Implementation of a multi-axial loading path material characterization system

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Objectives

- Point out that structural material characterization has not changed in principle in 500 years
- Demonstrate that a need exists for alternative methods for material characterization
- Provide overview of the methodology
- Show results through examples
The Beginnings of Mechanics

- Leonardo da Vinci (1452-1519)
  "Testing the Strength of Iron Wire of Various Lengths"

Timoshenko, "History of Strength of Materials"
The Beginnings of Mechanics

Robert Hooke (1635-1703)

Hooke’s Law

William Oughtred (1632)
Invented the logarithmic slide rule

Timoshenko, “History of Strength of Materials”
The Beginnings of Mechanics

Cauchy (1789-1857)
Generalized Hooke’s Law

Timoshenko, “History of Strength of Materials”
Operational Philosophy

- Why change?
- Science “Push” vs Industry “Pull”
- Computational power of the computer
- Resistance to change
- Standards Organizations (ASTM etc)
- Building Codes
- End users
- Academic Scientific Method
Operational Philosophy

- Industry Pull
- Realistic Systemic Simulation/ Prediction
- Inexpensive Material Qualification/Certification
- Quick Material Insertion
- Rapid Prototyping and Production
Operational Philosophy

- Technology Pull
- Computational Technology
- Automation
- Computational Symbolic Math
- Automated Software Synthesis
Operational Philosophy

- Producers view:
  - Rapid and inexpensive characterization of new materials
  - Utilization of existing material behavior databases constructed from massive automated testing
  - Automated synthesis of material behavior theories and finite element models for structures of interest
  - Studies of material/structural behavior as a function of operational system requirements
Operational Philosophy

- Measure first, then Model (Data driven Modeling)
- Interpolate, NOT Extrapolate
- Locally flat Parameter Spaces (Continuity of parameters)
- Work only with commonly accepted composition rules
- Automate, then Apply
Physical System Identification

Physical World

- Physical System
  - External Appearance

Conceptual World

- Modeled System
  - Internal Appearance

Behavior Appearance

Graphs:
- Hybrid 10 Load versus Stroke
  - Open Hole, Net Tension

Load (kN) vs. Stroke (mm)
Physical System Identification

- Axioms of Enrichment:
- The Axiom of Continuous Behavior
- The Axiom of Composition Behavior
- The Axiom of Zero Order of Reality
Physical System Identification
Physical System Identification

- “Mechanics is the paradise of mathematical science because here we come to the fruits of mathematics.”

- Leonardo da Vinci
Physical System Identification
Physical System Identification

**General Case and Planar Mode:**
3 displacements + 3 rotations + 3 forces + 3 moments + Np x 6 strains + Np x Nf = 12 + (6+Nf)xNp Datastreams

**Special Case:** In-Plane Mode
2 displacements + 1 rotation=3 DOFs=6 Datastreams

![Specimen Image](image)

FPL & NRL’s Automated 6-D Loader

Data Acquisition & Control

Compute coefficients of $\phi$ that minimize the system of equations derived from the energy balance:

$$
\int_{0}^{L} \tilde{\epsilon}_{k} q_{k} d q_{k} - \frac{1}{2} \int_{0}^{L} u_{k} u_{k} d x_{k} + Q = \int_{V} \phi \left( \varepsilon_{k}(x_{j}), f_{k}(x_{j}) \right) d x_{j}
$$

Store measured coefficients of (dissipated energy density) in data base
Physical System Identification

Systematic Material Identification, 3 DOF Motions:
Physical System Identification
Physical System Identification

Proportional Path

Winding Path
Physical System Identification

Optimal Solution:
Wood-Plastic Composites
Wood-Plastic Composites

The graph displays the relationship between Normal (in/in) and Shear (rad.) Strain and Normal (psi) and Shear (psi) Stress for different types of wood-plastic composite loading conditions: Compression, Tension, Flexure, and Torsion. The axes represent the strain and stress values, with the strain ranging from 0 to 0.05 and the stress ranging from 0 to 2500 psi. The graph shows distinct curves for each type of load, with Compression and Tension exhibiting higher stress levels compared to Flexure and Torsion.
# Wood-Plastic Composites

<table>
<thead>
<tr>
<th>Profile</th>
<th>$Ef$ Actual (psi)</th>
<th>$Ef$ Predicted (psi)</th>
<th>⊗%</th>
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<tbody>
<tr>
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<td>311000</td>
<td>319000</td>
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<tr>
<td>Box</td>
<td>182000</td>
<td>179000</td>
<td>-1.6</td>
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</table>
Wood-Plastic Composites

Design Load = 20000 lbss

Actual Load = 20007 lbs
COV = 3.6%
Modeling SIPs
Modeling SIPs

Compression

Stress (psi)

Strain (in./in.)

40%
Modeling SIPS

Tension

Stress (psi)

Strain (in./in.)

4%
Modeling SIPs

Shear

Stress (psi)

Strain (radians)

7%
Modeling SIPs

FE Results

Test data

Applied Load (lbs)

Center Displacement (in.)
Conclusions

- Hardware exists to evaluate materials in multi-physics environment.
- First generation software is available to analyze data.
- Second generation data is being developed.
  - Utilize objective functions to optimize loading path.
  - Non-proportional loading paths perform better.
- Data-Driven approach is appropriate to meet the demands of “Industry Pull.”
- Need to overcome resistance to implement changes.
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Nothing in Nature is random. ... A thing appears random only through the incompleteness of our knowledge.

Spinoza