Critical energy densities of resin systems: the key to matrix dominated composites failure

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Failure of composite structures



Matrix dominated failure



Which comes first: fibre debonding or matrix cracking?

Governing mechanisms – fibre debonding vs. matrix cracking



Micro structure – fibre distributions



Micro structure

- stress distributions from thermal loading



Local stress state from thermal and mechanical loads depends on:

Fibre and matrix properties; fibre distribution and V_f .

Local stress state from transverse loading (including thermal stresses)



Effect of Dilatational (hydrostatic tension) stress



Effect of dilatational (hydrostatic tension) stress

 σ_2 When dilatational energy reaches critical value, cavities burst open, causing debonding σ_2

Effect of Distortional stresses



Debonding vs. Matrix cracking

 Depends on manufacturing induced fiber distributions and voids

Engineering Approach:

Find worst-case (extreme) scenarios for design
Consider thermal loads in micro-mechanical analyses

Composite unit cell

- Fibres and voids explicitly represented in the microstructure
- Material model
 - Fibre: linear elastic
 - Matrix deformation: Macromolecular model, glassy polymers
 - Matrix fracture: Yielding, e.g. New craze model (Rice-Tracy ductile fracture model)
 - Fibre-Matrix debonding: Dilatational energy density criterion
- Loading: Plane strain tension
 - Temperature
 - Strain rate



Matrix cracking: design data

- Material data are to be <u>measured on glassy polymers</u> (not on composite materials!)
 - High distortional energy densities: measure yield stress
 - High dilatational energy densities: measure stress at crack initiation by micro cavitation



High distortional energy density tests – Yield stresses

- Uniaxial tests according to ASTM D638M-81
- Plain strain compression test (friction free)



High dilatational energy density tests – Cavitation stress (3D)

The Poker-chip test, a 3D-tension test

- Very difficult test to perform



High dilatational energy density tests – Cavitation stress (plane stress)

 Biaxial tension tests of hybrid composite/glassy polymer laminates (1.25mm thick polymer layer), thermal stresses considered.





High dilatational energy density tests – Cavitation stress (equibiaxial stress)

- Thermo-mechanical disk test (loaded by cooling down to temperatures of -160°C)
- Equibiaxial, meaning that radial and tangential stress components are equal.



Dilatational vs Distortional energy density criteria

- The dilatational energy density criteria is applicable only when the level of distortional energy density is low.
- There is a need to identify these regions in stress space where matrix failure is governed by either dilatational or distortional energies.
- These <u>tests</u> are to be performed <u>on neat resins</u> and to be used in computational analyses of composite materials and their structures.

Prediction of matrix cracking/ debonding in composite materials

 Measured dilatational and distortional energy densities are employed in micromechanical analysis of composites

- Debonding:
$$U_{\nu} = \frac{1-2\nu}{6E} (\sigma_1 + \sigma_2 + \sigma_3)^2 = U_{\nu}^{crit}$$

 cracking/yielding: von Mises or modified yield criteria for polymers.

Rice-Tracy ductile fracture model

Example: Failure initiation predictions

- Matrix cracking predicted by von Mises yield stress
- Matrix debonding/cavitation was predicted by the dilatational energy density criterion.

Glass/epoxy laminates

Assuming square array fibre distribution.

| Material | Young's modulus (GPa) | Poisson's ratio | Thermal expansion coefficient (10 ⁻⁶ /ºC) |
|----------|--------------------------|-----------------|---|
| E-glass | 70 | 0.22 | 7 |
| Ероху | 3.2 | 0.37 | 67.5 |

Results

Transverse failure by debonding, i.e. cavitation, predicted for all composite laminates.



Conclusions

- Prediction of matrix dominated failure in polymer composites should rely on test data on the glassy polymer considering:
 - Matrix cracking
 - Fibre debonding/matrix cavitation
- Test methods for biaxial tensile loading with varying biaxiality ratio should be expanded
- Further studies needed:
 - composite matrix failure under more general imposed loading should be performed
 - Influence of voids, misalignments, and other defects

References

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