Helius:MCT™
Enhanced Composites Simulation

"We have been very impressed with the Firehole team and see great potential for MCT to substantially impact CTD's future spacecraft product designs,"
Naseem Munshi
President
Composite Technology Development Inc. (CTD)

Helius:MCT™provides engineers quick access to the constituent level information necessary to accurately analyze complex composites and obtain superior analytic results. The technical approach adopted by Helius:MCT, not available in other commercially available composite simulation solutions, has been proven by over 15 years of testing and research by a diverse set of industry and government agencies. Helius:MCT enables the design of composite structures without the numerous expensive testing cycles traditionally deployed:

- Faster time to market
- Reduced testing costs
- More reliable designs

Superior Accuracy That Maintains Simulation Efficiency

Helius:MCT is based on MultiContinuum Technology (MCT), an analysis technology for composite structures that decomposes stress and strain fields of a composite material into stress and strain fields for the fiber and matrix components. This specific information provides insight into understanding sources of structural level behavior and allows a more fundamental principle to predict initiation and progression of material damage. <u>Helius:MCT provides accurate simulation capabilities while at the same time is numerically efficient and simple to use:</u>

- The efficiency advantage of Helius:MCT allows for the modeling of entire structures, often eliminating tedious sub-modeling.
- Superior results have been validated through years of use inside the US DoD, in both World Wide Failure Exercises (WWFE I and II) and numerous technical publications.

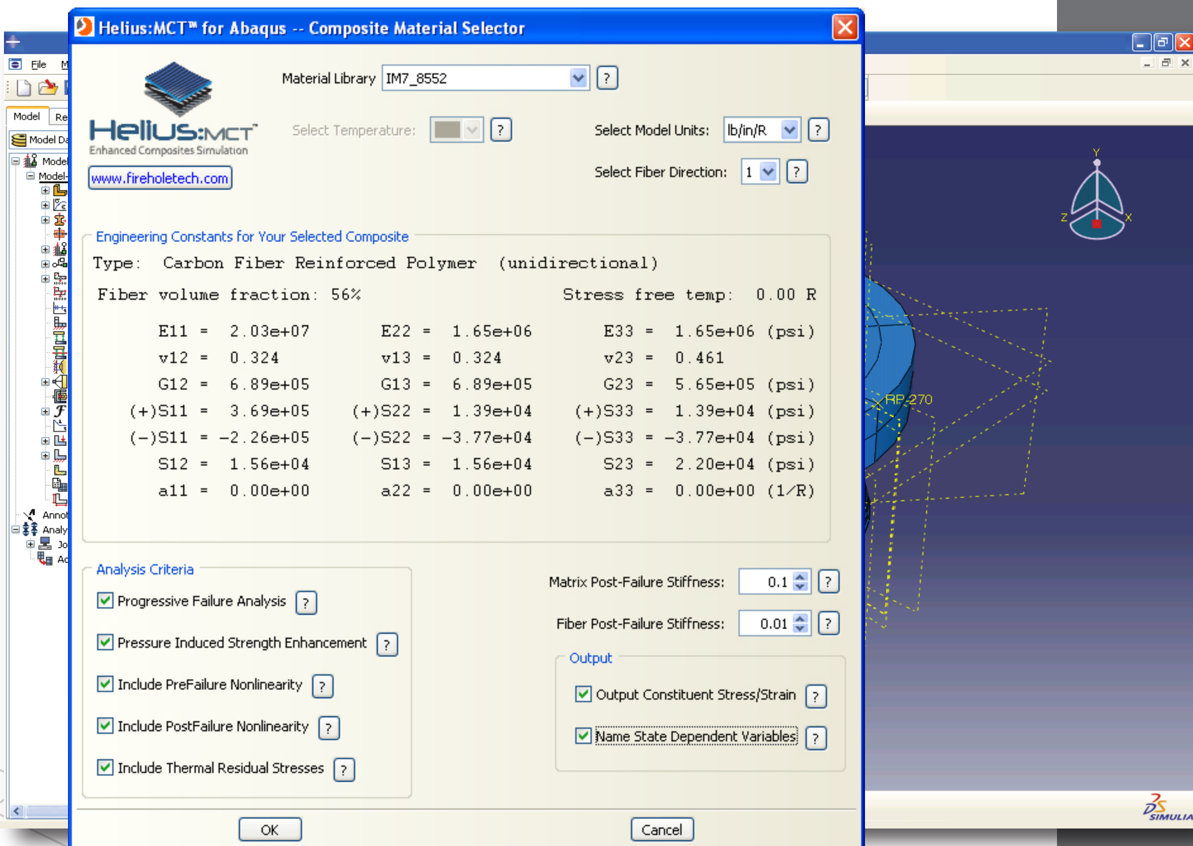
Advanced Features Designed Specifically for Composites

Traditional methods used to predict composite failure (e.g. Tsia-wu, Hashin, or Hill criterions) treat the composite as if it were an orthotropic "black aluminum." While successful in limited situations, these approaches mask the interaction between the fiber and matrix, thereby limiting the detail at which the composite's behavior can be modeled. Helius:MCT includes features that allow for the capture of additional behavior specific to composites:

- Vastly improved failure predictions based on fiber and matrix behavior
- Failure induced material degradation in the component where it occurs
- Customizable material nonlinearity that can be tailored to specific problem needs
- Pressure induced strength modification of the matrix material for high/low pressure applications
- Implemented to ensure robust convergence upon material degradation
- Handles both unidirectional and woven composite materials

Helius:MCT™

User Interface



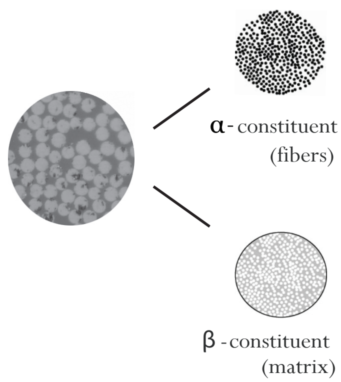
Architected for Easy Adoption

Rolling out a completely new application is a overwhelming endeavor and a significant investment for an organization. To eliminate this adoption hurdle, Helius:MCT seamlessly links to the industry leading Computer Aided Engineering (CAE) packages that are likely already in use within your organization. Currently, Helius:MCT is integrated with ANSYS and SIMULIA's Abaqus package; however, Firehole is actively working to expand integration with additional FEA partners. Please contact us for further information.

Helius:MCT also utilizes industry-standard composite test data, eliminating the need for expensive and difficult to obtain material characterization.

MultiContinuum Technology

The knowledge of continuum stresses and strains in the constituents generates an improved physical basis for predicting initiation and progression of material damage.



$$\underset{\sim}{\sigma}_{\alpha} = \frac{1}{V_{\alpha}} \int_{D_{\alpha}} \underset{\sim}{\sigma}_{\alpha}(x)\, dV_{\alpha}$$

(averaged stress over the fiber domain)

$$\underset{\sim}{\sigma}_{\beta} = \frac{1}{V_{\beta}} \int_{D_{\beta}} \underset{\sim}{\sigma}_{\beta}(x)\, dV_{\beta}$$

(averaged stress over the matrix domain)

We retain the identity of the constituents and refer to their coexistence as a "multicontinuum".

$$\underset{\sim}{\sigma}_{composite} = \phi_{\alpha} \underset{\sim}{\sigma}_{\alpha} + \phi_{\beta} \underset{\sim}{\sigma}_{\beta}$$

(averaged stress over the composite domain)

"A simple, robust and predictive simulation tool, able to accurately identify the failure and the post-failure behavior of general composite structure was an analyst's dream until now. The innovative Firehole multi-scale approach provides an outstanding value to our customers because of its proven effectiveness and sound physical basis "

Simone Ragionieri
General Manager
SmartCAE

New Functionality for Helius:MCT 3.0

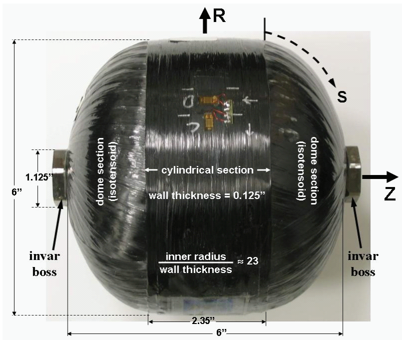
- Extend the concept of MCT to address woven composite structures

The same progressive failure methodology that has been successfully used for unidirectional composite structures has been extended to model progressive failure in woven composite structures. This approach allows volume averaged constituent stresses to be extracted from homogenized composite stresses using simple equations so that failure of each constituent can be evaluated. If failure is detected, the elastic properties of the failed constituent are degraded and the resulting composite stiffness is updated to reflect this failure. As described modeling unidirectional composites, the approach continues to be very computationally efficient and the proprietary intelligent discrete softening (IDS) method is used to ensure robust convergence.

- Temperature dependent material properties
- Auto calculation of extraneous stiffness parameters

Practical Application

Unlined Cryo Composite Pressure Vessel (Unidirectional)



Customer Challenge: Accurately and efficiently predict leak failure of an unlined cryogenic composite pressure vessel (replacement for the aluminum design) in a thermo and mechanical loading scenario. Six nominally identical tanks tested to failure for analytic comparison:

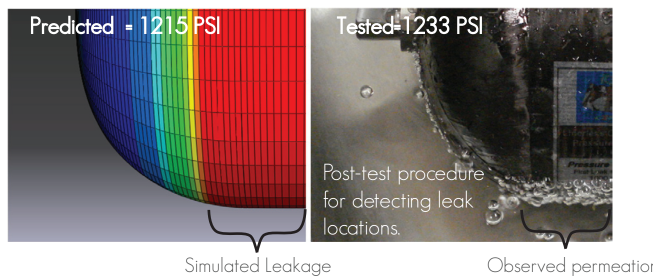
- Submerge tank in liquid nitrogen (Δ T= -216°C)
- Pressurize tank until consistent leakage detected

Solution: Using Helius:MCT, Firehole addresses the mismatch in coefficients of thermal expansion between the fiber and matrix upon cooling (traditional FEA would completely neglect these internal stresses) and uses this information to better predict the mechanical loading at this temperature.

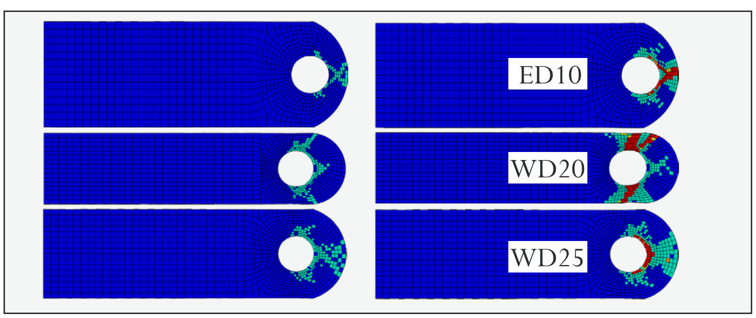
Results:
- Helius:MCT accurate within 1.5% (*one-point-five percent*) of experimental leak pressure
- Heluis:MCT correctly predicts location of failure

Helius:MCT's accuracy allows for the replacement of the aluminum design with a composites tank:

· 40% lighter
· 18% more volume
· 12x capacity



Pin-Loaded Coupons in Tension (Woven)

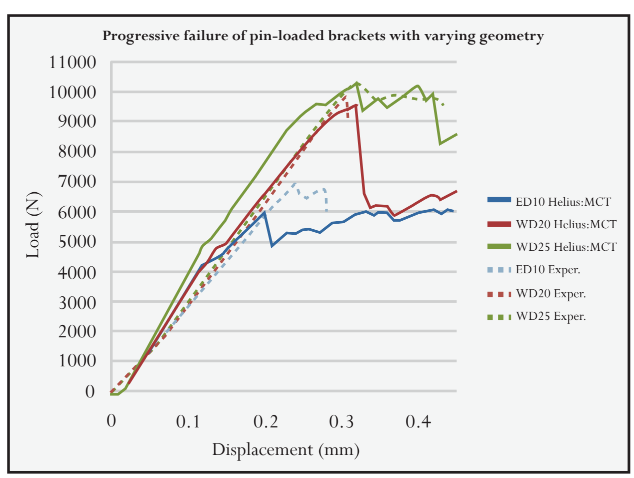


Challenge: Model three different geometries of a pin-loaded composite coupon: ED10, WD20, and WD25. The composite laminate was a combination of carbon/epoxy woven laminae and unidirectional laminae. A tensile load was applied via a pin through the hole of the coupon.

Solution: Using Helius:MCT, Firehole predicted three different failure modes: shear out (ED10), net tension (WD20), and bearing (WD25). The figure above shows the predicted failures in the coupons at two different times: the images on the left correspond to a time when only matrix failure (light blue) is present, while the images show fiber and matrix failure (fiber failure in red).

Results: The models shown above are exactly the failure modes reported in Ahn et al. for each coupon. The load displacement curves to the right compare predicted results with experiment, revealing the high level of accuracy of Helius:MCT.

The accuracy of the stresses at failure for the three samples are:
· WD25 - 0.06%
· WD20 - 3.42%
· ED10 - 14.2%



References

Reference articles for additional information:

Nelson EE, AC Hansen, JS Mayes (2008) “Failure analysis of composite laminates subjected to hydrostatic stresses: a multicontinuum approach,” *Composites Science and Technology,* January, 2008.

Mayes, J.S. and Hansen A.C. (2004) “Composite laminate failure analysis using multicontinuum theory,” Part A of the Worldwide Failure Exercise sponsored by DERA, Great Britain, *Composites Science and Technology*, 64(3-4), 379-394.

Mayes, J.S., and Hansen, A.C. (2004) “A Comparison of Multicontinuum Theory Based Failure Simulation With Experimental Results,” Part B of the World-wide Failure Exercise sponsored by DERA, Great Britain. *Composites Science and Technology*, 64(3-4), 517-527.

Mayes, J.S., and Hansen, A.C. (2001) “Multicontinuum Failure Analysis of Composite Structural Laminates,” *Mechanics of Composites Materials and Structures*, 8(4):249-262.

C. Key, R. Six, and A. Hansen (2003) “A three-constituent multicontinuum theory for woven fabric composite materials,” *Composites Science and Technology*, vol. 63, pp. 1857-1864.

R. Fertig (2010) “An accurate and efficient method fo constituent-based progressive failure modeling of a woven composite,” *Collected Proceedings: Advances in Composite, Cellular, and Natural Materials*, Seattle, WA: TMS.

H. Ahn, J-H Kweon, and J. Choi (2005) “Failure of unidirectional-woven composite laminated pin-loaded joints,” *Journal of Reinforced Plastics and Composites*, vol. 24, pp. 735-752.

Firehole Technologies, Inc
210 S. 3rd Street, Suite 202
Laramie, WY 82070 US
307.460.4763
info@fireholetech.com