168-16.html
https://cdn.standards.iteh.ai/samples/114213/cf7abc8b20ab4a7199c64642866e8342/ASTM-E168-16-2023-.pdf
https://www.youtube.com/watch?v=oMQXV9lEd5k
https://www.stress.com/services/materials-engineering/polymers-elastomers-composites/fourier-transform-infrared-spectroscopy/

PRJ #5, Problem #14 (K-5)

- ASTM D1621
  - Standard test method for compressive properties of rigid cellular plastic cells (i.e. foam)
  - Measured properties
    - Compressive stress at any load
    - Effective modulus of elasticity
  - Used for R&D, quality control, material acceptance/rejection
  - Note suitable for engineering design in impact, creep, or fatigue-sensitive applications

Compressive Stress (σ_c)

$\sigma_c = F / A$

Where:

- σ_c = Compressive stress (MPa)
- F = Applied compressive force (N)
- A = Original cross-sectional area of the specimen (mm^2)

Compressive Strain (ε_c)

$\varepsilon_c = \Delta L / L_0$

Where:

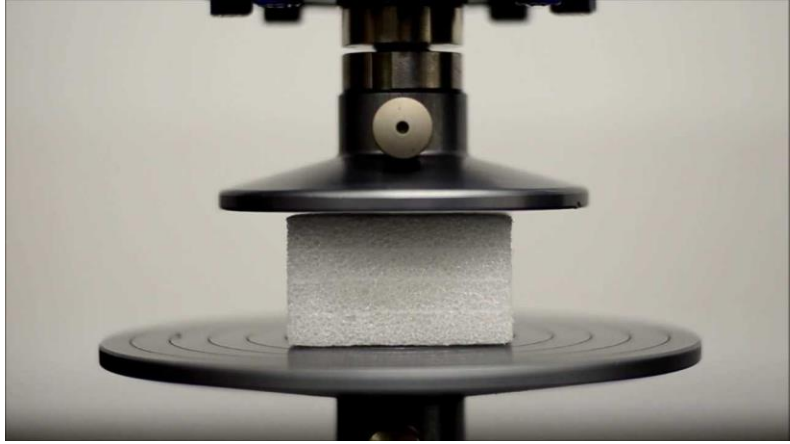
- ε_c = Compressive strain (unitless or %)
- ΔL = Change in length under compression (mm)
- L_0 = Original specimen length (mm)

Compressive Modulus (E_c)

$E_c = \Delta\sigma_c / \Delta\varepsilon_c$

Where:

- E_c = Compressive modulus (MPa or GPa)
- $\Delta\sigma_c$ = Change in compressive stress (MPa)
- $\Delta\varepsilon_c$ = Change in compressive strain (unitless)



Ultimate Compressive Strength ($\sigma_{c,max}$)

$\sigma_{c,max} = F_{max} / A$

Where:

- $\sigma_{c,max}$ = Ultimate compressive strength (MPa)
- F_{max} = Maximum applied force before failure (N)
- A = Original cross-sectional area (mm^2)

Source:
https://cdn.standards.iteh.ai/samples/115268/fa54e680e0b6417c9f5197fc69e74ac2/ASTM-D1621-16-2023-.pdf
https://www.astm.org/d1621-16.html
https://www.youtube.com/watch?v=eOmsBWj8Mdw

PRJ #5, Problem #14 (K-6)

- ASTM D1002
  - Standard test method for apparent shear strength of single-lap-joint adhesively bonded metal specimens by tension loading (Metal-to-Metal)
  - Assess strength properties of tested adhesive systems
  - Not suitable for determining design-allowable stresses in structural joints
  - Strength values vary with adherend type, bonding process, temperature, and moisture changes
  - Environmental conditions can induce internal stresses or alter adhesive properties
  - Used to compare adhesives for fatigue and environmental susceptibility – but results depend on join configuration
  - Data produced
    - Load at failure
    - Shear strength
    - Type of failure (cohesion or adhesion)

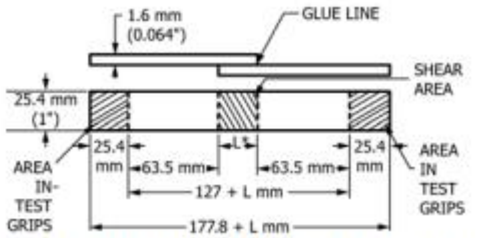


FIG. 1 Form and Dimensions of Test Specimen

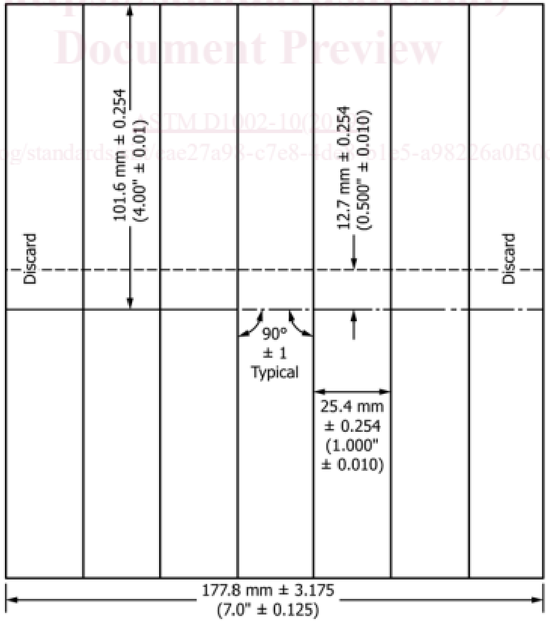


FIG. 2 Standard Test Panel

Source:
https://www.astm.org/d1002-10r19.html
https://www.youtube.com/watch?v=z-cKD2LgEJk
https://www.intertek.com/shear-testing/d1002/
https://cdn.standards.iteh.ai/samples/102945/015d35644e3843edbaf2881bf0fd6ee5/ASTM-D1002-10-2019-.pdf

PRJ #5, Problem #14 (K-6 Cont.)

- Governing formulas

Apparent Shear Strength (τ)

$\tau = F / A$

Where:

- τ = Apparent shear strength (MPa or psi)
- F = Maximum applied force before failure (N or lbf)
- A = Bonded area of the adhesive (mm^2 or in^2)

Overlap Shear Stress (σ_s)

$\sigma_s = F / (b * L)$

Where:

- σ_s = Shear stress in the overlap region (MPa)
- F = Applied load (N)
- b = Width of the bonded joint (mm)
- L = Overlap length of the bonded joint (mm)

Shear Strain (γ)

$\gamma = \delta / L$

Where:

- γ = Shear strain (unitless)
- δ = Displacement due to shear deformation (mm)
- L = Overlap length of the bonded joint (mm)

Adhesive Shear Modulus (G)

$G = \tau / \gamma$

Where:

- G = Adhesive shear modulus (MPa or GPa)
- τ = Shear stress (MPa)
- γ = Shear strain (unitless)

Stress Concentration Factor (K_s)

$K_s = \tau_{max} / \tau_{avg}$

Where:

- K_s = Stress concentration factor
- τ_{max} = Maximum shear stress at bond edges (MPa)
- τ_{avg} = Average shear stress in the adhesive layer (MPa)

Lap Joint Strength Efficiency (η)

$\eta = (\tau_{adhesive} / \sigma_{yield, adherend}) * 100\%$

Where:

- η = Joint strength efficiency (%)
- $\tau_{adhesive}$ = Adhesive shear strength (MPa)
- $\sigma_{yield, adherend}$ = Yield strength of adherend material (MPa)