Bachelor in Aerospace Engineering

Universidad Carlos III de Madrid

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Department of Continuum Mechanics and Structural Engineering

Aerospace Structures

Chapter 4. Laminate and sandwich structures

Failure criteria

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Chapter 4. Composite beams and plates

Failure criteria

Authors: Enrique Barbero Pozuelo, José Fernández Sáez, Carlos Santiuste Romero

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Failure mechanisms

Matrix cracking

↑

Intralaminar failure mechanisms

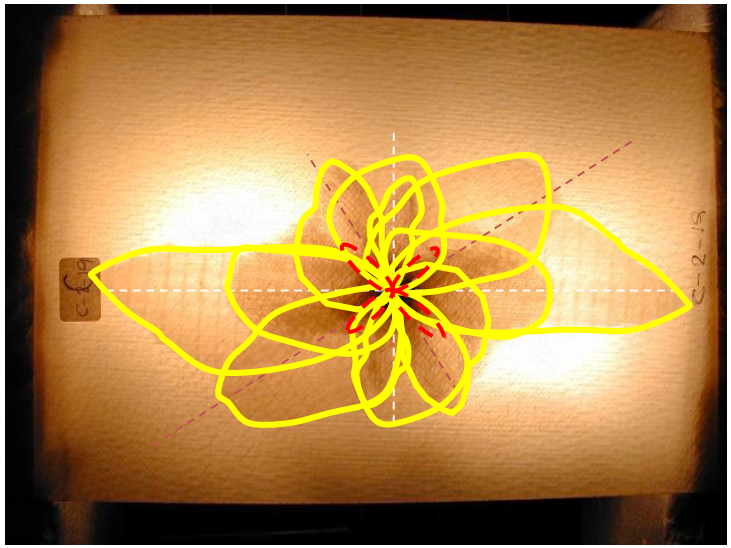
↓

Fibre failure

Interlaminar failure mechanisms

↓

Delamination



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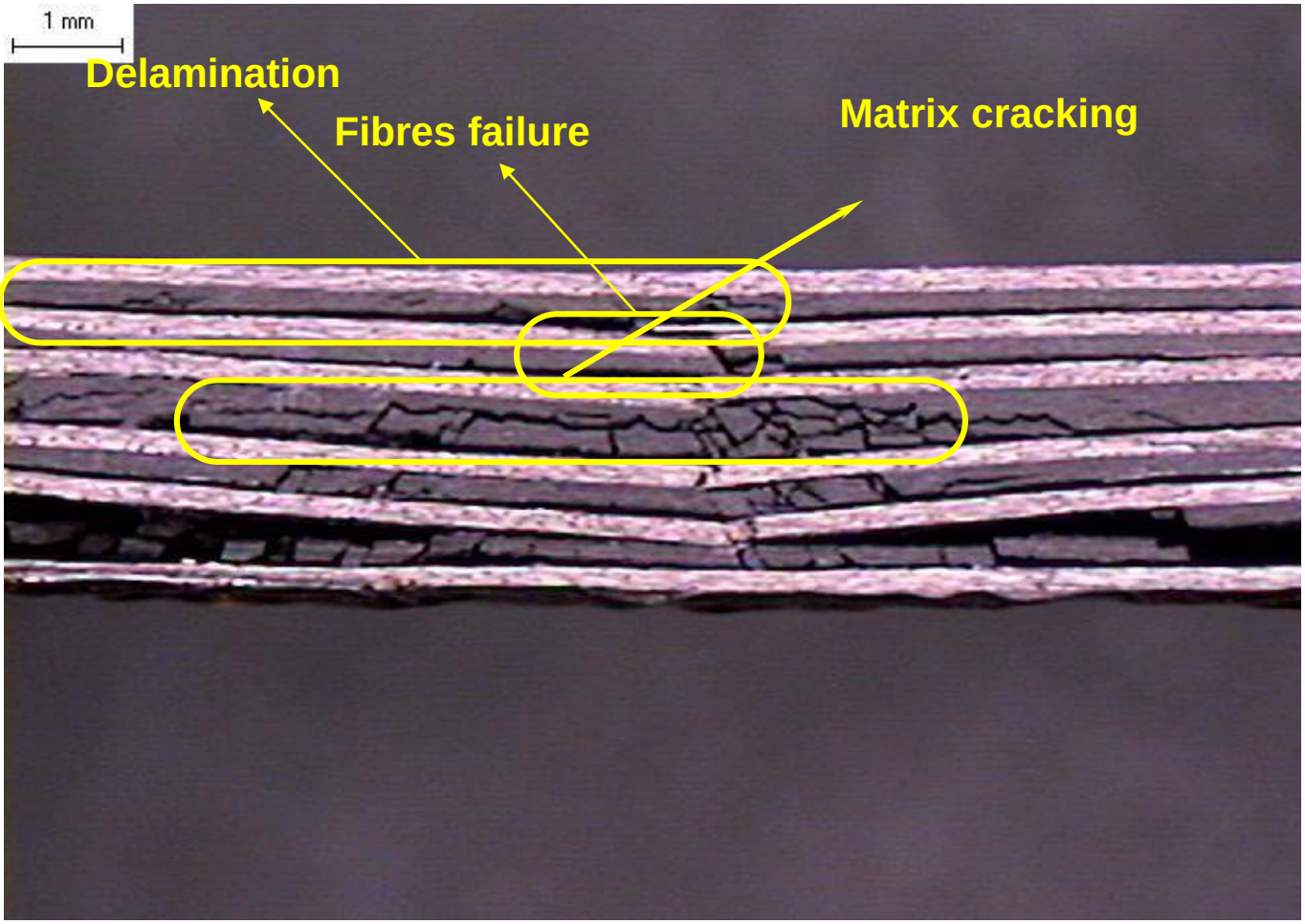
Failure mechanisms



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Global failure criteria

Failure criteria for isotropic materials

Tresca plasticity criterion

$$\sigma_1 - \sigma_3 = 2k$$

$$\sigma_1 \geq \sigma_2 \geq \sigma_3$$

$$k = \frac{\sigma_y}{2}$$

Von Mises plasticity criterion

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 6(k')^2$$

$$(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2) = 6(k')^2$$

$$J_2 = (k')^2$$

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Global failure criteria

Failure criteria for composite materials

Tsai-Hill criterion

$$I_f = \frac{\sigma_{11}^2}{X^2} - \frac{\sigma_{11}\sigma_{22}}{X^2} + \frac{\sigma_{22}^2}{Y^2} + \frac{\sigma_{12}^2}{S^2}$$

Tsai-Wu criterion

$$I_f = \left(\frac{1}{X_t} - \frac{1}{X_c}\right)\sigma_{11} + \left(\frac{1}{Y_t} - \frac{1}{Y_c}\right)\sigma_{22} + \frac{\sigma_{11}^2}{X_t X_c} + \frac{\sigma_{22}^2}{Y_t Y_c} + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + 2F_{12}\sigma_{11}\sigma_{22}$$

$$F_{12} = -\frac{1}{2}\sqrt{\frac{1}{X_t X_c Y_t Y_c}}$$

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Intralaminar failure criteria

Intralaminar failure criteria for composite materials

Failure criterion	Hou 3D	Hashin 3D
Fibres tensile	$d_{ft}^2 = \left(\frac{\sigma_{11}}{X_t}\right)^2 + \left(\frac{\sigma_{12}^2+\sigma_{13}^2}{S_L^2}\right)$	$d_f^2 = \left(\frac{\sigma_{11}}{X_t}\right)^2 + \alpha\left(\frac{\sigma_{12}^2+\sigma_{13}^2}{S_L^2}\right)$
Fibres compressive		$d_{fc}^2 = \left(\frac{\sigma_{11}}{X_c}\right)$
Matrix cracking	$d_{mt}^2 = \left(\frac{\sigma_{22}}{Y_t}\right)^2 + \left(\frac{\sigma_{12}}{S_L}\right)^2 + \left(\frac{\sigma_{23}}{S_T}\right)^2$	$d_{mt}^2 = \left(\frac{\sigma_{22}+\sigma_{33}}{Y_t}\right)^2 + \left(\frac{\sigma_{12}^2+\sigma_{13}^2}{S_L^2}\right) + \left(\frac{\sigma_{23}^2-\sigma_{22}\sigma_{33}}{S_T^2}\right)^2$
Matrix crushing	$d_{mc}^2 = \frac{1}{4}\left(\frac{-\sigma_{22}}{S_T}\right)^2 + \frac{Y_c^2\sigma_{22}}{4S_T^2Y_c} - \frac{\sigma_{22}}{Y_c} + \left(\frac{\sigma_{12}}{S_L}\right)^2$	$d_{mc}^2 = \frac{1}{Y_c}\left[\left(\frac{Y_c}{2S_T}\right)^2 - 1\right](\sigma_{22}+\sigma_{33}) + \left(\frac{\sigma_{22}+\sigma_{33}}{2S_T}\right)^2 + \frac{(\sigma_{23}^2+\sigma_{22}\sigma_{33})}{S_T^2} + \frac{(\sigma_{12}^2+\sigma_{13}^2)}{S_L^2}$

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Delamination criteria

Delamination criteria

Delamination onset criteria

Maximum stress

$$\sigma_{33} \geq Z_t \quad ó \quad \sigma_{31} \geq S_{31} \quad ó \quad \sigma_{23} \geq S_{23}$$

Lee

$$\sigma_{33} \geq Z_t \quad ó \quad \sqrt{\left(\sigma_{12}^2 + \sigma_{13}^2\right)} \geq S_{23}$$

Hashin

$$\left(\frac{\sigma_{33}}{Z_t}\right)^2 + \left(\frac{\sigma_{23}}{S_{23}}\right)^2 + \left(\frac{\sigma_{13}}{S_{31}}\right)^2 \geq 1$$

Goyal

$$\left(\frac{\sigma_{33}}{Z_t}\right)^2 + \left(\frac{\sigma_{23}}{S_{23}}\right)^\gamma + \left(\frac{\sigma_{13}}{S_{31}}\right)^\gamma \geq 1$$

Wisnom

$$2.6\sigma_e^2 = \left(\sigma_I - \sigma_{II}\right)^2 + \left(\sigma_{II} - \sigma_{III}\right)^2 + \left(\sigma_{III} - \sigma_I\right)^2 + 0.6\sigma_e\left(\sigma_I + \sigma_{II} + \sigma_{III}\right)$$

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Failure criteria

1. Failure mechanisms
2. Global failure criteria
3. Intralaminar failure criteria
4. Delamination criteria
5. **References**

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