Analysis of Composite Materials for Improved Vehicle Performance and Reduced Weight

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Introduction

• **What is a fibre-reinforced plastic composite material?**

  “A structural composite is a material system consisting of two or more phases on a macroscopic scale, whose mechanical performance and properties are designed to be superior to those of the constituent materials acting independently.”
  (Daniel and Ishai, 2006)

  ⇒ Ideal material when high stiffness-to-weight and strength-to-weight ratios are required – For example:

  BMW i3  
  (Bloomberg, 2013)

  Boeing 787 Dreamliner  
  (1001crash.com)
Demand for Composites is Increasing

- Use of composite materials is still expanding
  - Aerospace and Wind turbines largest users carbon fiber
    - 43,500 tons used in 2012
    - Aerospace 18%
    - Wind turbines 23%
  - Automotive use of carbon fiber to be >$6 billion by 2020, overtaking aerospace
Categories of composite materials

- Particulate filler
- Discontinuous fibers
- Continuous fibers
- Other (e.g. sandwiches)

- Injection Molded
- Molding Compound

Diagram showing the process of injection molding and SMC.
Composite Materials

- Categories of composite materials

  - Particulate filler
  - Discontinuous Fibers
  - Continuous Fibers
  - Other (e.g. sandwiches)

  - Unidirectional
  - Woven fabrics
  - Laminates

Unidirectional composite lamina (Jones, 1999)

Woven composite lamina (Jones, 1999)

Unbounded view of a laminate (Jones, 1999)
Short Fiber Injection Molded Composites
Importance of Manufacturing on Material Properties

Resulting material is:
- Inhomogeneous
- Anisotropic
- Temperature sensitive
- Environment sensitive (polyamides)
- Viscous component to behaviour
Short Fiber Approaches in nCode DesignLife

- Stress Life Analysis; Material properties from nCode database
  - Linear anisotropic results from standard FE solution
  - Nonlinear results from FE solution and multi-scale modeler
- Stress Life Analysis; Co-processing with multi-scale modeler
  - Every location requests an SN curve
  - Curve created based on location using micro-mechanics
- Strain Energy Density as damage parameter
  - FE uses anisotropic material model
  - Fatigue calculation is isotropic
Short fiber SN Fatigue Solution using Standard FE Stress Results

- CAD Geometry
- Manufacturing simulation
- Structural FE
- Material parameters
- Material data (SN curves)
- Service loads
- DesignLife
- Fatigue durability
  - Orientation tensor file
  - Layered shell element results
Short Fiber SN Composite Engine – SN interpolation model

- Fibre share $\lambda = \text{orientation tensor resolved in stress direction} \ (0 \leq \lambda \leq 1)$
- Family of SN curves reverse engineered from coupon tests each associated with a value of $\lambda$
- Abs Max Principal or Critical Plane stress calculated
- $l$ is critical plane or dominant stress direction
- Local SN curve determined by interpolation or extrapolation based on $l$
Short fiber SN Fatigue Solution Co-computing with Multi-scale Modelling

- CAD Geometry
- Manufacturing simulation
- Material parameters
- Material data (SN curves)
- Service loads
- Structural FE
- DesignLife
- Fatigue durability
- Multi-Scale Modelling

Fatigue durability
**Strain Energy Damage Parameter – The Concept**

**Damage equation**

\[ \Delta W = K \ (N_f)\alpha \]

**Strain energy history**

\[ W(t) = \varepsilon_{ij}(t) \ \sigma_{ij}(t)/2 \]

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**Strain Energy Density Curve**

**Stiff**

![Stiff Strain Energy Density Curve diagram](image1)

**Not Stiff**

![Not Stiff Strain Energy Density Curve diagram](image2)

**εσ** = **εσ**

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Strain Energy Curve Based on Local Stresses and Strains

Net section stress-life curve converted to local strain energy-life curve based on the FE simulation results for each orientation
Continuous Fiber Composite Failure Criteria
Composite Failure Criteria in nCode DesignLife

- **Limit or non-interactive failure criteria**
  - Maximum stress
  - Maximum strain
- **Partially interactive failure criteria**
  - Christensen
  - Hashin-Rotem
  - Hashin
  - Hashin-Sun
  - NU
- **Fully interactive failure criteria**
  - Franklin-Marin
  - Hoffman
  - Norris
  - Norris-McKinnon
  - Tsai-Hill
  - Tsai-Wu
- **Custom (Python-based)**
• **Metals**
  • For multiaxial load cases, a yield criteria is used to characterise the end of linear elastic behaviour
  • Examples of yield criteria (Jones, 1999):
    • Maximum stress
    • Tresca
    • Von-Mises
Example #2 ($\sigma_1$-$\sigma_2$ plane)

- Material: Satin-weave glass/epoxy

Refs:
Tsai-Hill Static Failure Criteria

\[
F(\sigma_1, \sigma_2) = \frac{\sigma_1^2 - \sigma_1 \sigma_2}{S_1^2} + \left(\frac{\sigma_2}{S_2}\right)^2 + \left(\frac{\tau_{12}}{S_{12}}\right)^2 = 1
\]

Where \( S_1, S_2, S_{12} \) are strength parameters
Fatigue of Composites R&D


Tsai-Hill Fatigue Failure Criteria

- Formulation:

\[
\left[ \frac{\sigma_{1a}}{S_1(N_f)} \right]^2 - \frac{\sigma_{1a}\sigma_{2a}}{[S_1(N_f)]^2} + \left[ \frac{\sigma_{2a}}{S_2(N_f)} \right]^2 + \left[ \frac{\tau_{12a}}{S_{12}(N_f)} \right]^2 = 1
\]

where \(S_1(N_f), S_2(N_f)\) and \(S_{12}(N_f)\) are S-N curves.

- Solve the above fatigue failure equation for \(N_f\)

- Damage parameter (Miner’s rule): For each block \(k\) of \(n^{(k)}\) cycles:

\[
D^{(k)} = n^{(k)}/N_f^{(k)}
\]

- Damage accumulation:

\[
D = \sum_{k=1}^{N_{cycles}} D^{(k)}
\]
Summary

- Demand for the use of composites is increasing, especially in automotive.
- Fatigue of short fiber composites can be analyzed now with DesignLife.
- Continuous fiber composites are required for large structural components and DesignLife 2018 has new beta capabilities available for evaluation.
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