Service Life Assessment Methodology for Composites (SLAM-C)

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Opportunity

- Composite materials are being used increasing in construction
  - used for primary structure, repairs and reinforcements
  - increased specific strength and stiffness; reduced part count and weight

- Durability of composites not well understood or considered
  - more formulations than metals with many fewer data points in existence
  - complex and interacting damage modes complicate further problem

- Need exists to develop software to predict composite durability
  - many viable analytical models presently exist in the literature
  - formal framework must be put in place to standardize evaluation
  - ideally as few tests as possible would be performed for efficiency
  - ASTM tests should be used wherever possible
SLAM-C Architecture

- **Service Life Assessment Methodology for Composites**
  - durability standards and procedures integrated with models
  - implementation tool with simple software interface, service life output

- **Top level menu**
  - select category of structure (bridge, building, etc.)
  - select sub-category of structure (standard, near ocean, desert, artic, etc.)
  - these selections define durability modules, unit loads and survival criteria

- **Data entry forms**
  - physical properties: chopped/uni/woven, # plies, layup, thickness
  - mechanical properties: as tested stiffness ($E_{1,2}$, $G$) and strength ($\sigma_{1,2}$, $\tau$)
  - durability properties: tested constants for thermal, moisture, UV & creep

- **Final report**
  - certified service life given based on category/sub-category criteria
  - graphical display of performance (strength/stiffness) vs service life
SLAM-C Methodology

• Software would be maintained by certified testing houses
  - criteria for each category determined by Army and building codes
  - further durability modules could be added in software revisions
  - companies would approach certified test house with proposed laminates

• Testing performed by the test house to populate the software
  - company indicates category and sub-category they intend to develop
  - software output would request the appropriate specimens for testing
  - could be machined by the company or test house or a 3rd party
  - as-tested results can be archived in library for future certifications

• Printable “Service Life Certificate” endorsed, sent to company
  - certifies the service life of the given material in the desired environment
  - perform in parallel to compare the performance in multiple applications
Top Level GUI

- Specifies structural category and operating environment
- Logic indicates loading & failure criteria, determines models

ASC 2007
Physical Property GUI

- Enter laminate type, layup, ply thickness for reverse CLPT
- Can archive material to be used for future certification
### ASTM Testing GUI

**SERVICE LIFE ASSESSMENT METHODS FOR COMPOSITES**  
**SLAM-C**

<table>
<thead>
<tr>
<th>DEMO</th>
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<table>
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<tr>
<th>1-Structure</th>
<th>2- Laminate Design</th>
<th>3- ASTM Tests</th>
<th>4- As Tested Properties</th>
<th>5- Report</th>
</tr>
</thead>
<tbody>
<tr>
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<td><strong>UPLOAD</strong></td>
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<td><strong>LINK</strong></td>
<td><strong>Quantity</strong></td>
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**Key Points**

- Provides link to testing standard, generates test matrix
- Upload results directly into software for data reduction (future)
As-Tested Property GUI

- Mechanical and durability properties and constants displayed
- Can archive laminate results to be used for future certification
• Residual properties plotted with failure criteria; “Service Life”
• Export to standard certification form to be printed/endorsed
Modeling

• Only 2 representative environments investigated due to time constraints for accelerated testing

• Moisture (warm/wet ~ jungle)
  - assumes Fickian diffusion
  - swelling in laminate causes degradation
  - Chamis, Crews, Foch & McManus

• Elevated temperature (hot/dry ~ desert)
  - diffusion problem as well
  - Arhennius-type reaction laws
  - Chamis, Crews, Cunningham & McManus
Experimental Validation

- E-glass/VinylEster [0/90/90/0] laminate, VARTM RT cured

- Hot/Dry temperature was selected by TGA mass loss study
  - at 150°C the mass loss was small during a 24 hours period, no charring
  - at higher temperatures, charring was evident around the edges

- Warm/wet temperature selected to be 60°C at 100% RH to guarantee degradation within the remaining test time
Experimental Setup

- Tensile specimens were 25mm wide by 250mm long
  - 0/90 tensile specimens were consistent with ASTM Standard D 3039
  - ±45 tensile specimens were consistent with ASTM Standard D 3518
- Short beam shear specimens were 12.5mm wide by 50mm long
  - 0/90 and ±45 both consistent with ASTM Standard D 2344
  - Span/thickness = 5, and cross-head speed = 1 mm/min
**Software Validation**

- Short beam shear (SBS) test results used to calibrate models
  - solid lines represent model output for phenomenon (same as software)
  - redundant data points collected from tensile tests for validation

- Good agreement between predictions and data for both cases
  - hot/dry showed modest strength increase due to post-cure effect
  - warm/wet exhibited significant loss in strength, slower stiffness reduction
Service Life Prediction Example

• Simple to adjust time scale of static/cyclic loading
  ➢ significant degradation over time due to thermo-oxidative degradation
  ➢ service life of ~1 year predicted w/80% strength failure criteria

• Calibrated model can used to predict variations of conditions
  ➢ 40C and 60% humidity simulated (realistic harsh terrestrial conditions)
  ➢ service life <1 year predicted w/80% strength failure criteria
Conclusions

• SLAM-C methodology is simple way to standardize certification of service life for composite laminates exposed to environment
  - modular software architecture allows for seamless integration of new models and/or update of existing phenomenological models
  - short beam shear (SBS) tests sufficient to characterize the macroscopic behavior of laminates; much simpler and cheaper than traditional tests

• Software guides user through service life certification process
  - forced to use “as tested” data, result files directly uploaded to models
  - particular laminates can be archived in the system for future use
  - output presents a certified service life based on the coded failure criteria

• Good agreement between models and experimental results
  - for both cases examined software prediction matched tensile results
  - TGA results for time-to-char matched model for all temperatures
Acknowledgments

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