Prediction of Carbon Fibre Composite Failure using ML

CS-433

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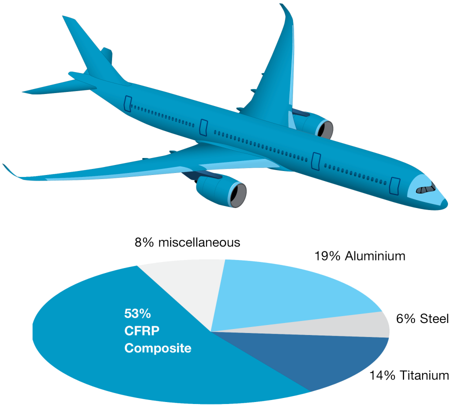
Introduction

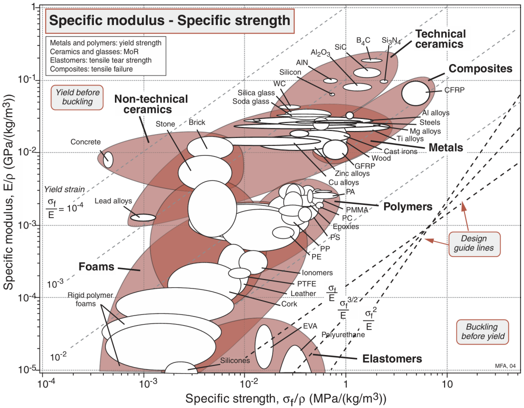
Alfa Romeo 2023 livery

Introduction

CFRP: Carbon Fibre Reinforced Plastic

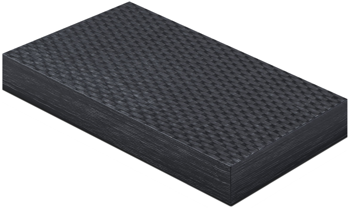


Airbus A350 XB

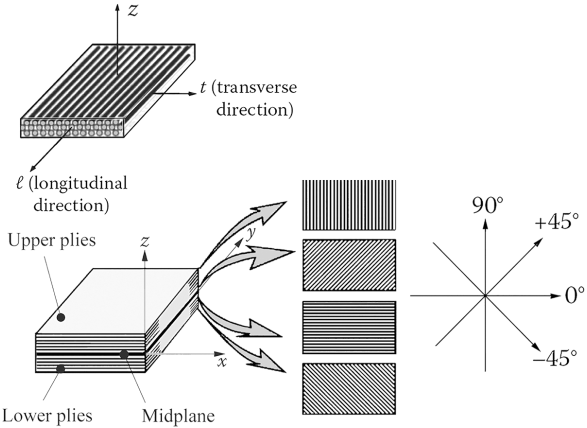


Ashby chart

Composite laminate

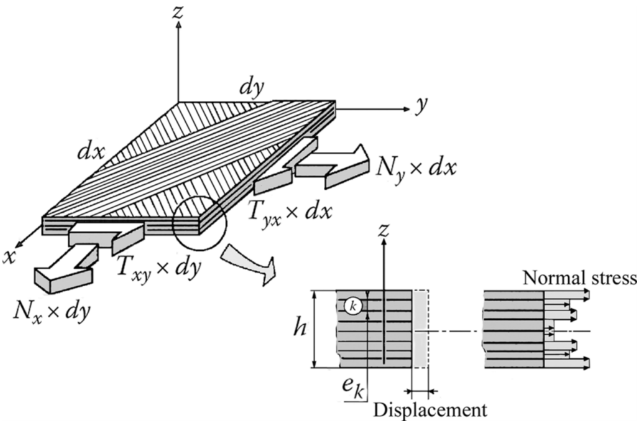


A CFRP plate



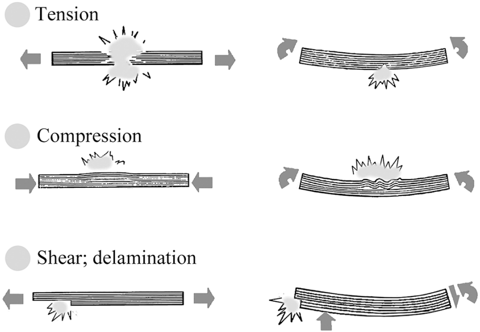
Ply and Laminate

Loading mechanisms

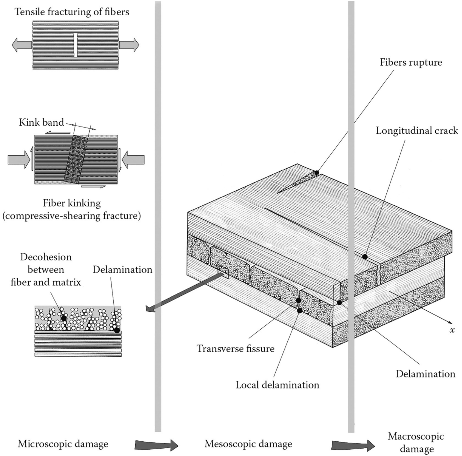


Loading mechanisms

Damage mechanisms



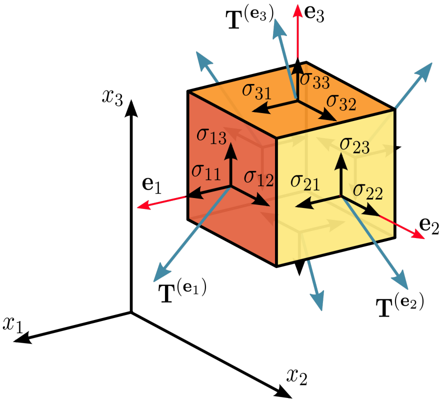
Modes of damage



Damage evolution in a laminate

Any questions so far?

Stress-strain state



Stress state of a cube of matter

Tensor notation:

$$\boldsymbol{\sigma} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}, \quad \boldsymbol{\varepsilon} = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{bmatrix}$$

Constitutive relation: $\boldsymbol{\sigma} = \mathbf{C}\,\boldsymbol{\varepsilon}$ with **C** the stiffness matrix.

Voigt/Engineering notation:

$$\boldsymbol{\sigma} = \begin{bmatrix} \sigma_1 & \sigma_2 & \sigma_3 & \tau_{23} & \tau_{13} & \tau_{12} \end{bmatrix}^T$$
$$\boldsymbol{\varepsilon} = \begin{bmatrix} \varepsilon_1 & \varepsilon_2 & \varepsilon_3 & \gamma_{23} & \gamma_{13} & \gamma_{12} \end{bmatrix}^T$$

Relations between tensor and engineering components:

$$\begin{aligned} \sigma_1 &= \sigma_{11}, & \sigma_2 &= \sigma_{22}, & \sigma_3 &= \sigma_{33}, \\ \tau_{23} &= \sigma_{23}, & \tau_{13} &= \sigma_{13}, & \tau_{12} &= \sigma_{12}, \\ \varepsilon_1 &= \varepsilon_{11}, & \varepsilon_2 &= \varepsilon_{22}, & \varepsilon_3 &= \varepsilon_{33}, \\ \gamma_{23} &= 2\varepsilon_{23}, & \gamma_{13} &= 2\varepsilon_{13}, & \gamma_{12} &= 2\varepsilon_{12} \end{aligned}$$

Failure criterion

Concept: A failure criterion/index predicts when a composite ply fails under a given stress state.

$$\boxed{\boldsymbol{F} = \boldsymbol{f}(\boldsymbol{\sigma}; \boldsymbol{P})}$$

$\boldsymbol{\sigma}$: stress state in ply coordinates $\rightarrow [\,\sigma_x, \sigma_y, \sigma_z, \tau_{yz}, \tau_{xz}, \tau_{xy}\,]^T$
$\boldsymbol{P}$: material parameters (e.g. strengths, stiffness, empirical coefficients, etc.)

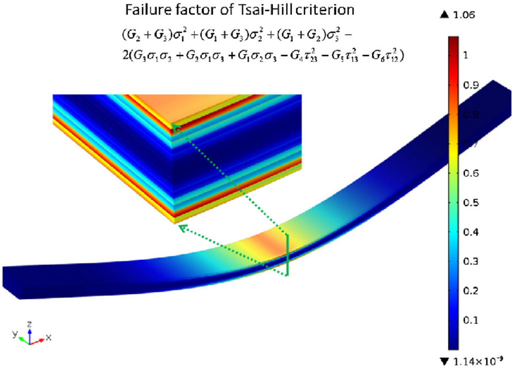
$$F < 1 \Rightarrow \text{safe}, \quad F = 1 \Rightarrow \text{failure onset}, \quad F > 1 \Rightarrow \text{failed}$$

Tsai-Hill criterion (2D only)

$$F = f(\sigma_x, \sigma_y, \tau_{xy}; X, Y, S) = \left(\frac{\sigma_x}{X}\right)^2 - \frac{\sigma_x \sigma_y}{X^2} + \left(\frac{\sigma_y}{Y}\right)^2 + \left(\frac{\tau_{xy}}{S}\right)^2$$

with X, Y, S the strengths in resp. the fiber, transverse, and shear directions

Project motivation



Failure index in a long-beam bended laminate

$\longrightarrow$ Model the laminate as a homogeneous material and apply a failure criterion directly

Dataset

Generation

1. Generation of a global random strain state ε
2. Evaluation of the stresses for 4 different ply orientations, $k \in [0, 45, 90, -45]°$
3. Evaluation of 4 different failure criteria

	Tension (t)	**Compression (c)**
Fibre (f)	$F_{\mathrm{f,t}}$	$F_{\mathrm{f,c}}$
Matrix (m)	$F_{\mathrm{m,t}}$	$F_{\mathrm{m,c}}$

$$
{}^{k}\mathbf{F} = \begin{bmatrix} {}^{k}F_{\mathrm{f,t}} \\ {}^{k}F_{\mathrm{f,c}} \\ {}^{k}F_{\mathrm{m,t}} \\ {}^{k}F_{\mathrm{m,c}} \end{bmatrix}
$$

Dataset

```
results (list)
    +-- [i] (dict)
    |   +-- 'eps': np.ndarray(6,)
    |   +-- 'plies' (dict)
    |       +-- 0.0 (dict)
    |       |   +-- 'criteria' (dict)
    |       |       +-- 'F_ft': np.float64
    |       |       +-- 'F_fc': np.float64
    |       |       +-- 'F_mt': np.float64
    |       |       \-- 'F_mc': np.float64
    |       +-- 45.0 (dict)
    |       +-- 90.0 (dict)
    |       \-- -45.0 (dict)
```

Different possibilities of subject

1. Pure regression: e.g., predict the max failure index, predict all the failure indices
   $\longrightarrow$ 16 different indices
2. Pure classification: e.g., predict if the stress-state is safe or not, predict the failure mode or the first failing ply (ffp)
3. Hybrid: e.g., predict failure mode and then failure index

If you are accepted, we will define your subject together during our first meeting.

Enrollment & others

- It would be best to provide an answer before Friday (07.11) afternoon
- You will receive a confirmation of acceptance by Wednesday (12.11) morning
- I would be available during the project to discuss and help

Thanks for your attention!

Any questions ?