Subcomponent Validation of Composite Joints for Marine Energy Structures

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UMERC + METS Conference 2022

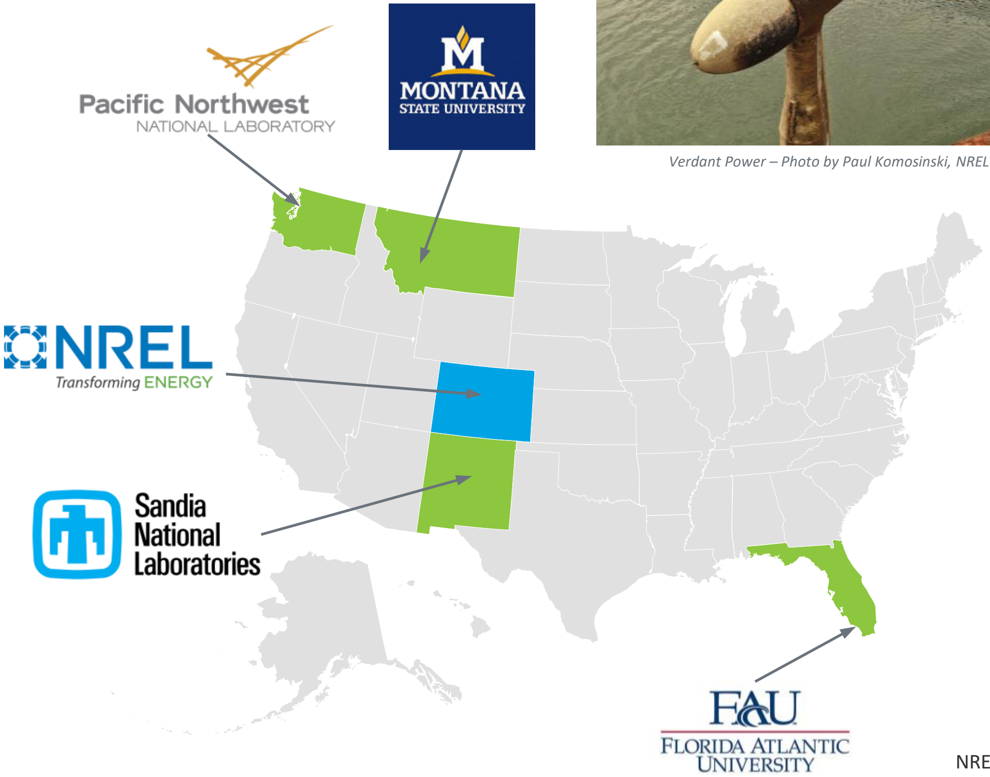
Overview

1. Marine Energy Advanced Materials Project
2. Structural Validation at NREL
3. Materials, Manufacturing, and Conditioning
4. T-Bolt Structural Validation
5. Bonded Insert Structural Validation
6. Project Outcomes and Future Work

Marine Energy Advanced Materials

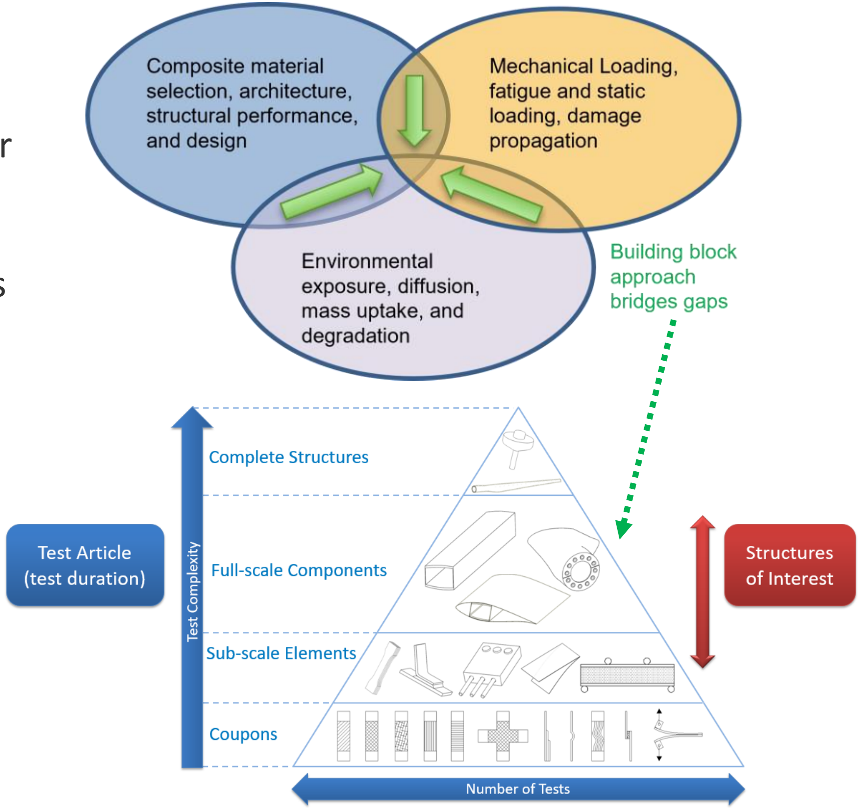
- Multiyear, multilaboratory materials research project
- Reduce barriers and uncertainties to adopting advanced composite materials
- Understand environmental effects on complex structures
- Sandia – lead laboratory
- **NREL – subcomponent validation**
- MSU – material characterization
- PNNL – biofouling and coatings
- FAU – corrosion.

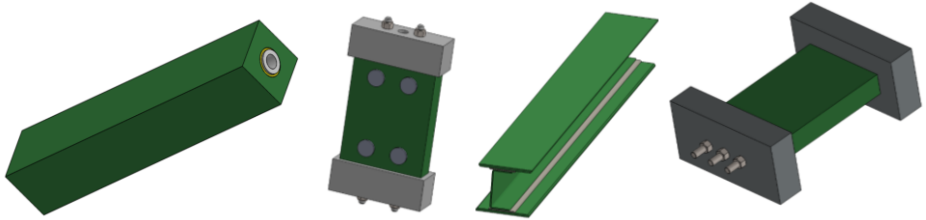
Verdant Power – Photo by Paul Komosinski, NREL 64565



NREL Objectives

- **Address knowledge gaps highlighted in industry surveys and workshops**
- Develop subcomponent-scale validation methods for marine energy materials
- Improve understanding of design allowables with environmental degradation of full-scale components and joints
- Reduce the time and cost required for full-scale structural validation
- Provide near-net-scale static and fatigue data on composite subcomponents of materials for marine energy systems.





Illustrations by Scott Hughes, NREL

Structural Validation

Coupon Characterization

Photo by Paul Murdy, NREL

- ISO 17025 accredited
- Range of test stands
- Hydraulic infrastructure
- State-of-the-art data acquisition, sensor, and non-destructive test equipment.

Subcomponent Validation

Photo by Taylor Mankle, NREL 67493

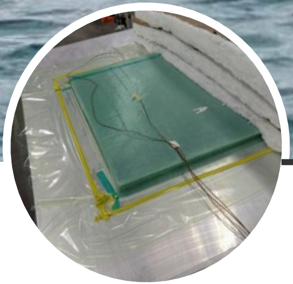
Full-Scale Validation

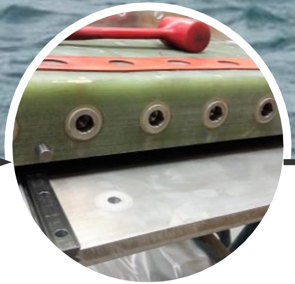
Photo by Taylor Mankle, NREL 67467

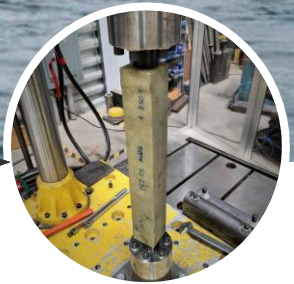
Full-Scale Validation

Photo by Scott Hughes, NREL 14708

Project Timeline







Composite Panels

Thick fiberglass composite panels manufactured at MSU (May 2019)

Composite Specimens

Panels manufactured into specimens at NREL (June 2019 to October 2019)

In-Water Conditioning

Specimens conditioned in ocean water at PNNL and FAU (November 2019 to May 2021)

Maintaining Conditions

Specimens returned to NREL to await testing (April 2021 to December 2021)

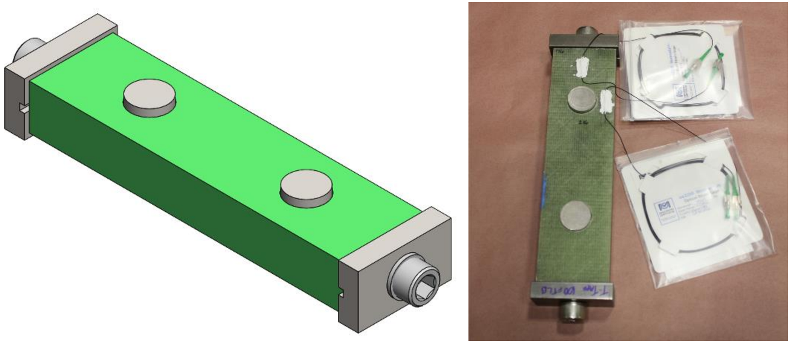
Structural Validation

Static and fatigue testing in 500-kN load frame (July 2021 to February 2022)

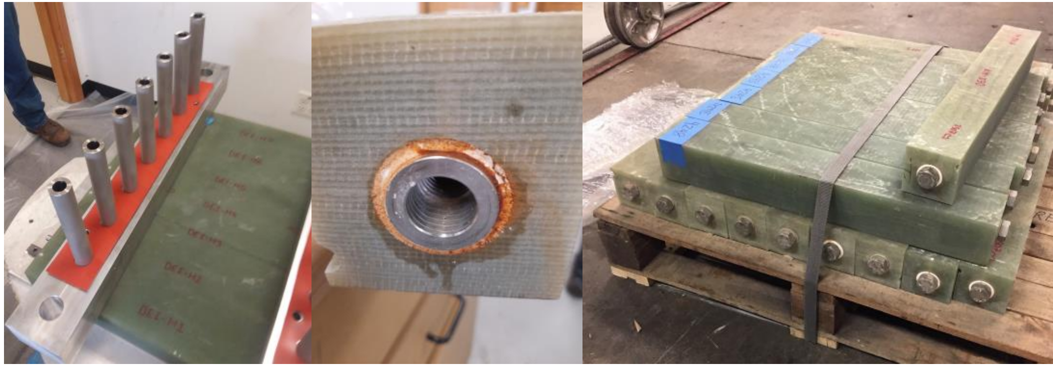
Photos by Ocean Renewable Power Company 68118, David Miller (MSU), Francisco Presuel-Moreno (FAU), and Paul Murdy (NREL)

Materials and Manufacturing

- Panels of varying thickness manufactured at MSU
- Vectorply E-QX 9000 E-glass fabric
- Hexion 035c epoxy resin
- Derakane vinylester-epoxy resin
- Vacuum infusion
- Several specimen geometries
- Over 300 specimens in total
- T-Bolt and double-ended-insert (DEI)
- Araldite epoxy and Plexus methyl-methacrylate adhesives
- 316 and 2507 stainless steels.



T-Bolt – metal/composite interconnect

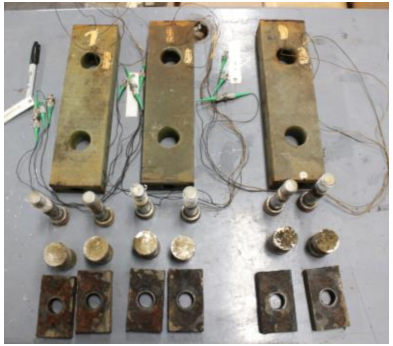


Double-Ended-Insert – metal/composite interconnect

Photos by Paul Murdy and Bill Gage, NREL

Conditioning

- 24 T-Bolt and 14 DEI specimens conditioned
- Dry control specimens remained at NREL
- Half at PNNL under ambient conditions
- Half at FAU at elevated temperatures (58 °C)
- Tracked salinity levels
- 5–18 months
- Returned to cold-water tanks to maintain saturation levels
- Weighed before and after.



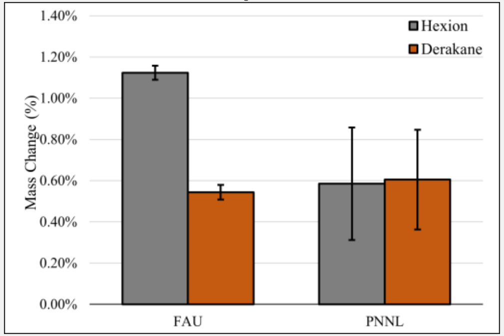
Photos by Paul Murdy and Bill Gage, NREL

Water Absorption Results

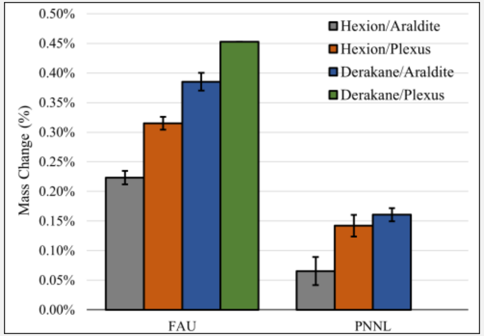
- All specimen masses recorded before and after conditioning
- Specimens cleaned, disassembled, and surface water dried prior to weighing
- Some specimens had fiber-optic strain sensors bonded to them throughout the conditioning period.

- Specimens absorbed more water at FAU accelerated aging
- Hexion epoxy T-Bolt specimens absorbed more water than the Derakane vinylester-epoxy specimens
- Water ingress observed deep in DEI bond lines
- Corrosion of 316 steel insert at adhesive interface of DEI **only in specimens conditioned at PNNL**.

T-Bolt Specimens



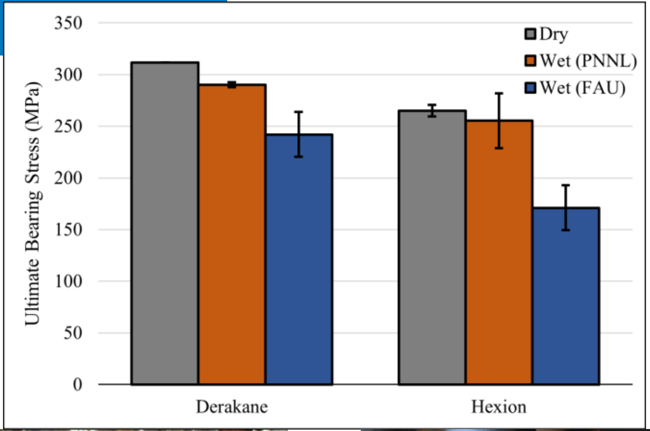
DEI Specimens



Photos and images by Paul Murdy and Bill Gage, NREL

T-Bolt Static Results

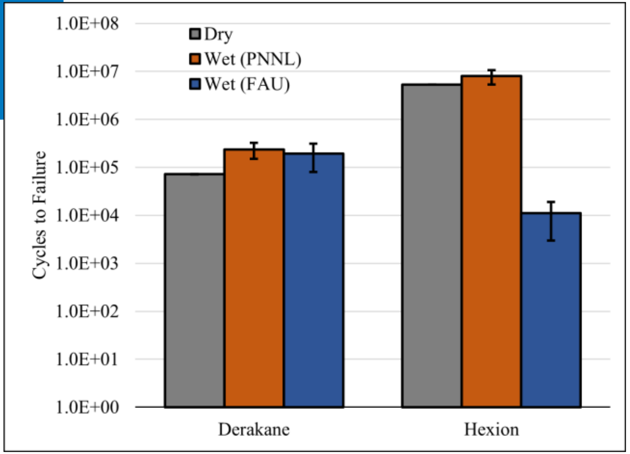
- Specimens tested in 500-kN load frame with bespoke test fixture
- Aermet 100 ultrahigh-strength studs
- 12 specimens – 2 under each environmental condition
- Tensile loading
- All exhibited bearing failures at through-hole
- Derakane generally had higher bearing strengths than Hexion
- All exhibited some degree of environmental degradation
- Hexion degraded more than Derakane at FAU.



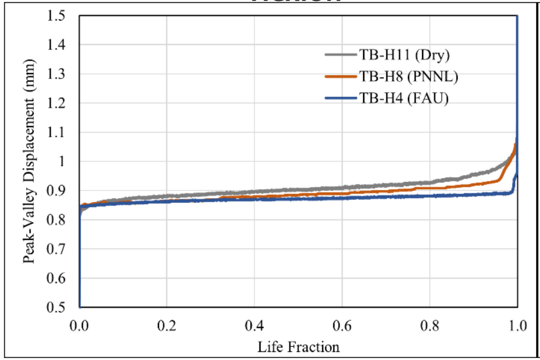
Photos and images by Paul Murdy, NREL

T-Bolt Fatigue Results

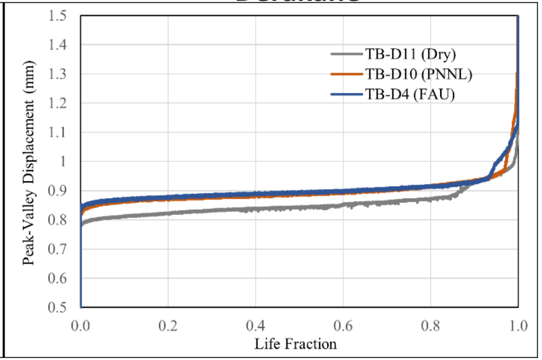
- Reduced width of specimens due to hardware limitations
- 1–2 specimens under each environmental condition
- Tension-tension, constant amplitude
- All specimens tested at same 130 MPa max tensile stress
- All specimens failed in tension ranging from ~10,000 cycles to ~10,000,000 cycles!
- Dry Hexion epoxy specimens had significantly better fatigue strengths, but suffered severe degradation at FAU
- Derakane vinylester-epoxy specimens had poor fatigue strengths but exhibited little to no degradation.



Hexion



Derakane



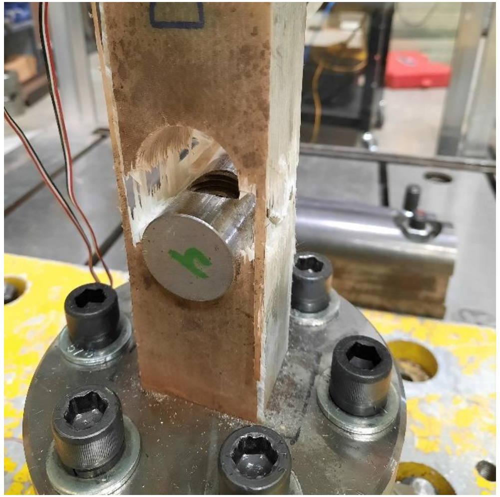
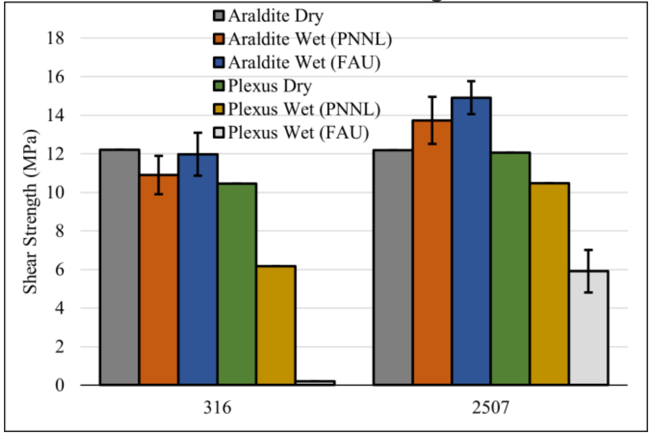


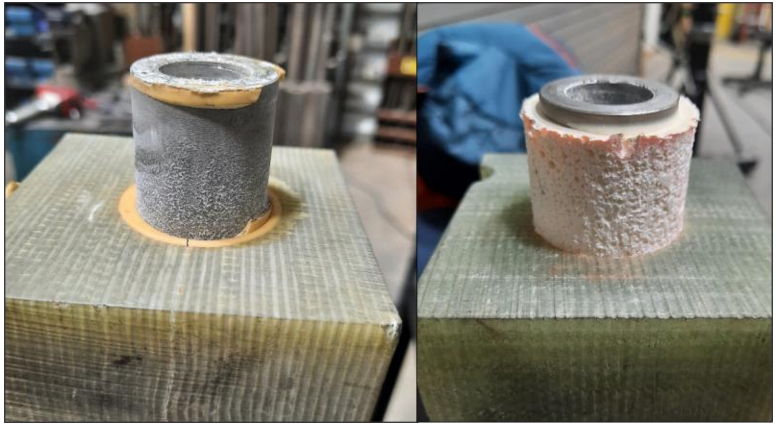
Photo and images by Paul Murdy, NREL

Double-Ended-Insert Static Results

- 1–2 specimens per adhesive and insert material combination
- Ultimate shear strengths calculated using insert bonded surface area
- Ultimate shear strength differences were difficult to interpret
- Plexus methyl-methacrylate adhesive did not perform well
- 2507 steel inserts performed better overall
- Observed water deep in bond lines
- Corrosion of 316 steel **conditioned at PNNL only**.

Adhesive Shear Strength





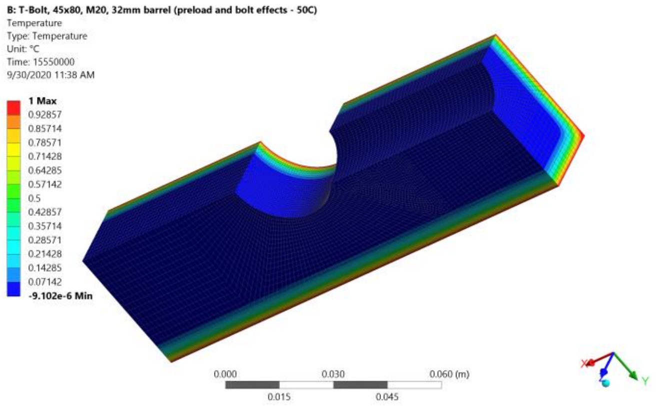
Photos and images by Paul Murdy and Bill Gage, NREL

Outcomes

- Partial saturation can have pronounced effects on larger structures under both static and fatigue loading.
- Conducting fatigue testing at the subcomponent scale can be incredibly time-consuming and requires detailed project planning to ensure like-for-like comparisons.
- Under the right conditions, there are interactions between 316 steel and adhesives.
- Selecting the correct composite, adhesive, and metals for multimaterial interconnects is a complex process for harsh marine environments.
- The results from this project will help marine energy developers make informed material choices and understand the requirements for evaluating new materials for use in marine structures.
- **Full report to be published soon.**

Future Work

- Develop models to understand how far water penetrated thick specimens
- Investigate cause of corrosion observed in some 316 steel/adhesive DEI specimens
- Understand synergistic effects of water/fatigue/temperature
- Develop models to support synergistic testing
- Continue to explore other commonly used composites and future materials.



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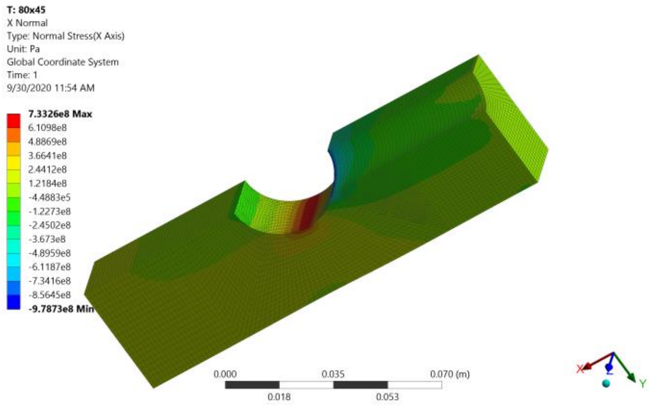

Thank You

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Water Power Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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