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MICROMECHANICS MODELING OF TENSILE/SHEAR BEHAVIOR AND CRACK DENSITY OF COMPOSITE MATERIALS

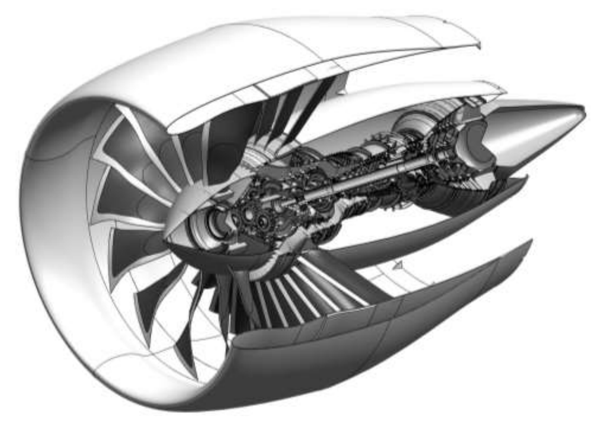
D. Haruyama[1], S. Onodera[2], and T. Okabe[3]

[1] Engine Technology Department, IHI Corporation, daichi_haruyama@ihi.co.jp

[2] Department of Aerospace Engineering, Tohoku University, sonodera@plum.mech.tohoku.ac.jp

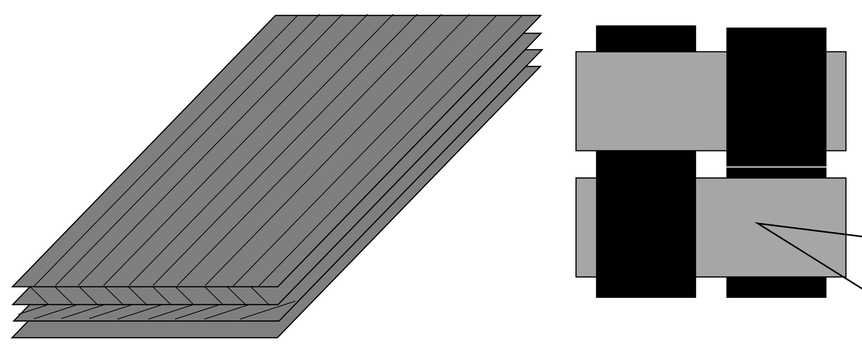
[3] Department of Aerospace Engineering, Tohoku University, okabe@plum.mech.tohoku.ac.jp

Background



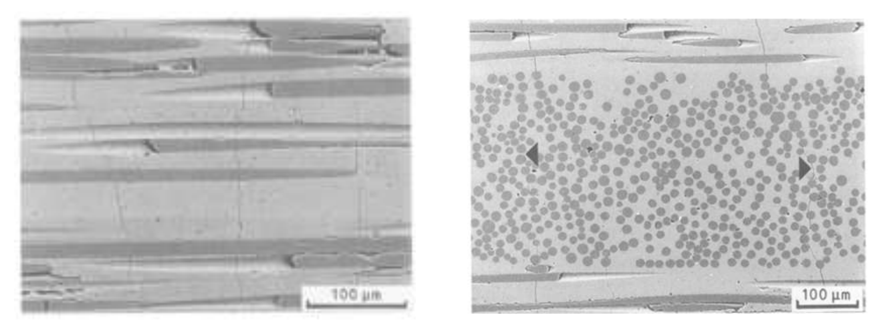
Conduct of the research to apply composite materials to engine parts

◆ Intermediate materials



Composite laminate   Woven fabric composite

◆ Microstructure [10]



Matrix crack   Transverse crack

[10] A. W. Pryce et al., Journal of Materials Science, Vo.27, No.10, 1992.

➢ Motivation

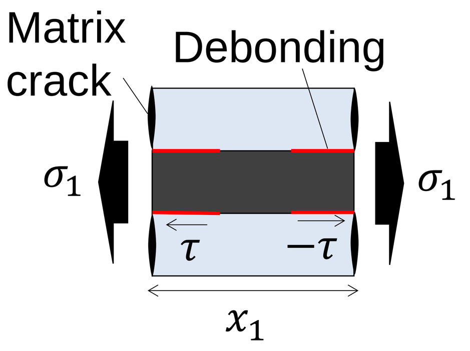
We want to
- ✓ predict the mechanical property of composite material.
- ✓ describe macro stiffness degradation from micro damages.

Objective We evaluate the relationship between damages and stiffness degradation of brittle matrix composites.

Micromechanics model and damage variable

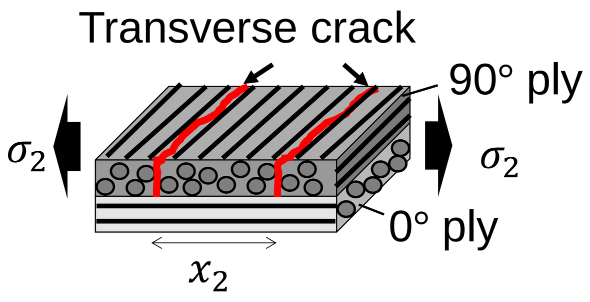
➢ Tensile damage

◆ Matrix crack [4]



- ✓ Model proposed by Curtin et al.
- ✓ Transition of nonlinear behavior by the condition of debonding

◆ Transverse crack [5][6]



- ✓ Model proposed by Okabe et al
- ✓ Load is supported by surrounding materials
- ✓ Material property: Homogeneous anisotropy

Calculation of $d_i(\rho_i, \epsilon_i)$ from micromechanical model

x_i: Crack space, ρ_i: Crack density($\rho_i = 1/\overline{x}_i$), σ_i: Stress, ϵ_i: Strain, d_i: Damage variable, τ: Sliding stress

➢ Shear damage [7]

$$(1-d_{ij})^{-1} = \frac{1}{2}\left\{(1-d_i)^{-1} + (1-d_j)^{-1}\right\}\ (i \neq j)$$

It is possible to calculate the shear behavior from tensile behavior

➢ Stress-strain behavior

$$\{\sigma\} = [M]^{-1}[D_0]\{\epsilon\}$$

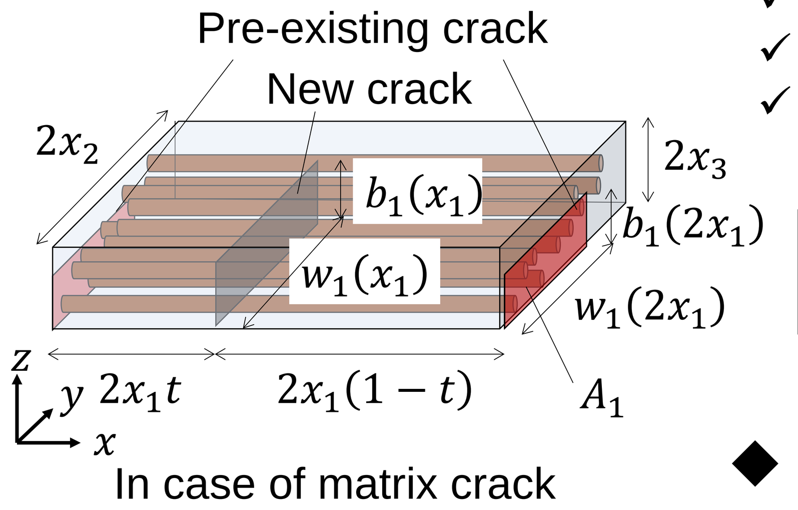
This equation is based on continuum damage mechanics.

$[M]$:Damage effect matrix, $[D_0]$:Elastic modulus matrix

[4] W. A. Curtin et al., Acta Materialia, Vo. 46, No.10, 1998.
[5] Tomonaga Okabe et al., International Journal of Damage Mechanics, Vol. 27, No. 6, 2018.
[6] PETER GUDMUNDSON et al., International Journal of Solids and Structures, Vol. 30, No. 23, 1993
[7] C. Chow, et al., Engineering Fracture Mechanics, Vol.34, No.3, 1989.

Damage evolution [9]

◆ Crack area and position



In case of matrix crack

Γ_i: Energy release rate, U: Elastic strain energy, σ_{ci}: Critical stress, Γ_{ci}: Fracture energy, b_i, w_i: Crack length, $2x_i$: Evaluation length, A_i: Crack area

[9] S. Onodera, et al., Advanced Composite Materials, Vol.26, No.5, 2017.

◆ Assumption

- ✓ Work is 0 from external loading
- ✓ Periodic cracks
- ✓ New crack position is center (t=0.5)

$$\Gamma(\rho_i) = -\frac{U_a(\rho_i) - U_b(\rho_i/2)}{A_i}$$

where $\rho_i = 1/x_i$

◆ Crack initiation criteria

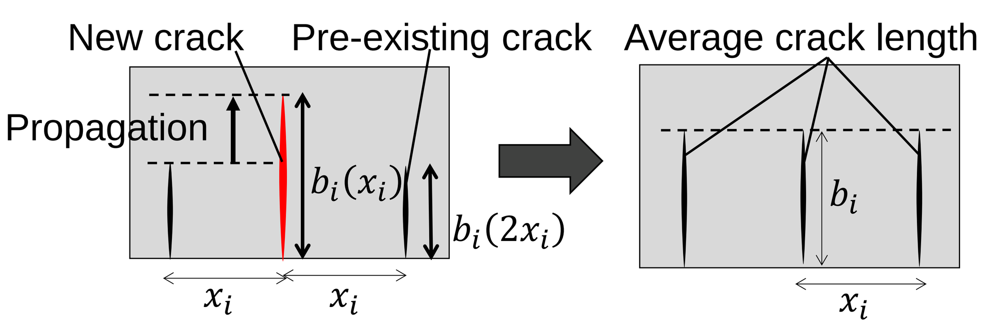
$$\sigma_i \geq \sigma_{ci}$$

◆ Crack growth criteria

$$\Gamma_i = \Gamma_{ci}$$

Crack density ρ_i is evaluated as above equation is satisfied

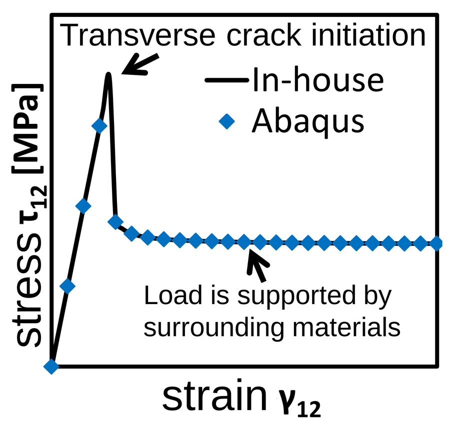
Crack length in these models

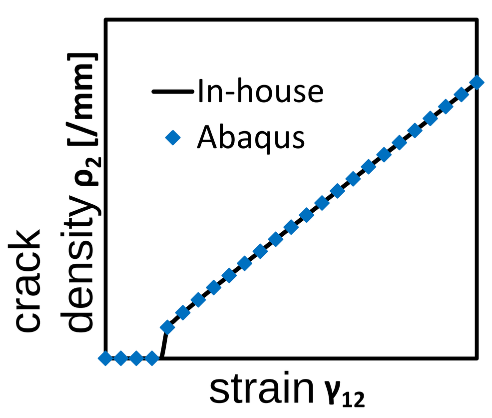


$b_i(2x_i)$: Crack length before new crack initiation
$b_i(x_i)$: Crack length after new crack initiation

- ✓ Crack length increases with increasing crack density
- ✓ Average crack length b_i was used because of equally distributed cracks.

Calculation example

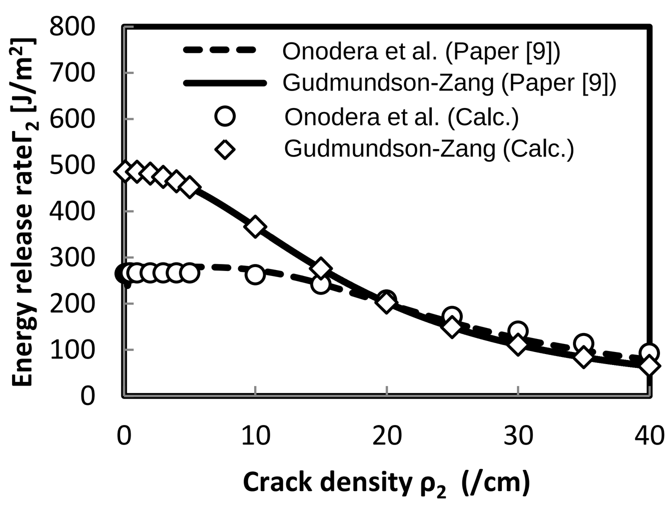




- ✓ These models were implemented in subroutine of Abaqus.
- ✓ Not only tensile behavior but also shear behavior can be calculated with these model.

Comparison of the paper and these models

➢ Verification by calculation in transverse direction

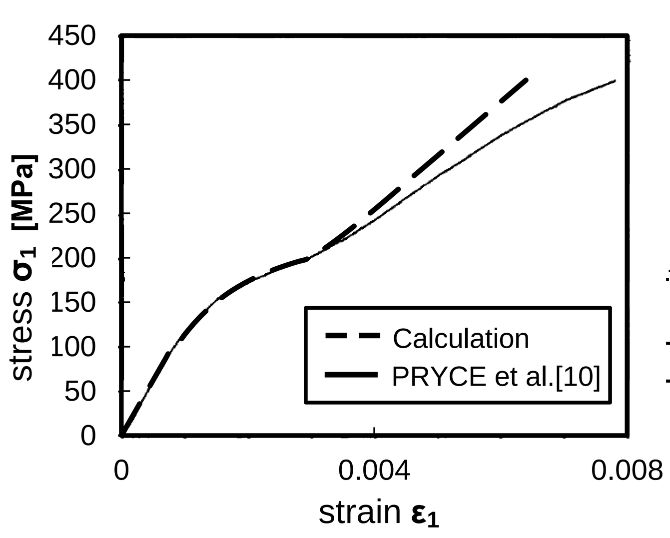


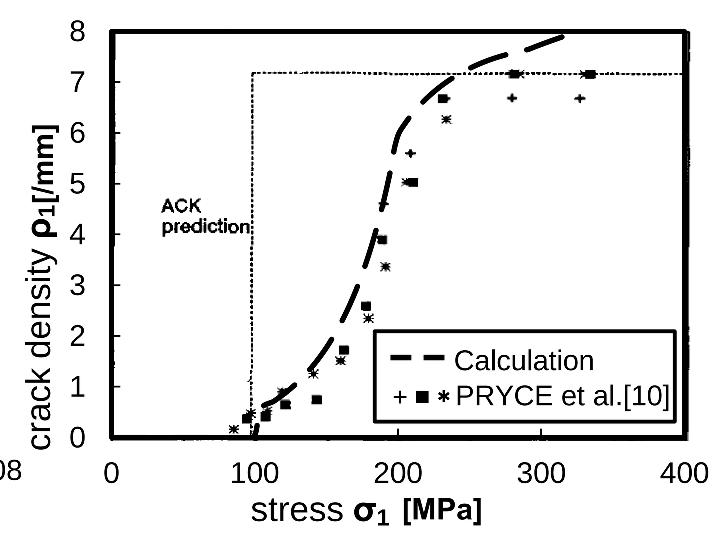
◆ Paper [9]
- ✓ Input strain is only ε_2 because of formulation in 1 dimension

◆ These model
- ✓ Input strain is not only ε_2 but also ε_1 (=$-\nu_{21}\varepsilon_2$) and ε_3 (=$-\nu_{23}\varepsilon_2$).

- ✓ These models have a good agreement in the paper results [9] .

➢ Validation by comparison of experimental results and calculation





Material parameters are experimental material properties or calibrated as stress-strain nonlinear behaviour of the numerical analysis agrees with the test result.

- ✓ These models have a good agreement in the experimental results before the infection point which is the crack saturation [10].

Future work These model will be applied to the composite materials such as the cross-ply laminates and the woven fabric for the validation

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