University of Edinburgh, November 13, 2019

SAND2019-13759PE

Developing Materials for Marine Renewable Energy Technologies

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Budi Gunawan & James Nicholas (SNL)

David Miller (MSU)

George Bonheyo (PNNL)

Scott Hughes & Paul Murdy (NREL)

Francisco Presuel-Moreno (FAU)

SAND2019-XXX

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Peter Kobos
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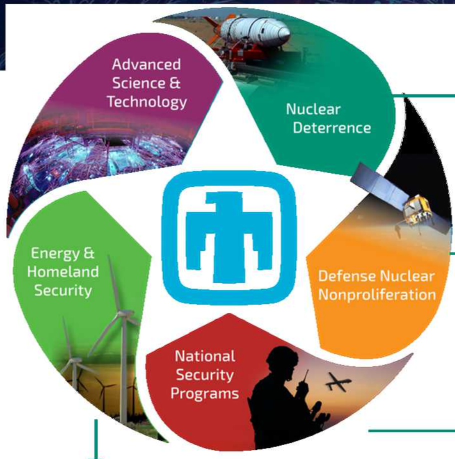

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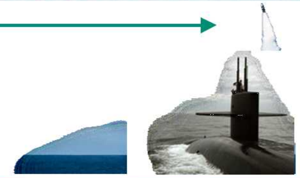
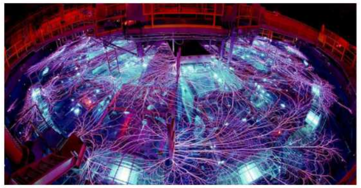


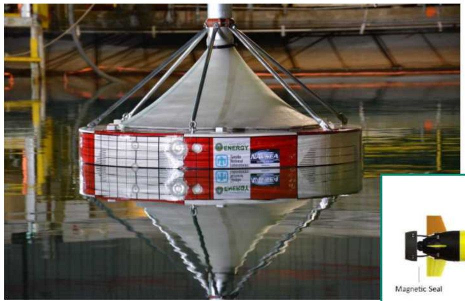
Sensor systems: monitoring emerging threats

Surveillance & reconnaissance

Adv. S&T: Weapons Science & Technology, Office of Science

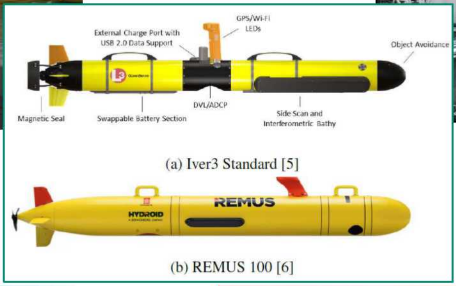


Water Power Device Testing & Robotics: Advanced Dynamics & Controls testing w/DOD, DOE, others



MASK Wave Basin Tests:
Increased power absorption by 200%+

AUV Recharging



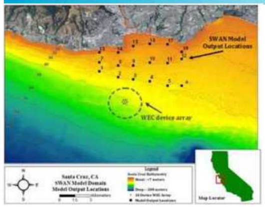
(a) Iver3 Standard [5]
(b) REMUS 100 [6]

Power Take Off Design & Testing

Mobile Lab Capability:
Software & Hardware Device Co-Design & Testing

Demo Video: https://youtu.be/IQgPLUfttN8

Deployment Support

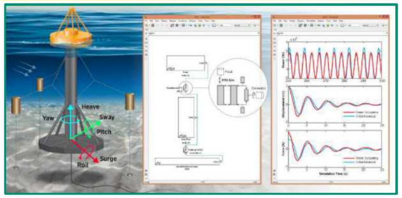


Device Array

Materials Testing

Lab & Field Testing

Design

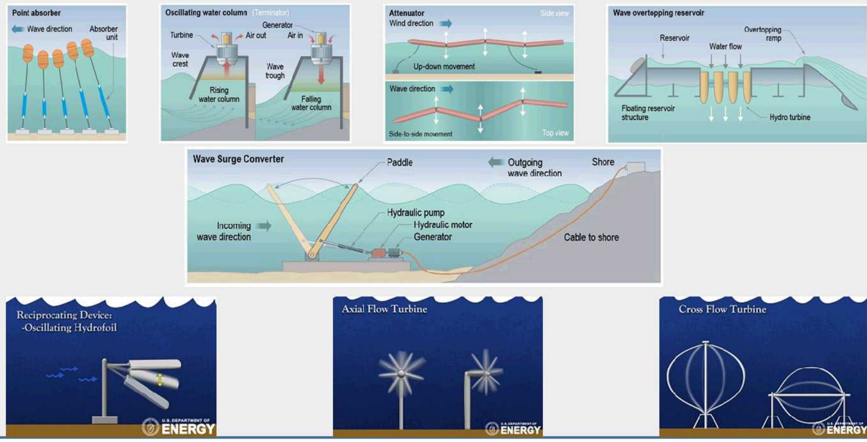


Software

Materials Challenges for Marine Renewables

Proper structural/component materials and coatings are critical to reducing engineering barriers, COE, and commercialization time.

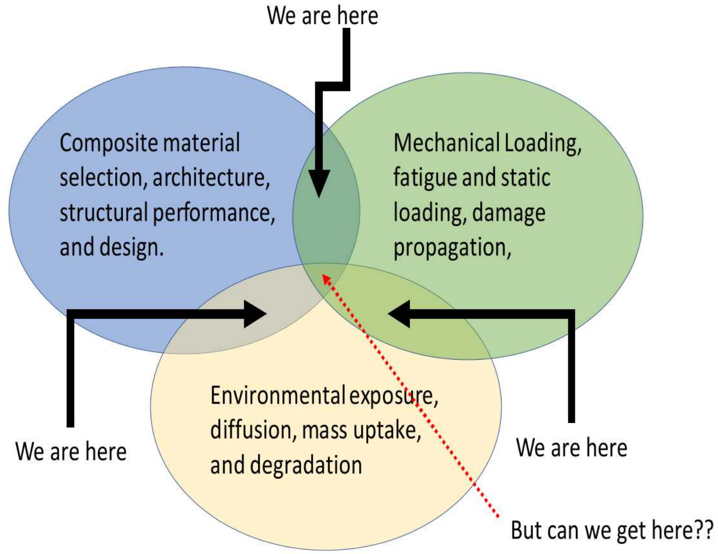
Design Challenge: Several Design Configurations & Operational Conditions



Significant Periodic Loading:

- Interaction with PTO & Control System
- Site Conditions
- IEC Design Standard (Fatigue/Ultimate)

Composites Research Needed



Hernandez-Sanchez et. al 13th EWTEC Proceedings "Evaluation of Composite Materials for Wave and Current Energy Technologies"

Coating & Environmental Challenges

Corrosion

Courtesy of Resolute Marine Energy

Biofouling

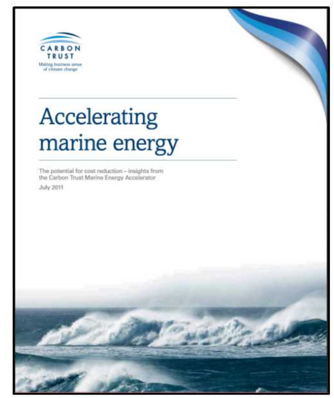
http://www.racerocks.ca/

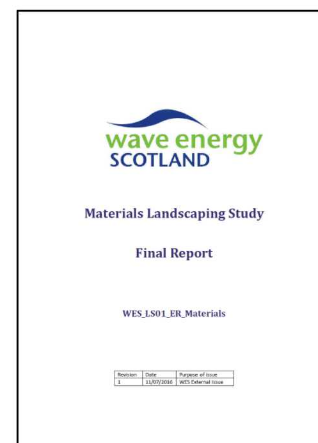
Joined Materials

Adhesive joint beams

Materials can impact cost and ….

- Structure costs
- Designs and manufacture
- Accelerate manufacturing or Advanced manufacturing strategies
- Testing of novel materials or materials from marine industries to reduce risk
- Open water testing on materials for validation
- Reliability & Survivability
- Operation & Maintenance
- Certification & Safety





Materials Team

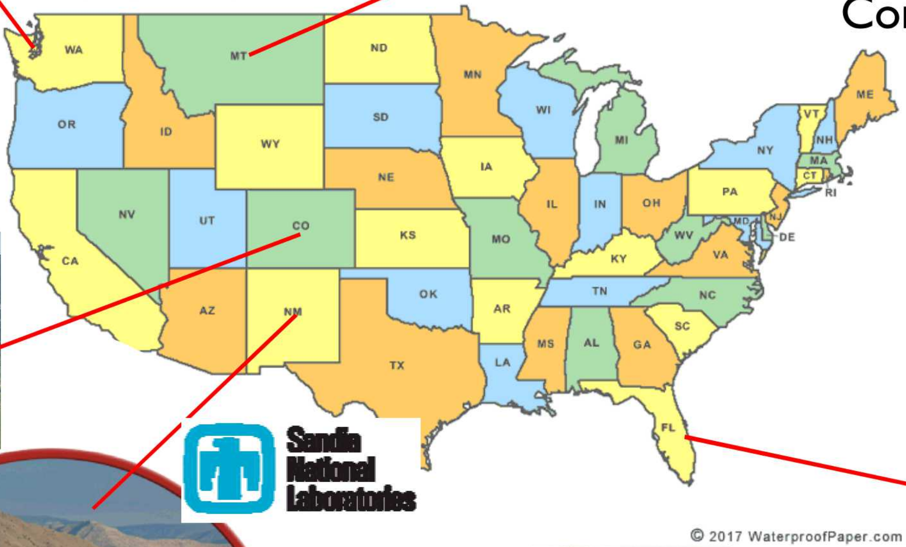
Marine Science Laboratory

George Bonheyo: Biofouling

Pacific Northwest NATIONAL LABORATORY

MONTANA STATE UNIVERSITY

David Miller: Composite Performance

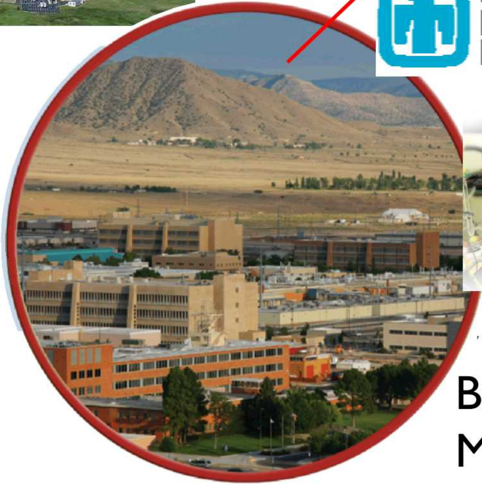


FAU FLORIDA ATLANTIC UNIVERSITY

Scott Hughes: Substructure Testing

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

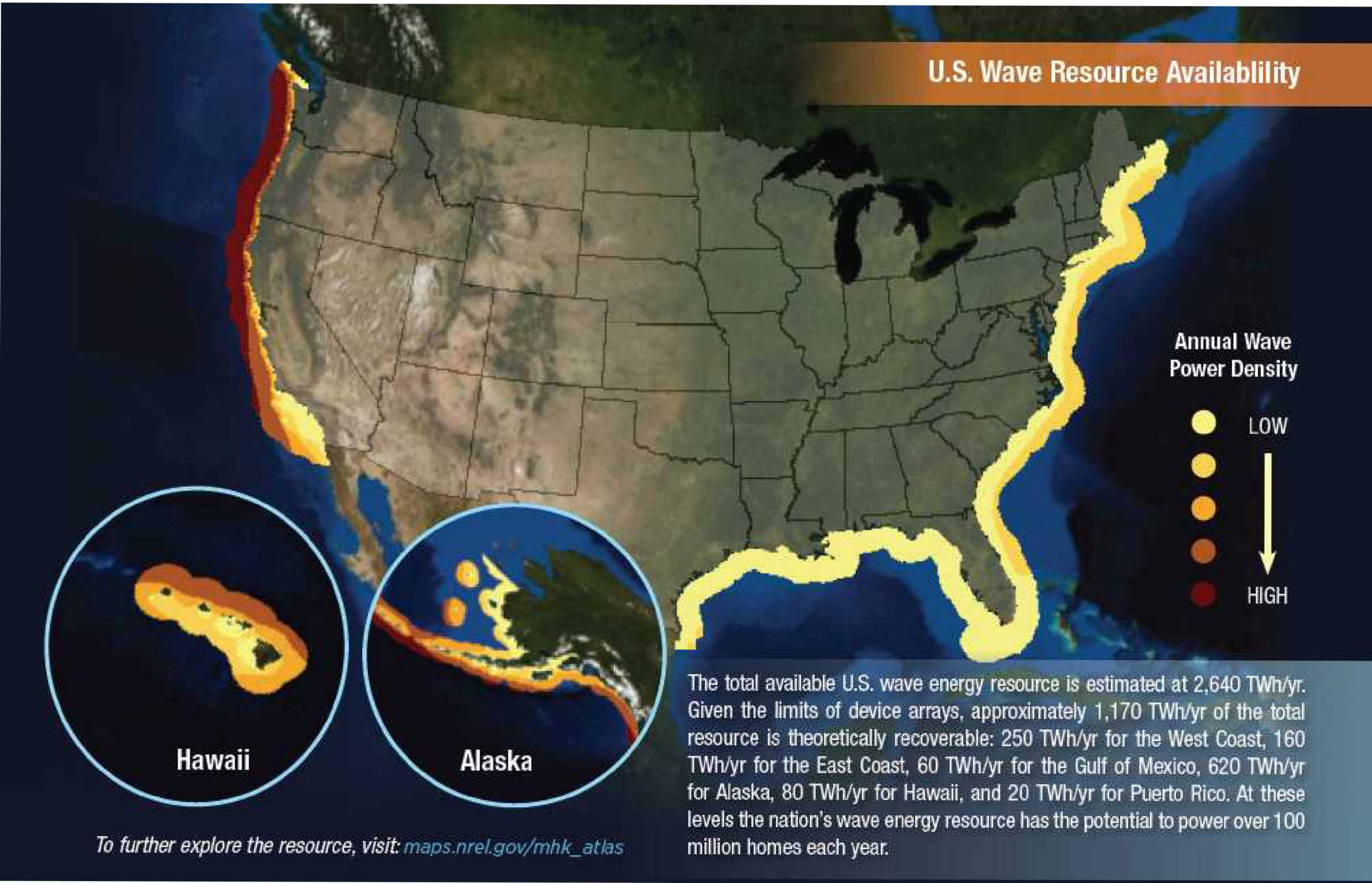


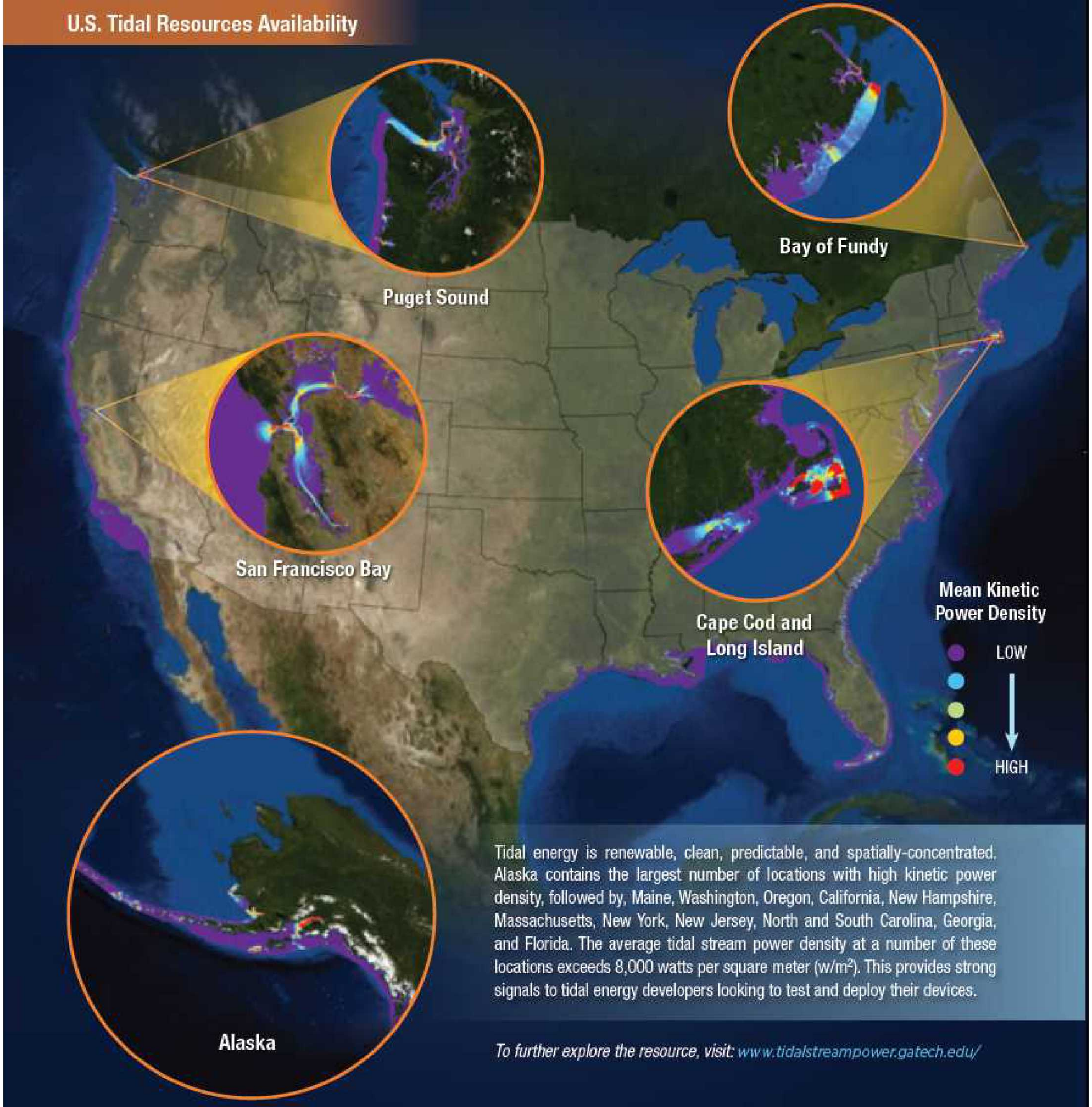
Francisco Presuel-Moreno: Corrosion

Bernadette A. Hernandez-Sanchez: (PI) Materials Chemistry

Budi Gunawan: Loads & FBG Sensors

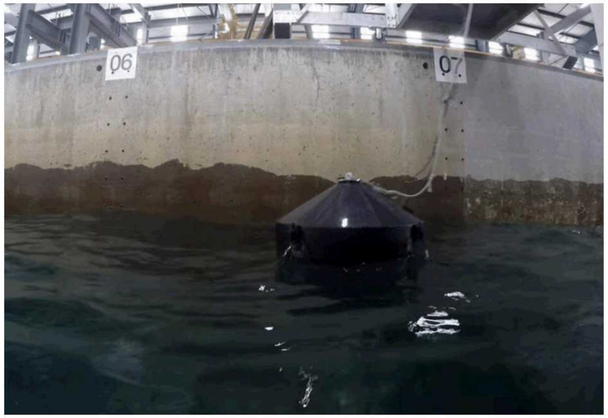
U.S. Wave Resource Available Along our Coasts total ~2,640 TWh/yr.





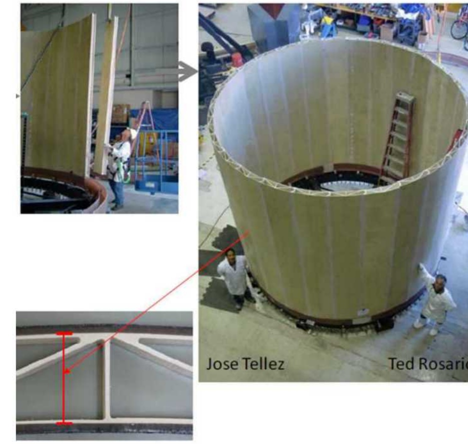
SAND2017-9281 C

Examples of Some MHK Designs Exploring Composite Materials (listed in alphabetical order)



AquaHarmonics

Columbia Power Technologies



Lockheed Martin-OTEC Cold Water Pipe

Ocean Renewable Power Company

Resolute Marine Energy

Verdant Power

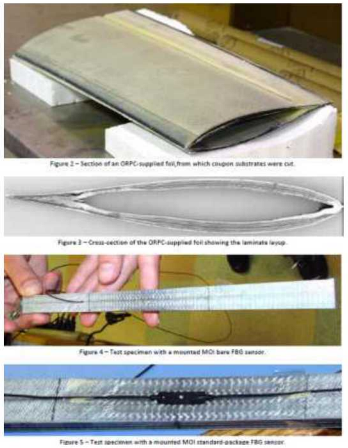
All Photos Obtained From Company Websites and Literature References

Previous MHK Advance Materials Research FY 12-16

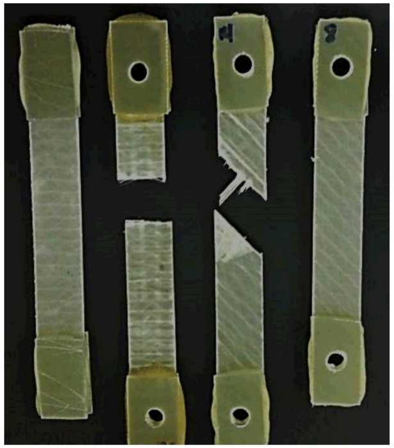
Pacific Northwest NATIONAL LABORATORY
MONTANA STATE UNIVERSITY
BYU

Biofouling & Marine coatings assessment

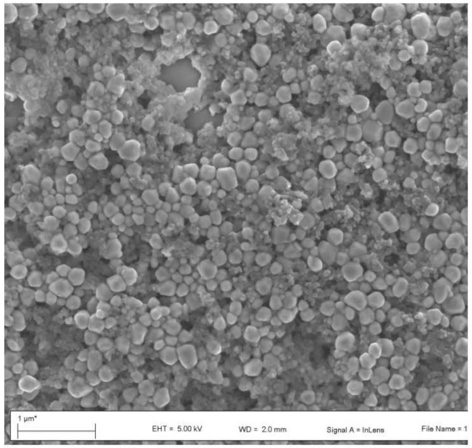
Structural Health Monitoring

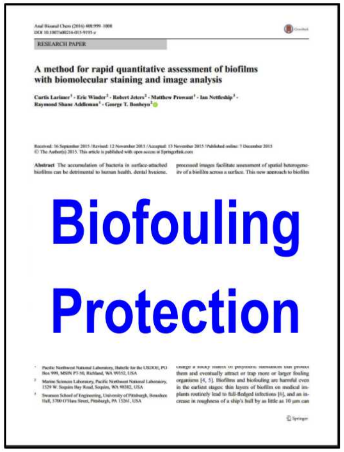


MHK Environmental Effects on Composites



Nanomaterials Development




Anal Bioanal Chem (2016) 408:999–1008
DOI 10.1007/s00216-015-9195-z
RESEARCH PAPER
A method for rapid quantitative assessment of biofilms with biomolecular staining and image analysis
Curtis Larimer[1] · Eric Winder[1] · Robert Jeters[1] · Matthew Prowant[1] · Ian Nettleship[3] · Raymond Shane Addleman[1] · George T. Bonheyo[2]
Received: 16 September 2015 / Revised: 12 November 2015 / Accepted: 13 November 2015 / Published online: 7 December 2015
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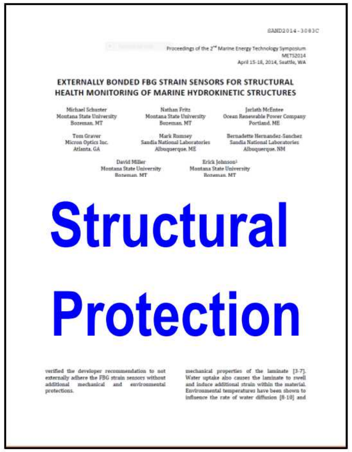
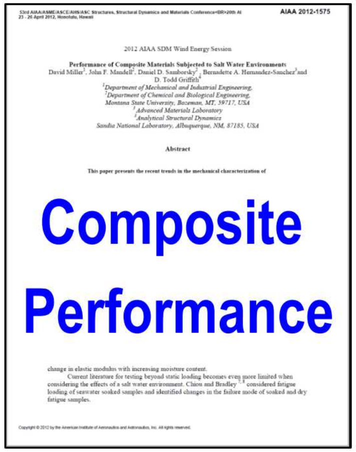
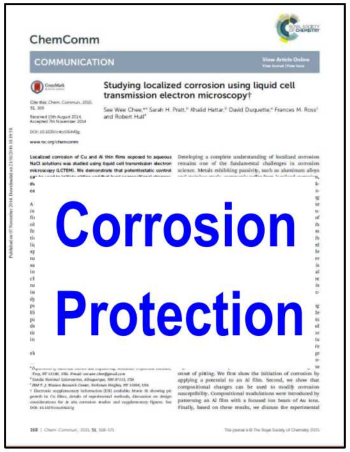
Biofouling Protection


SAND2014-3083C
Proceedings of the 2nd Marine Energy Technology Symposium
METS2014
April 15-18, 2014, Seattle, WA
EXTERNALLY BONDED FBG STRAIN SENSORS FOR STRUCTURAL HEALTH MONITORING OF MARINE HYDROKINETIC STRUCTURES
Michael Schuster, Montana State University, Bozeman, MT · Nathan Fritz, Montana State University, Bozeman, MT · Jarlath McEntee, Ocean Renewable Power Company, Portland, ME · Tom Graver, Micron Optics Inc., Atlanta, GA · Mark Rumsey, Sandia National Laboratories, Albuquerque, ME · Bernadette Hernandez-Sanchez, Sandia National Laboratories, Albuquerque, NM · David Miller, Montana State University, Bozeman, MT · Erick Johnson, Montana State University, Bozeman, MT

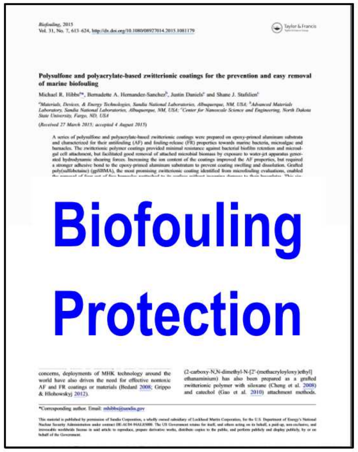
Structural Protection


53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference
20th AI
23 - 26 April 2012, Honolulu, Hawaii
AIAA 2012-1575
2012 AIAA SDM Wind Energy Session
Performance of Composite Materials Subjected to Salt Water Environments
David Miller[1], John F. Mandell[2], Daniel D. Samborsky[2], Bernadette A. Hernandez-Sanchez[3] and D. Todd Griffith[4]
[1]Department of Mechanical and Industrial Engineering, [2]Department of Chemical and Biological Engineering, Montana State University, Bozeman, MT, 59717, USA
[3]Advanced Materials Laboratory
[4]Analytical Structural Dynamics
Sandia National Laboratory, Albuquerque, NM, 87185, USA
Abstract
This paper presents the recent trends in the mechanical characterization of

Composite Performance


ChemComm
COMMUNICATION
Studying localized corrosion using liquid cell transmission electron microscopy†
See Wee Chee, Sarah H. Pratt, Khalid Hattar, David Duquette, Frances M. Ross and Robert Hull
Received 15th August 2014, Accepted 7th November 2014
www.rsc.org/chemcomm

Corrosion Protection


Biofouling, 2015
Vol. 31, No. 7, 613–624, http://dx.doi.org/10.1080/08927014.2015.1081179
Polysulfone and polyacrylate-based zwitterionic coatings for the prevention and easy removal of marine biofouling
Michael R. Hibbs, Bernadette A. Hernandez-Sanchez, Justin Daniels and Shane J. Stafslien
(Received 27 March 2015; accepted 4 August 2015)

Biofouling Protection

SAND2017-9281 C

Current US MHK Composites Program

Coupons provided by:

Composites Engineering Research Lab

Composites Technology Development

Hygrateck

Janicki,

Industries

Polyone

Ocean Renewable Power

Company

Verdant

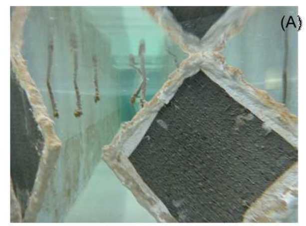
FY17

Salt Water Effects on Composite Performance Testing

Biofouling & Environmental Effects on Composites

FY18

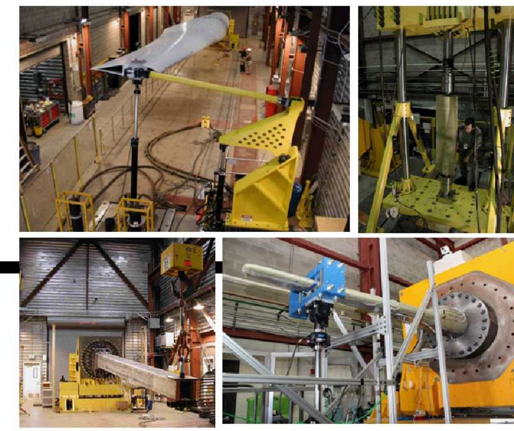
Metal – Carbon Fiber Composite Interconnects in Seawater

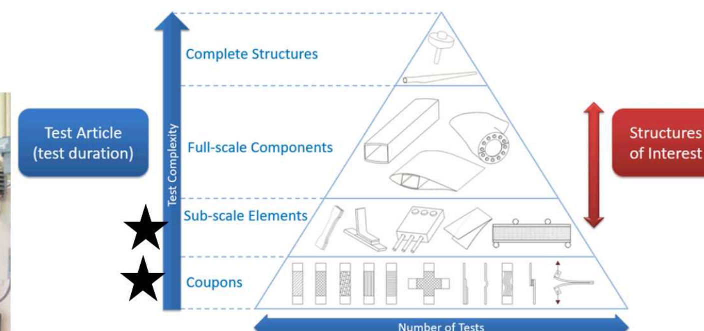


Industry directed sub scale elements & joined coupon fabrication/testing (Artificial & Actual Seawater)

FY19-20

Industry directed full scale subcomponent testing (Artificial & Actual Seawater)





Biofouling Program

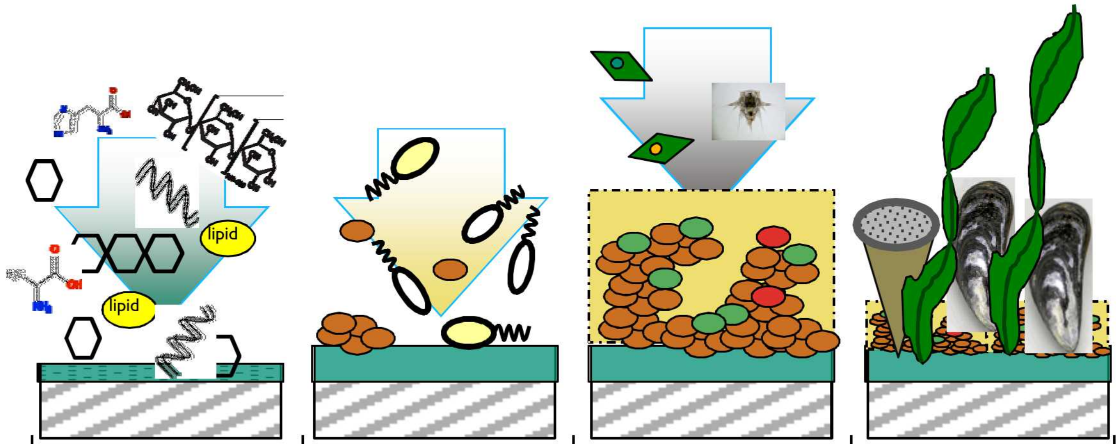
- Why does fouling matter
- Location
- Prior effort
- Test Methods
- Current Effort
- Early Results

Poorly Protected Device

Tidal turbine, Race Rocks, BC, Canada
http://www.racerocks.ca/2011/09/17/

Coating Failure

Fouling Process



	Formation of the conditioning film	Cellular contact and adhesion	Development of a complex biofilm	Outgrowth of macroorganisms
Timing	Seconds to minutes	Hours to Days	2 to 14+ days	Weeks
Scale	<1 µm thick	<200 um	10 µm to 10 mm	1 cm to >10 cm
Effects	Alters physical properties of the surface	Potentially reversible	50 µm surface roughness = 22% more drag	Calcification, expensive cleaning

Processes of Biofilm formation

Processes of Biofouling

Concerns with Fouling and Coatings

- Increased drag (effects on performance, strain on moorings)
- Accelerated corrosion (MIC, galvanic, pitting, crack and crevice)
- Physical interference with function
- Increased weight and inertia
- Safety (for operations and maintenance workers)
- Increased operations and maintenance costs
- Sensor failures
- Structures provide potential establishment of invasive species
- Artificial reef effect attracts macrofauna
- Toxins leaching from coatings

Disruption of cable interconnects (EMEC)

ADCP after 6 months (CMOP)
http://www.stccmop.org/news/multimedia/field-campaign2010

Severe pitting on clad aluminum (damaged region had been partially to mostly anaerobic).
Photo credit George Bonheyo

Prior 3-Year Effort: Antifouling Coatings

Challenges addressed

- Commercial coatings were developed for boats moving >10 kn (5.1 m/s)
- MRE devices typically experience velocities <10 kn or even <5 kn (2.6 m/s)
- Most employ potent toxins (primarily copper)
  - Emerging potential for copper restrictions in some locations

15 experimental coatings developed under this project

- Ceragenins (small-molecule mimics of antimicrobial peptides)
- Nanoparticulate silver
- Modified foul-release
- Soft, polyethylene glycol (PEG) based polymers

Testing at PNNL

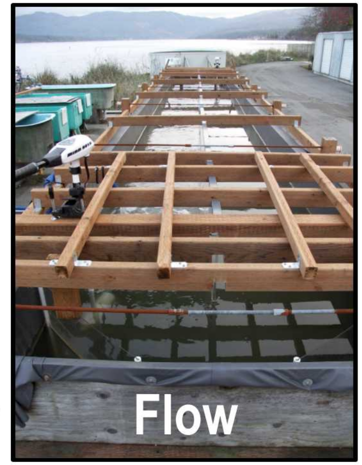
Biofouling & Environmental Exposure for MHK Coatings

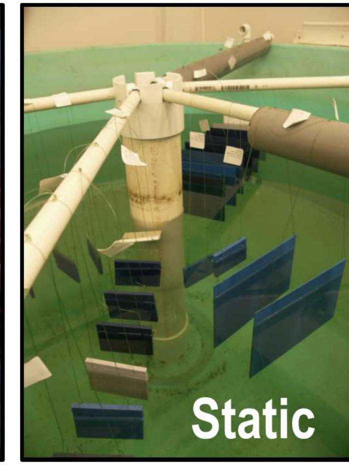
PNNL Marine Sciences Laboratory in Sequim , WA

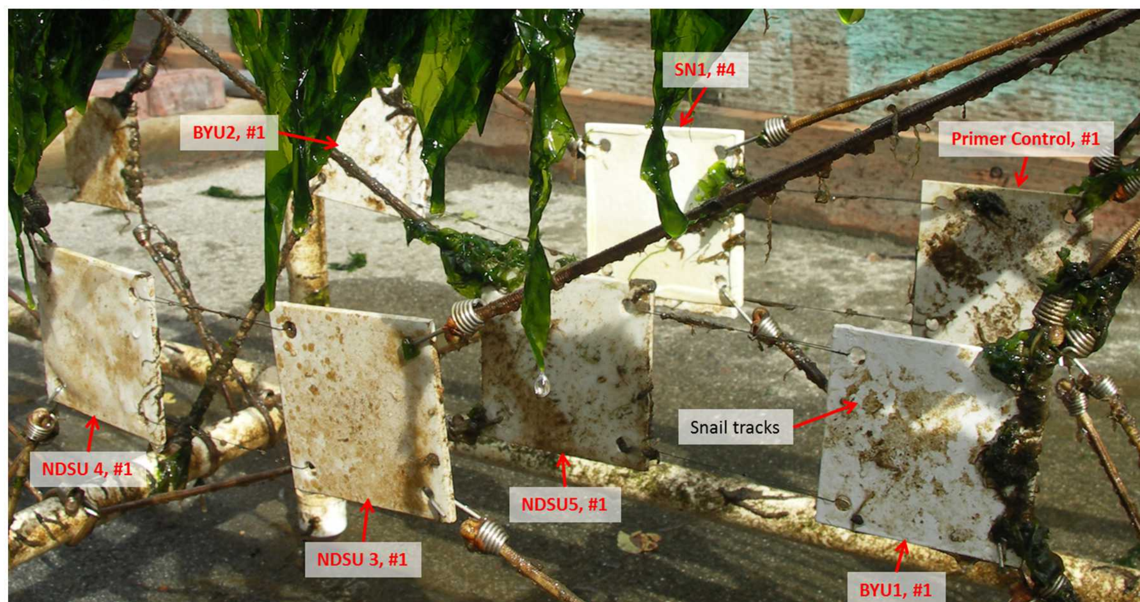
Determine Environmental Exposure Effects on Commercial & Sandia MHK Specific Coatings.

Evaluate under static & flow conditions with unfiltered natural seawater.

- MHK not operating under shipping conditions!







Materials & Conditions

- Glass fiber Reinforced Plastic (**GRP**)
- Polystyrene (**PS**)
- Polyethylene (**PE**)
- G10 Garolite Fiberglass (**G10, aka FR4**)
- Poly(phthalazinone ether amide) (**PPEA**)
- Poly(2,6-dimethyl-l,4-phenylene ether) (**PPE**)
- Nylon 11 (polyamide) (**PA11**)
- Polyamide 6 (**PA6**)
- Polyethylene Terephthalate (**PETG**)
- *Poly*(ethylene terephthalate) (**PET**)
- Carbon-carbon composite (**HDP**)
- **Aluminum**
- **Sanded Aluminum**
- **Stainless Steel**
- **Carbon Steel**

- Commercial coatings and paints
  - Except when integrated with a company's composite material
- Commercially available and emerging composites materials
- Samples provided by composites manufactures, MHK systems, coatings manufacturers (~500 individual coupons)
- Tests under MHK-relevant velocities (0.1 m/s and 2.6 m/s)
- Exposures from 6 months to 22 months
- Analyses: TOC/N, image analysis, wet/dry weight

Preliminary Findings (6 months exposure)

Exposure

- Minimal fouling in the tanks during fall and winter
- Massive die-off of barnacles and other invertebrates observed (even in non test tanks)

Durability

- Priming and adhesion of coatings failing on some surfaces
  - Improper preparation? (e.g., sanding to roughen)
- Failures on tapered and narrow edges (cracking, delamination)

Fouling

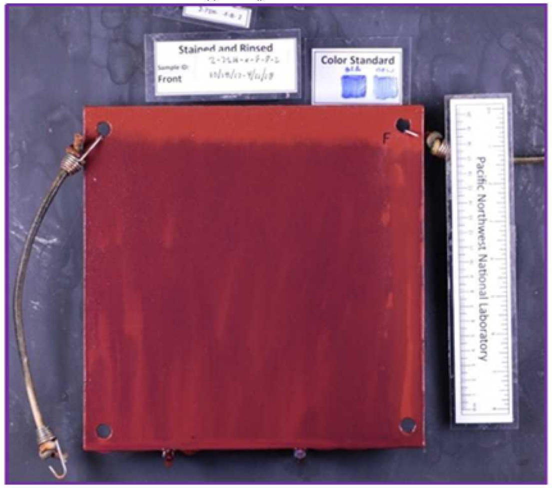
- ‘Slime’ on all coupons
- Many composites leached significant amount of carbon and the TOC data was not usable, but TON data appears to be good

Edge failure, 6 months

Bad (L) and good (R) performance on carbon fiber, 6 months

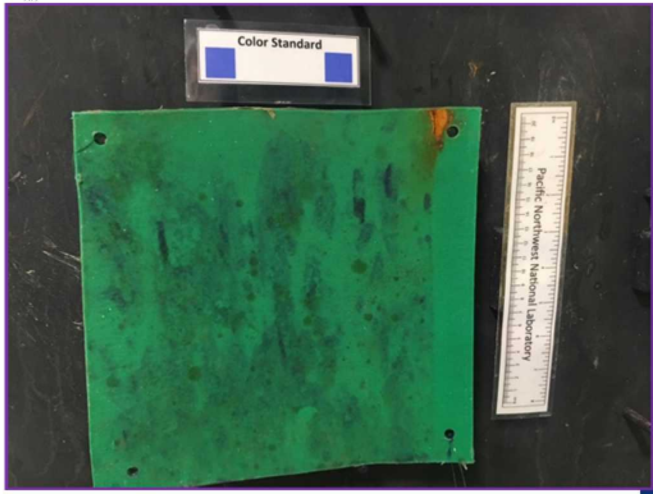
Example Photos

Promising new copper-based coating
Good performance, but the coating softened during exposure



FRP Samples – 8 months
Minimal algal growth so far, but it may be penetrating the surface

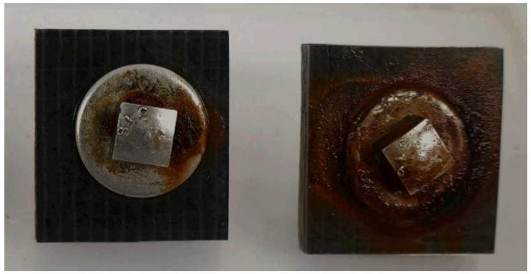
Soft composite– 6 months
Some material distortion and surface algal growth



- 12 months remaining with existing sample set
- Additional samples to be deployed in August/Sept

Metal-Carbon Fiber Composite Interconnects Need to be monitored for corrosion.

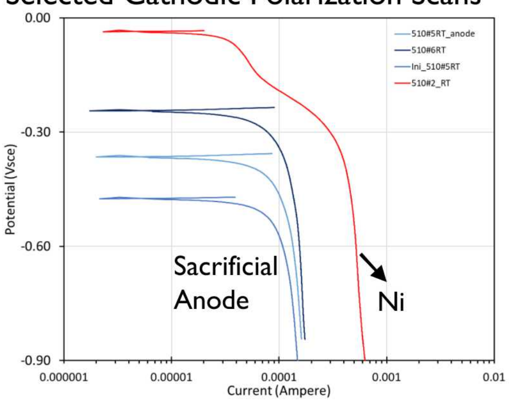
Corrosion can occur on metals connected to carbon fiber composite materials (i.e., CF composite to metal interconnects).



Study on effects of metal-carbon interconnects

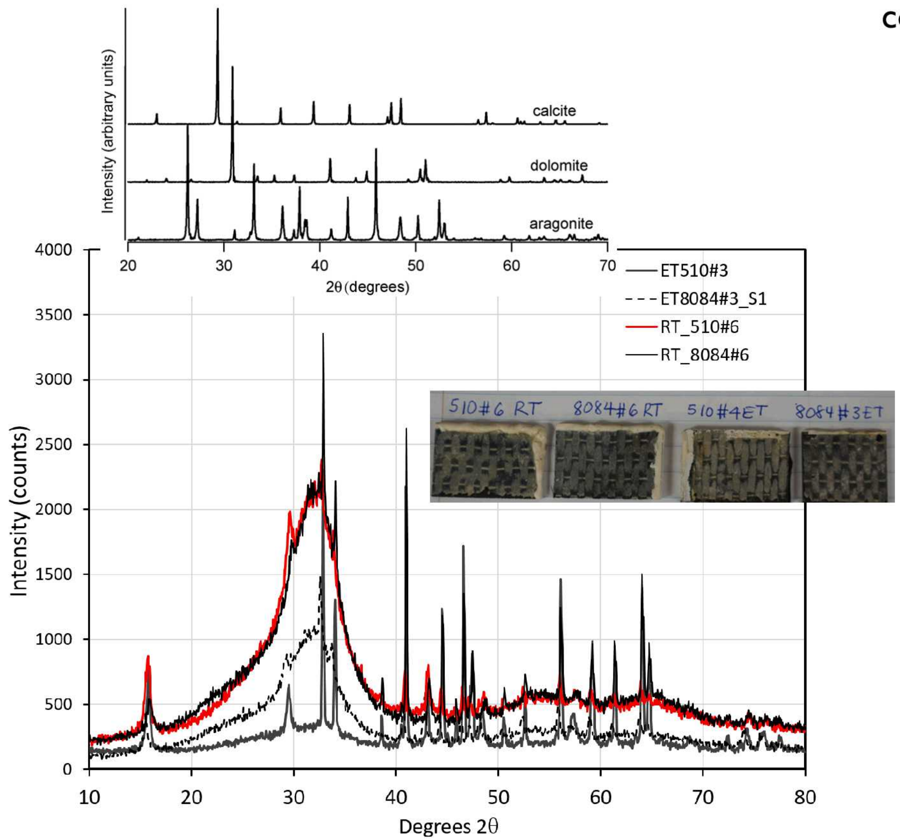
CF/VE interconnected to metal immersed in RT and ET seawater

Selected Cathodic Polarization Scans



Evidence of cathodic kinetics reduced due to calcareous deposits formed on samples connected to anodes. Smaller i_L

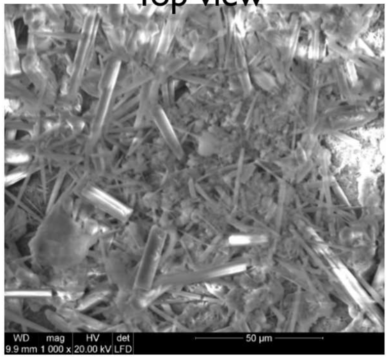
XRD on sections after exposure for 6 months



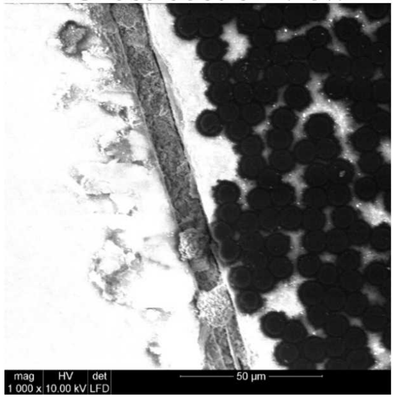
XRD of CF/VE composites connected to sacrificial anodes Crystalline structure identified. Thicker calcareous deposits present on ET-CF/VE510#3, no VE peak visible. Peaks offset

SEM Images of ET CF/VE8084 connected to sacrificial anode

Top view



Cross section view



Ti and Ni alloys did not show corrosion, nor the composites interconnected suffered degradation

Metal-Carbon Interconnects in Seawater

Materials Systems

- CF/VE 8084
- CF/VE 510A

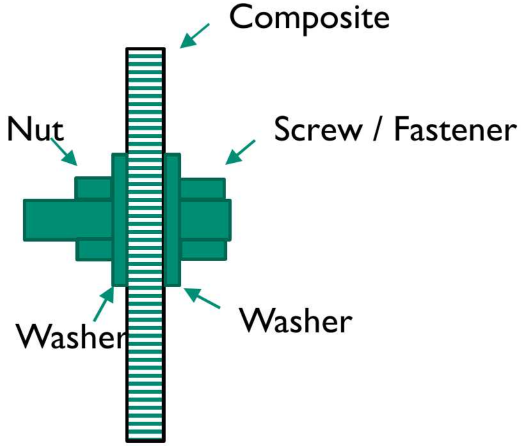
Environmental conditions

- Sea Water /RT
- Sea Water 100°F

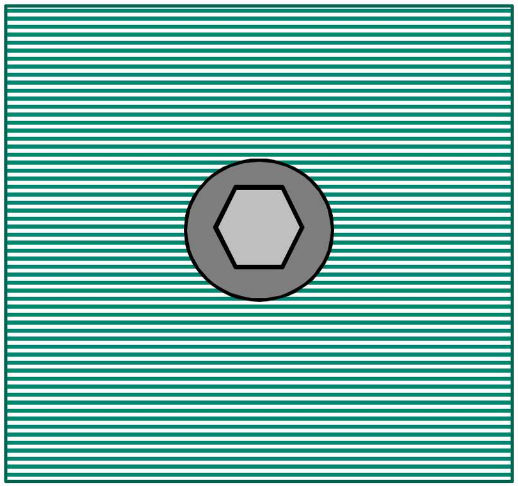
Alloys used for Composite Metal Interconnect

- Connected to Sacrificial Anode
- Connected to Ti alloy mesh
- Coupled to Ni foil

Bolted specimens, samples immersed in Sea Water at RT and 100°F



Crevice assembly using composite as the plate



Top view

Alloys used for bolted specimens

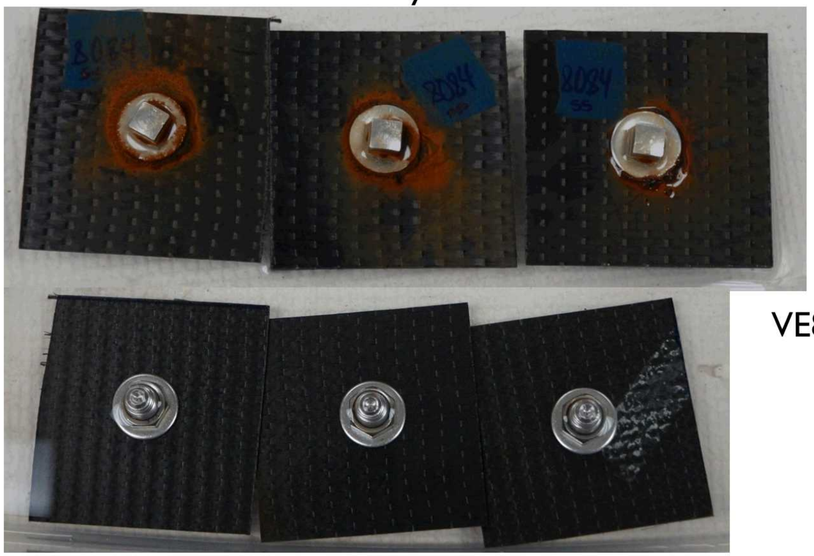
Stainless Steel (18% Cr)
Monel (NiCu alloy)
Ti alloy

Visual inspection at 55, 98, 197 and 273 days. In here selected samples inspected at 55, 197 and 273 days

Stainless Steel/CF composite Bolted sample room temperature

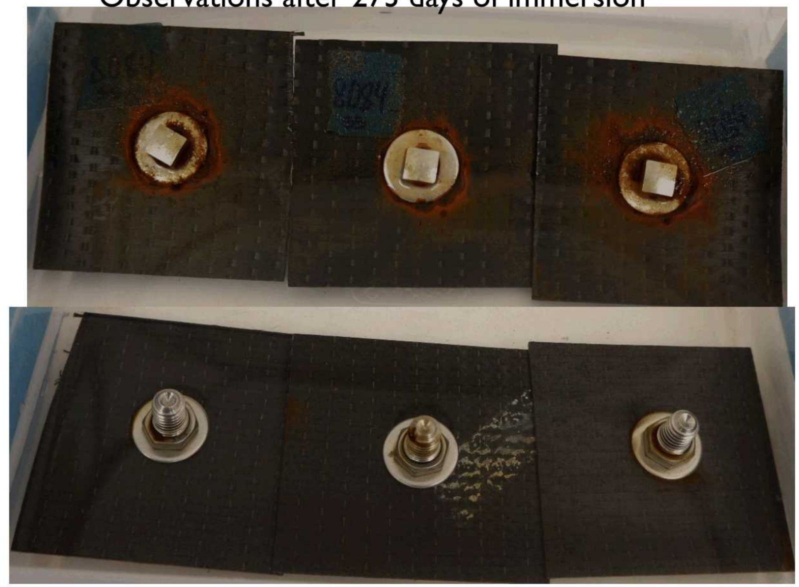
Stainless Steel/CF composite Bolted samples

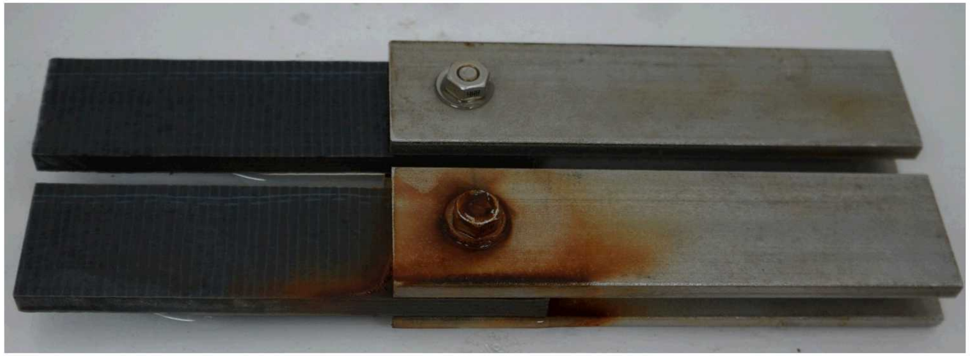
Room Temperature
Observations after 55 days of immersion



VE8084

Observations after 273 days of immersion



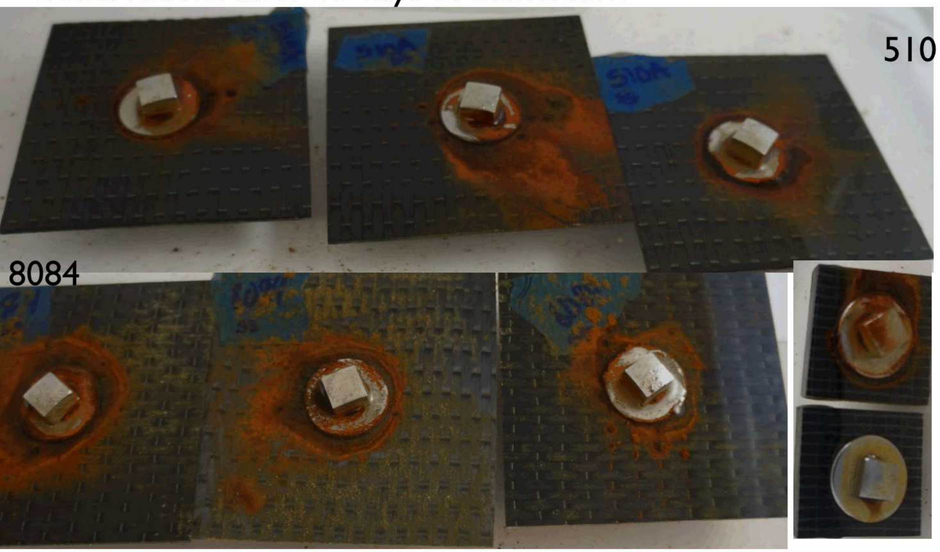


Observations after 197 days of immersion, prior to sending back to SNL.

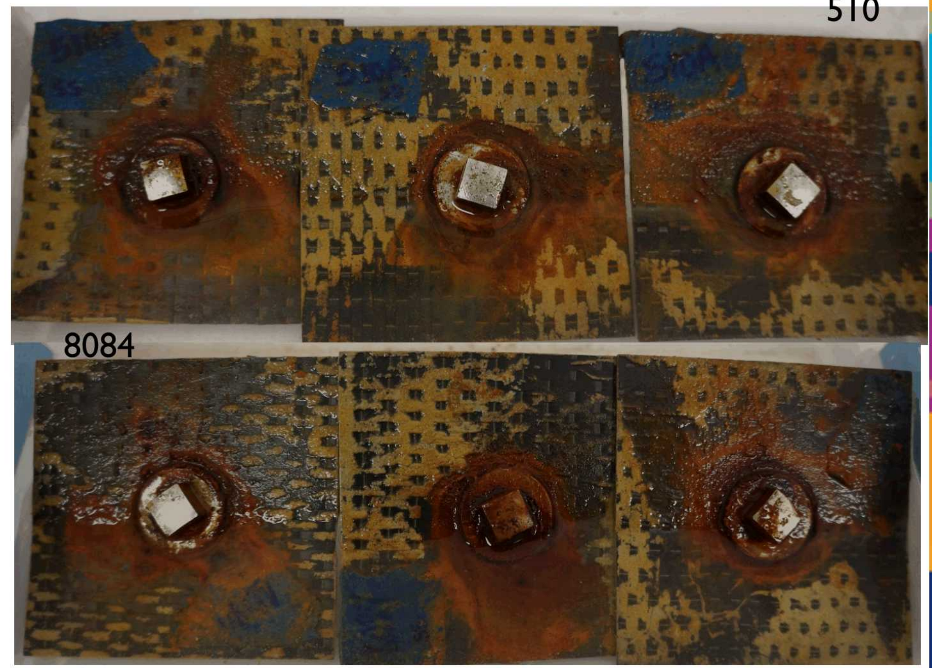
Stainless Steel/CF composite Bolted sample at elevated temperatures

Stainless Steel, Elevated Temperature

Observations after 55 days of immersion

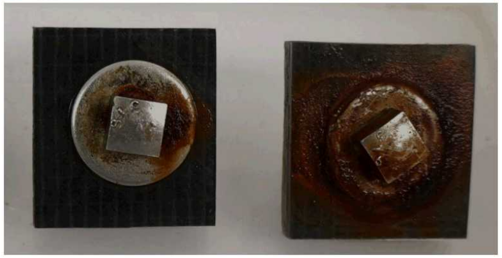


Observation after 273 days of immersion



Observations after 197 days of immersion, prior to sending back to SNL.

One of the 8084 samples was terminated and inspected

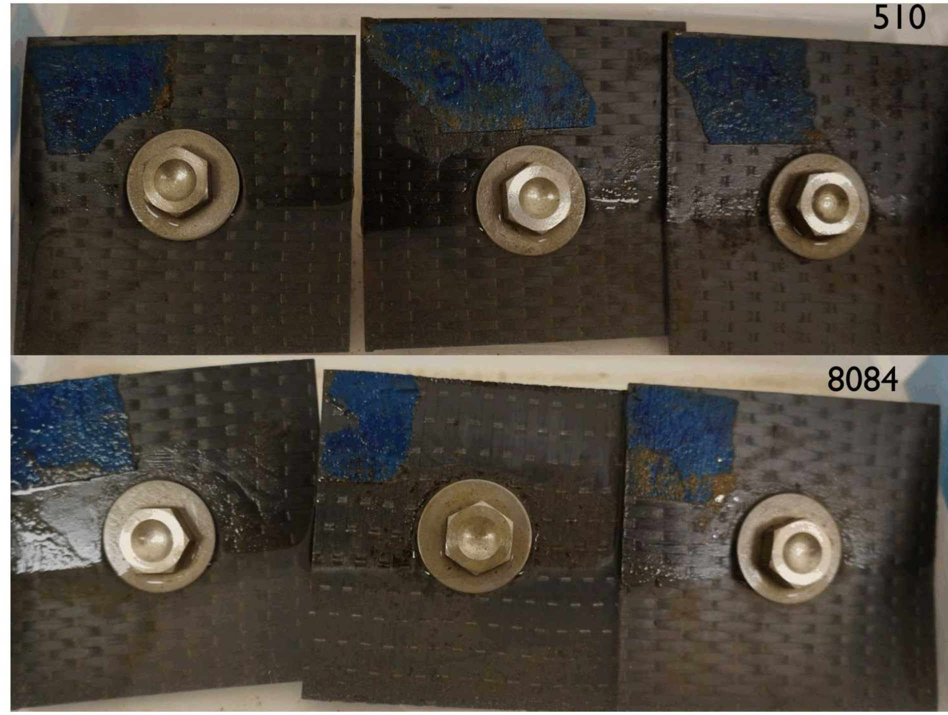


Monel and Titanium interconnects at elevated temperature

Elevated Temperature

Monel, immersed for 273 days

Ti, immersed for 273 days

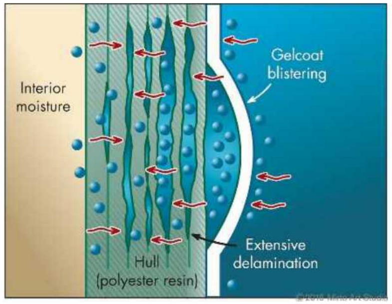


MHK Material Needs

Engineering designs of MHK devices have difficult, although not unique, materials challenges

They must be durable

They must be strong, stiff and yet lightweight



They must resist environment degradation

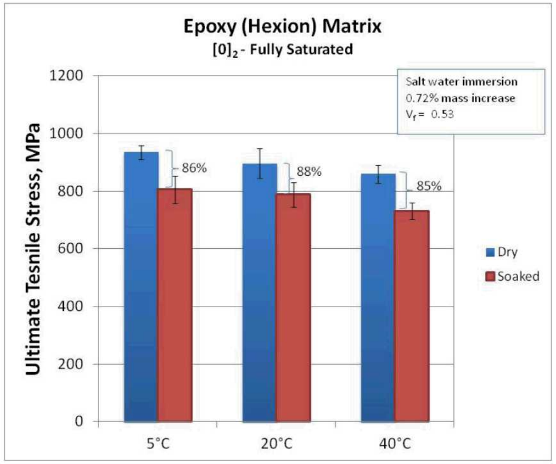
They must be inexpensive and easy to integrate into manufacturing

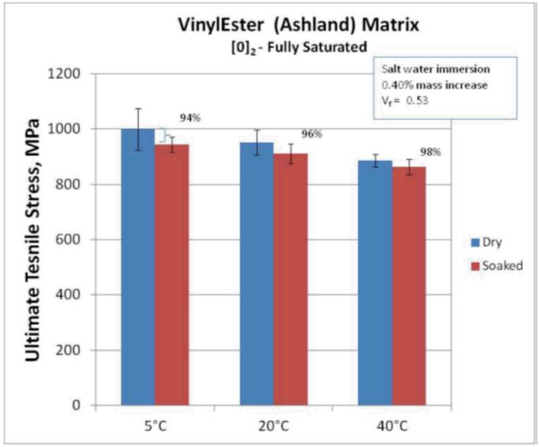
MSU Results from this project (in historical order and included in database)

- Effects of soaking and temperature
- Saturation under an applied stress
- Tension-Tension Fatigue
- Stacking sequence and partial saturation
- Altered damage mechanisms after saturation
- Industry-supplied coupon investigation

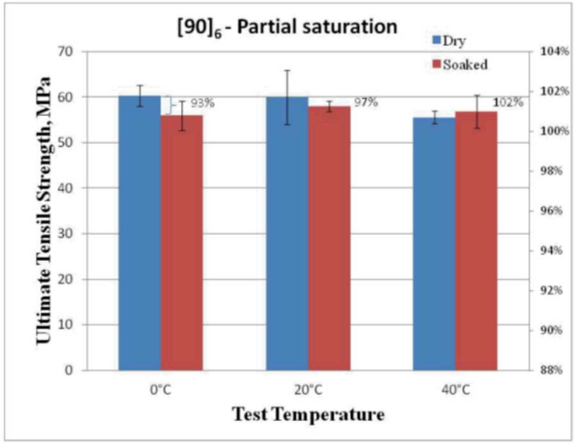
Effects of soaking and temperature

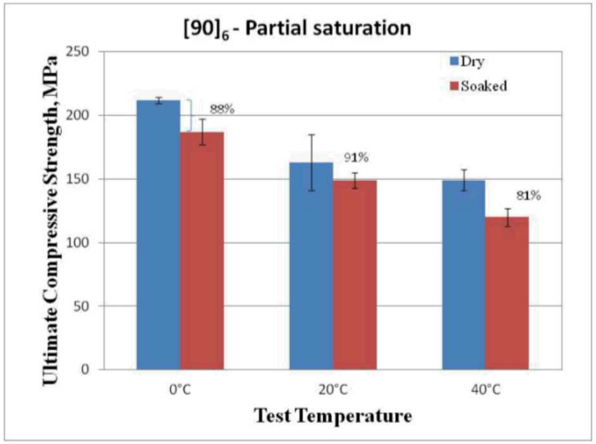
2012 AIAA SDM Wind Energy Session





Fully Saturated a) epoxy Tensile sample with 0.72 % Wt. Gain, V_f= 0.53 b) vinyl-ester Tensile sample with 0.40 % Wt. Gain, V_f= 0.53, Cured at 80 °C and soaked at 50°C.





Partially saturated epoxy sample with 0.47 % Wt. Gain, V_f= 0.56, Cured at 70 °C and soaked at 40°C tested in a) tension and b) compression.

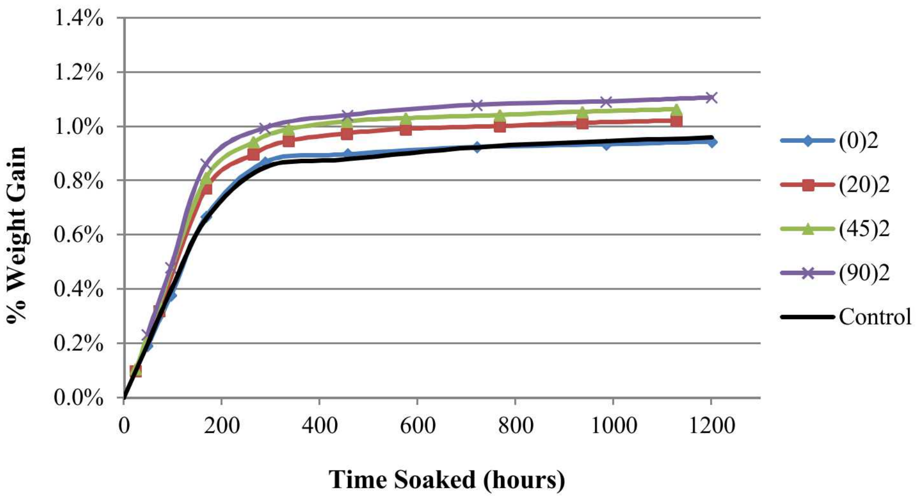
Saturation under an applied stress

- Changes in Diffusion Parameters
- Maximum Moisture Content

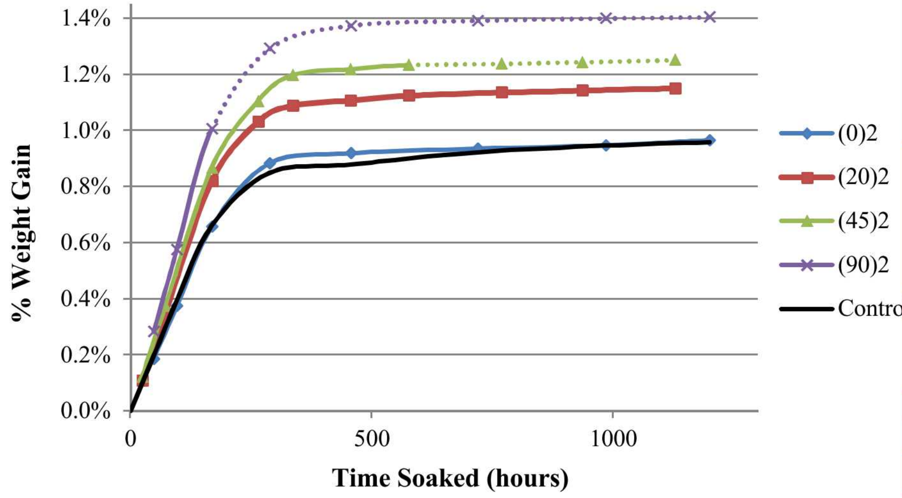
$$\ln\frac{D_\sigma}{D_0} = \frac{a}{\phi_m}\frac{(\Delta V/V_0)_m}{v_{f0}\left[v_{f0} + (\Delta V/V_0)_m\right]}$$

$$M_{\infty\sigma} = M_{\infty 0} + (\Delta V/V_0)_m\frac{\rho_w}{\rho_m}$$

18 MPa

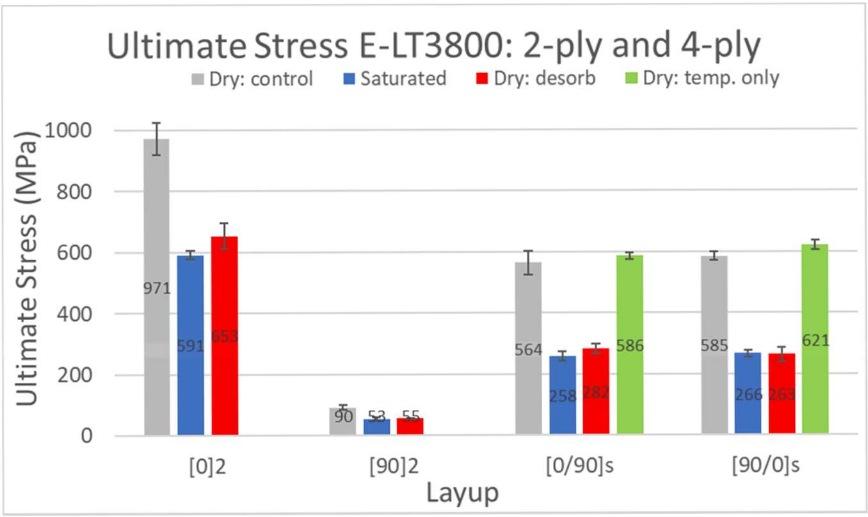


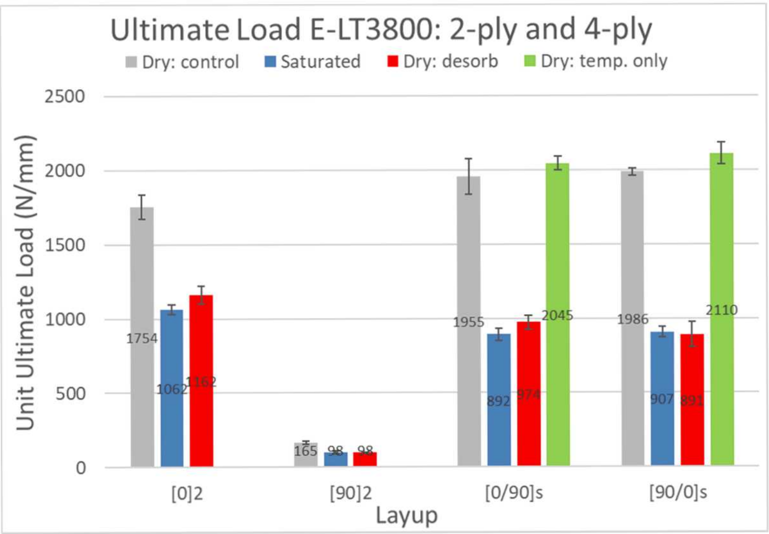
30 MPa

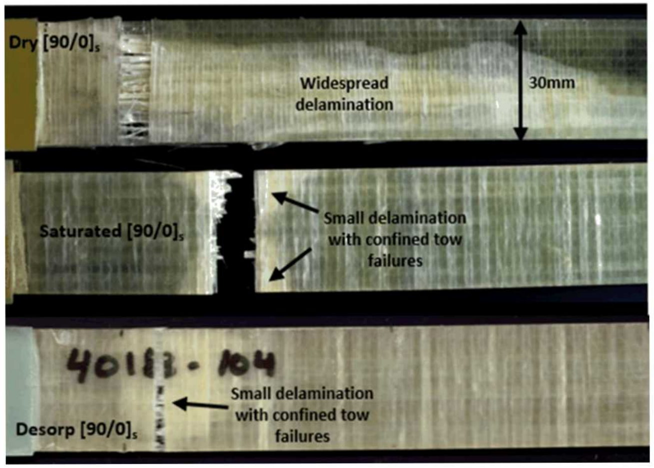


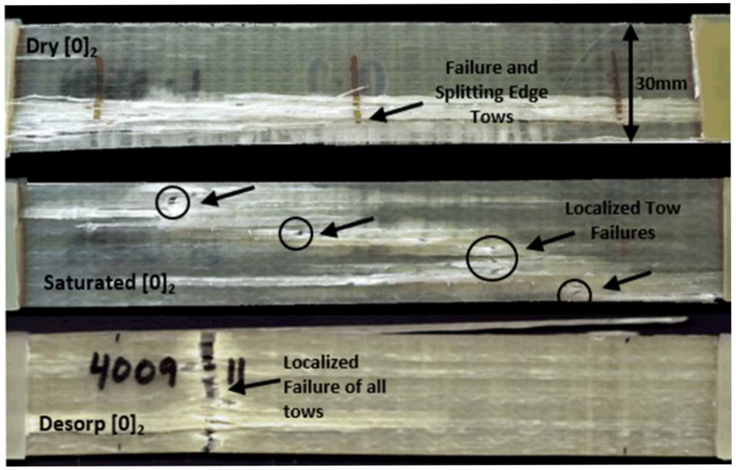
Stoffels, MSU MS Thesis, and 2013 AIAA SciTech

Altered damage mechanisms after saturation









Industry-supplied coupon investigation

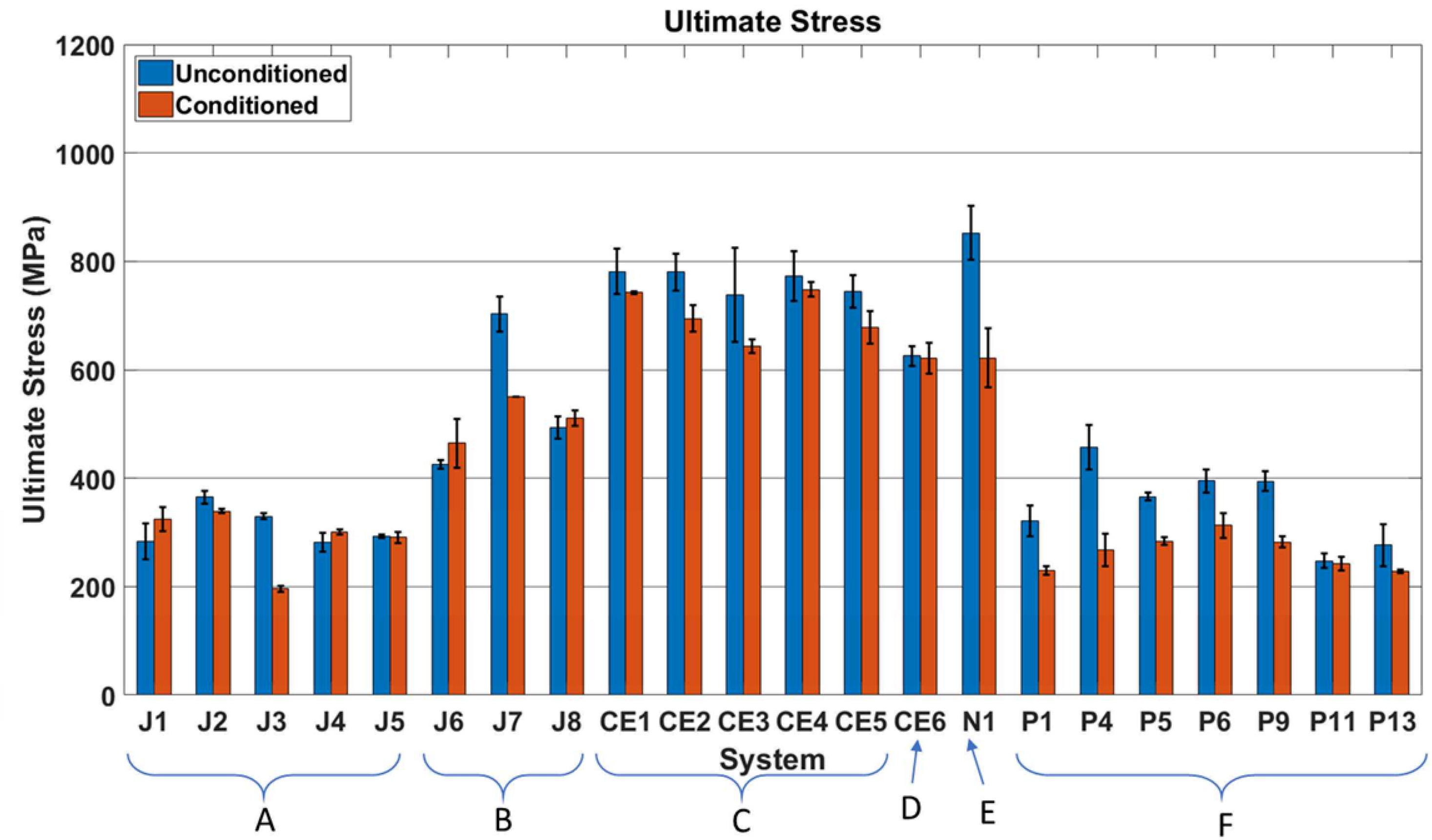
- Current program results
- Tensile static and fatigue, R = 0.1, testing on 33 different laminates, from five suppliers
- Testing was performed on unconditioned and simulated seawater conditioned coupons of each laminate
- The static and fatigue tests on the 33 different laminate configurations required over 175 machine days (4148 hours) of continuous testing time after 90+ days of moisture conditioning.
- Thermoset and thermoplastic coupon sets
- Acoustic emission data collected to investigate damage propagation in both dry and saturated coupons

Example of Database Results for CE Thermoset

- Hybrid thermoset made from both carbon and class
- Illustrates how moisture diffusion affects longitudinal and transverse mechanical behavior

MSU Material	Layup	Average V_F for static tests %	% Moisture	Longitudinal Direction			Transverse Direction		
				E, GPa	UTS, MPa	% strain	E, GPa	UTS, MPa	% strain
CE1	$[V/(+/-45)_g/0_c]_s$	40.9	0	56.1	786	1.38	10.7	98.3	3.17
			1.2	58.3	787	1.33	8.54	68.3	1.84
CE2		35.8	0	54.8	773	1.40	9.02	83.3	3.26
			1.33	55.3	725	1.30	7.79	58.9	1.84
CE3		40.7	0	54.1	792	1.43	9.96	95.3	3.67
			1.1	52.1	691	1.31	8.62	68	1.92
CE4		36.1	0	53.7	774	1.36	8.91	83.9	3.69
			1.2	53.1	712	1.30	8.18	60.5	1.82
CE5		36.4	0	56.5	733	1.29	9.69	77.8	3.54
			0.34	57.9	695	1.15	8.05	63.6	2.05
CE6	[V/0/45/-45/0/V]	42.3	0	29.2	695	2.69	12.0	109	2.52
			0.36	28.7	590	2.36	16.6	126	2.36

Summary Data from Industry Coupons



Group	Fiber	Matrix	Layup Type
A	Glass	Thermoset	Quasi-Isotropic
B	Carbon	Thermoset	Quasi-isotropic
C	Hybrid	Thermoset	[45/-45/0]s

Group	Fiber	Matrix Type	Layup Type
D	Glass	Vinyl ester	[0/45/-45/0]
E	Glass	Elium	[0b]s
F	Glass	Thermoplastic	[0/90]n

Degradation of strength and increase in failure strain seen across all 33 systems

Ultimate tensile strentth for uniaxial samples shown above

MHK Load measurement needs

MHK Materials Workshop, Albuquerque, NM, 2015:
Industry needs reliable sensors and instrumentation for measuring mechanical/structural loads during open water deployment/operation (short-term goal)

IEC

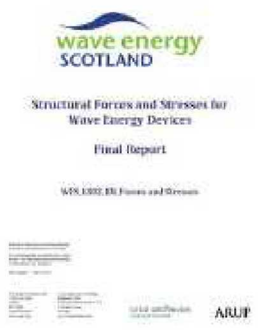
"In the current IEC TC 114 Strategic Business Plan, Load measurement and verification is identified as the highest priority standard for development based on input and agreement from the National Committees" (2017)

Other input from industry:

1. …immediate need of the MHK industry for inexpensive and reliable means of accurately measuring structural loads in real time during ocean trials of WEC and TEC devices (Resolute)
2. Load data during field operation to validate structural and hydrodynamic models, provide confidence in system reliability (ORPC)
3. Guidance for sensor selection, placement, and post processing procedure (CalWave)
4. Understanding of device load characteristics early in the development path for better and more economical design (AquaHarmonics)

Environmental effects and materials must be considered in structural loading.

IEC TS 62600 -2 ED2 (2018) Marine energy - Wave, tidal and other water current converters - Part 2: Design requirements for marine energy systems

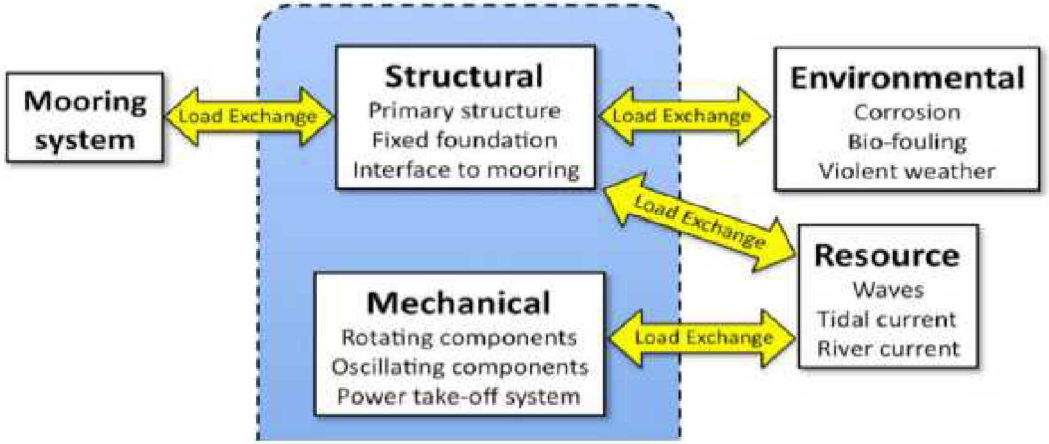

wave energy SCOTLAND

Structural Forces and Stresses for Wave Energy Devices

Final Report

ARUP

Structural forces and stresses for wave energy devices. Wave Energy Scotland Report (2016)



Load exchanges covered under IEC TS 62600 -2 ED2 (2018)

Design load

$$F_d = \gamma_f F_k$$

where:

F_d is the design value for loads acting on the MEC for the given design load case

γ_f is the partial safety factor for loads

F_k is the characteristic value for the load

Design materials

$$f_d = \frac{f_k}{\gamma_m}$$

where:

f_d is the design values for materials

γ_m is the partial safety factors for materials

f_k is the characteristic values of material properties

Ensure material's strength exceed design loads

Process for determining design loads via load cases

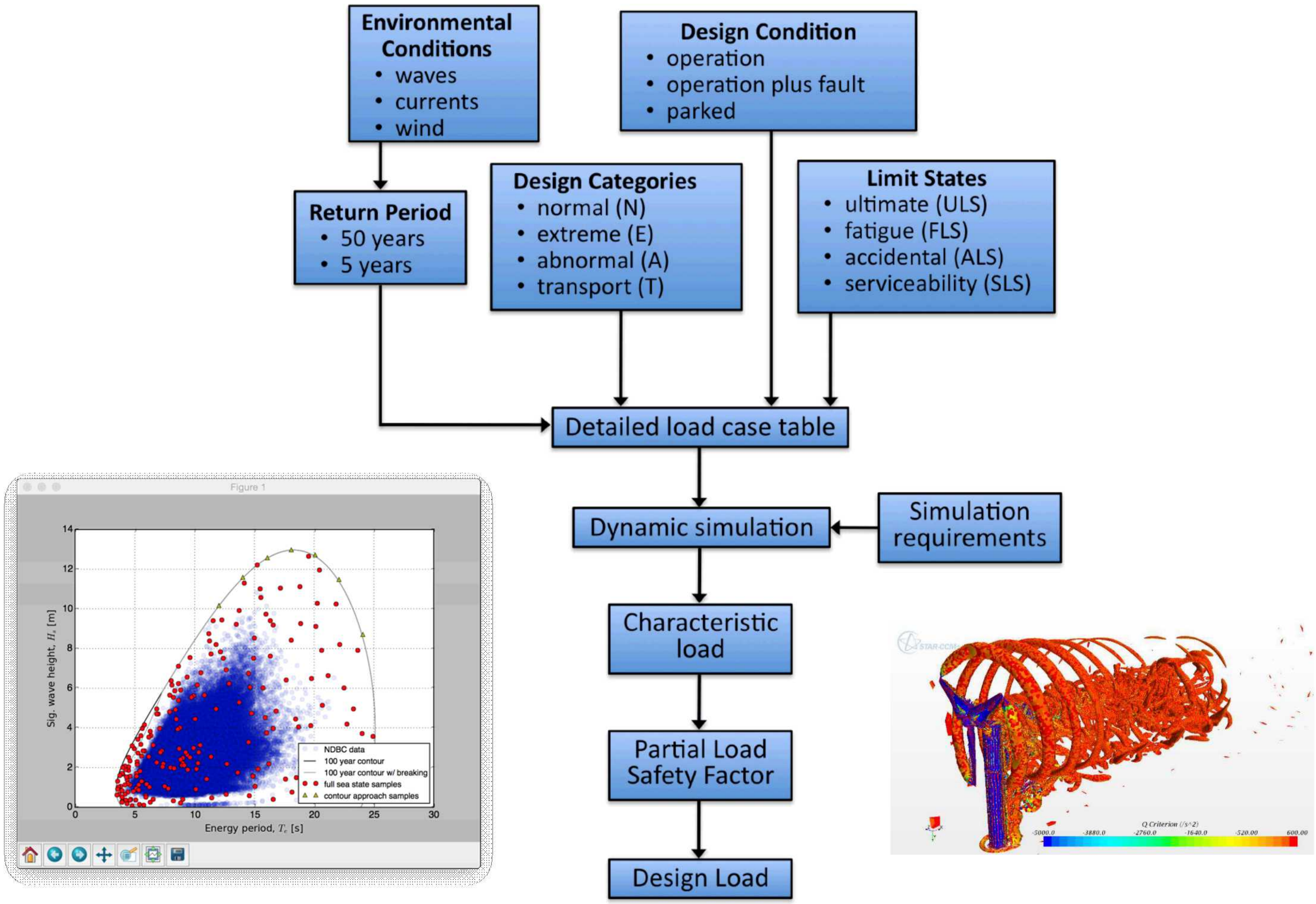


Figure 7-1. Process for determining design loads via load cases

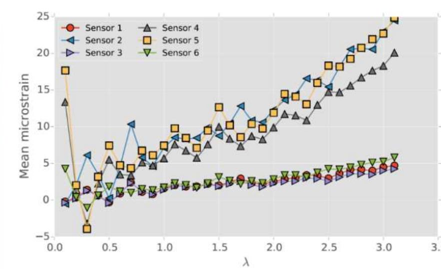
IEC TS 62600-2 Design Requirements for Marine Energy Systems (https://webstore.iec.ch/publication/25634)

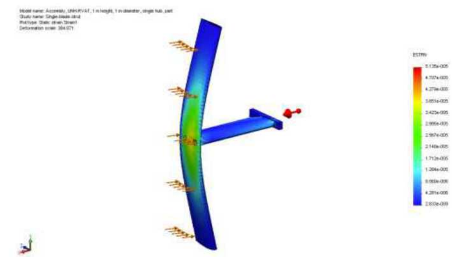
Composite & Sensor Testing

Objectives:

- Test the feasibility of using fiber optic (FBG) strain sensors for MHK load measurement (Laboratory and open water)
- Test dry and saturated composite samples

Fiber optic strain sensor on wind blades

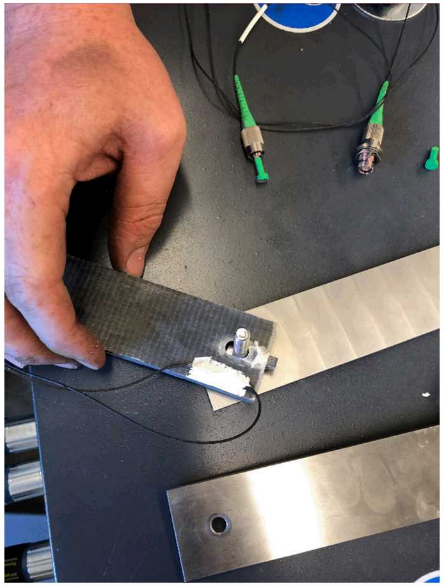


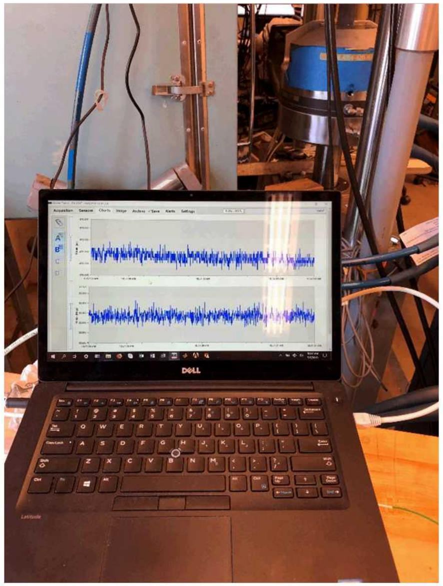


DOE RM2 testing – foil strain measurement using FBG (2014)

Composite & Sensor Testing

Objectives:
- Test the feasibility of using fiber optic (FBG) strain sensors for MHK load measurement
- Test dry and saturated composite samples

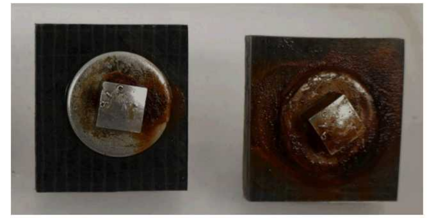


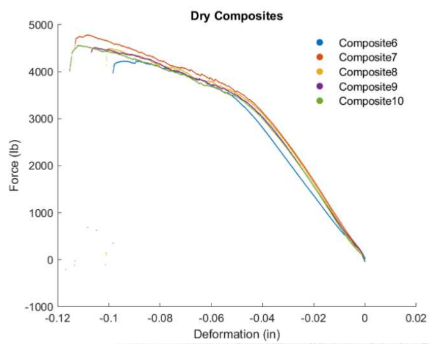


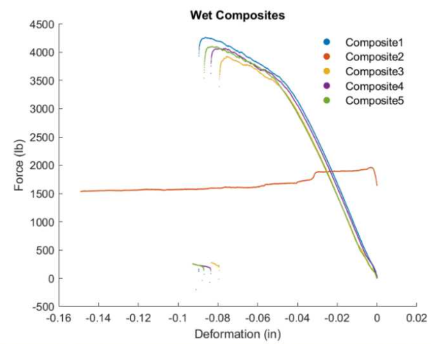
Test procedure: ASTM D5961: Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates

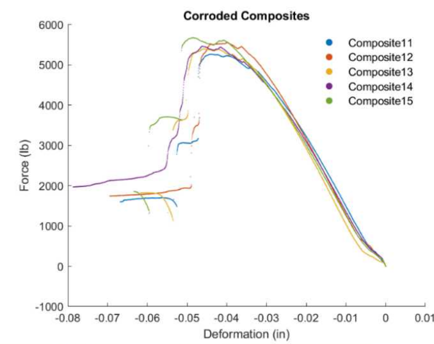
Results

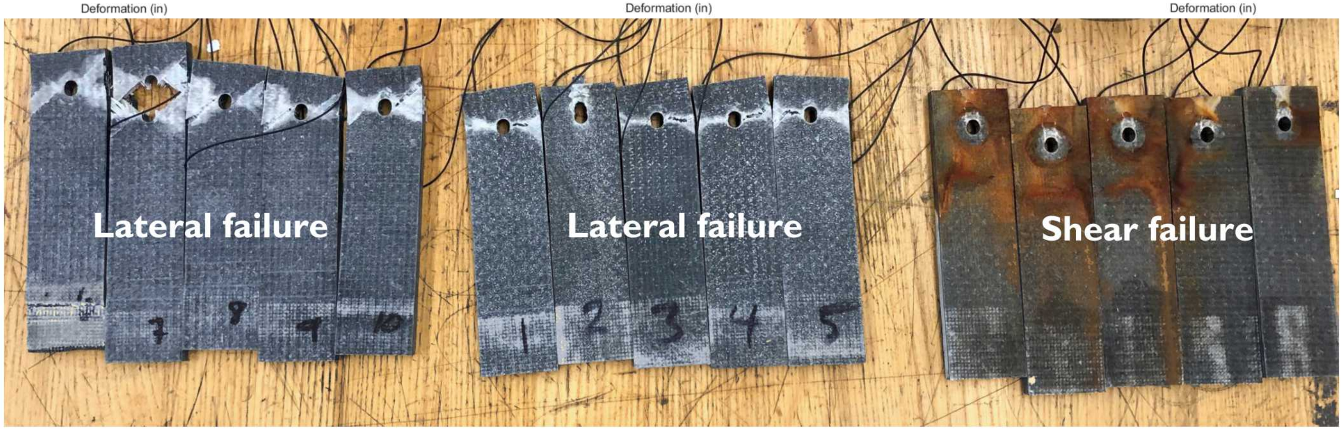
Corrosion Studies on Connections







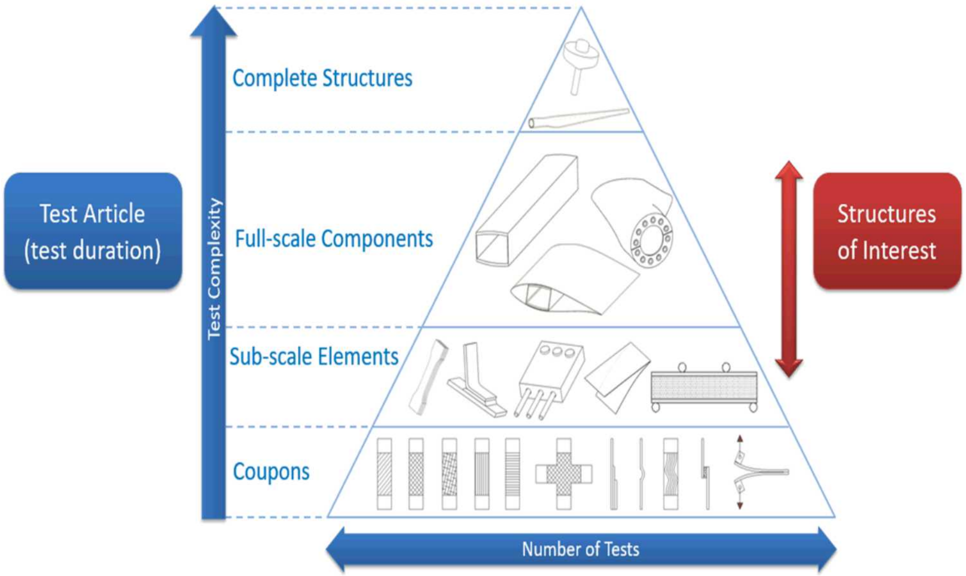




- Consistent FBG readings, even when sensors are saturated
- Different failure modes & yield strengths for dry and saturated samples

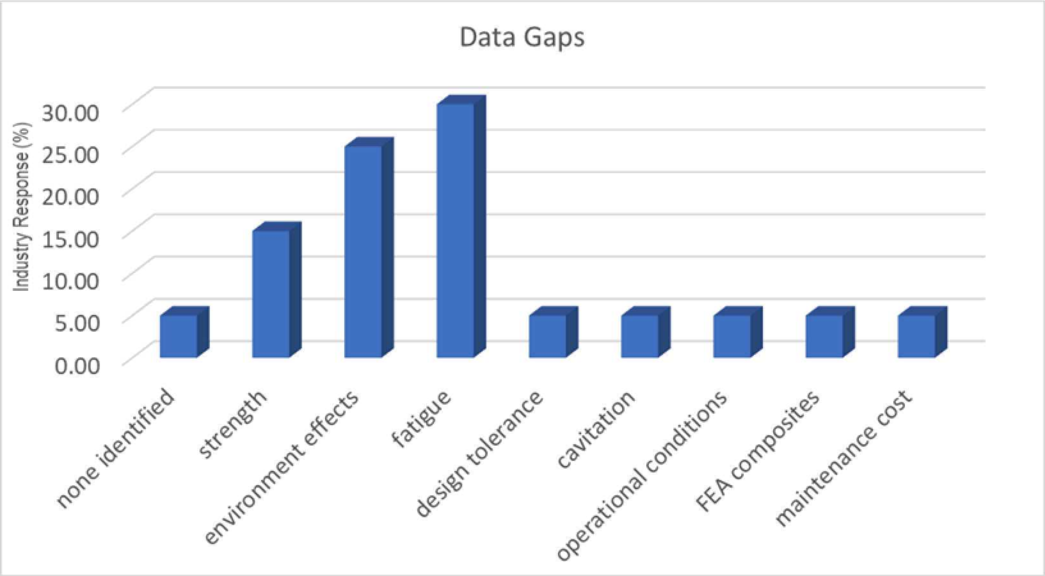
Subcomponet validation

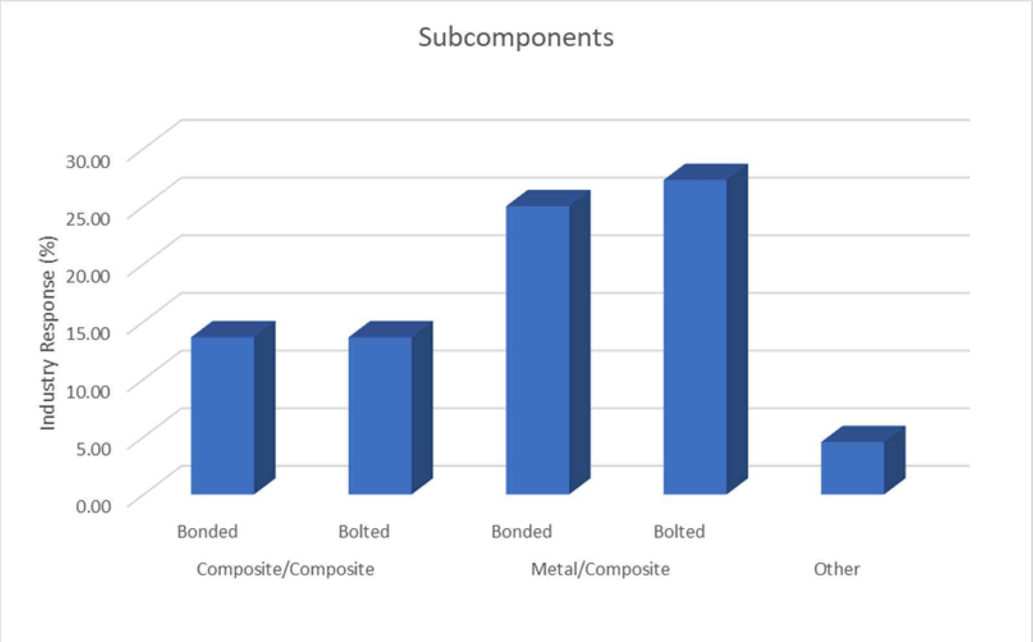
- Build upon results from coupon-level test results
- Establish design allowables that include composite scale effects
- Include environmental effects that may not be possible for validation of complete systems
- Inform standards development early in the process by advancing definition of a building block approach for MHK
- Potential to reduce complete-system structural test requirements
- Validation of modular components and structures



Subcomponets were identified by surveying industry and using "building blocks" that many designs can use.

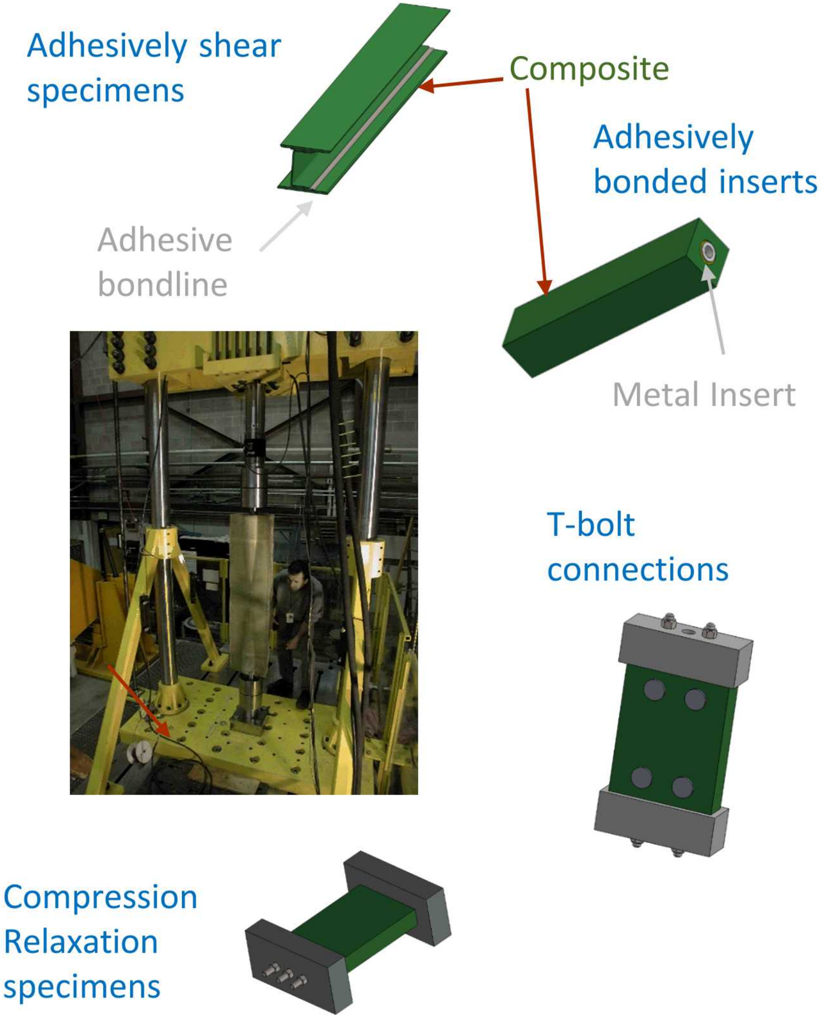
- Questionnaire for industry input
- Phone interviews
- Identify:
    - What materials are being used
    - Gaps in existing data
    - Design and manufacturing challenges
    - Components where composites may be used
- Results informed the development of subcomponent types





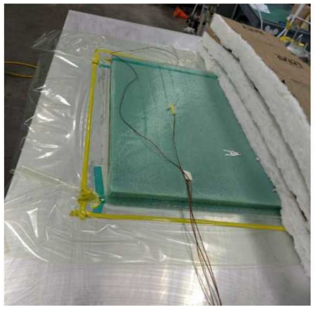
Subcomponents

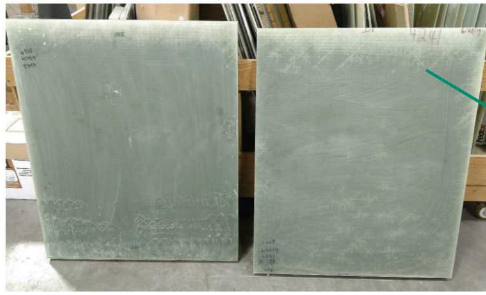
- **Subcomponent types**
  - Adhesively bonded inserts
  - T-bolt connections
  - Adhesive shear specimens
  - Compression relaxation
- **Test Program**
  - 50 subcomponent specimens
  - Testing in 500 kN load frame
  - Strength and fatigue
  - Dry and saturated conditions
  - Load, displacement, strain, NDE instrumentation
- **Status**
  - Manufacturing of panel materials complete in August
  - Fabrication of test specimens complete in September
  - Testing of dry specimens through December
  - Saturation of wet specimens at PNNL and FAU through January
  - Test of wet specimens by March 2020

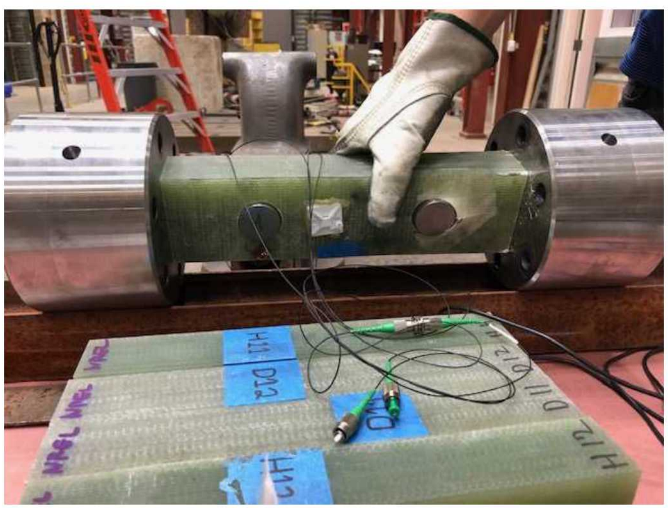


Examples of subcomponent fabrication being conducted. Dry and conditioned specimens will be evaluated

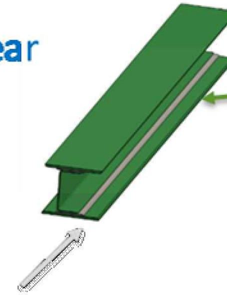
Subcomponent Fabrication







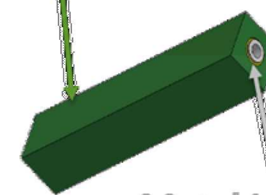
Adhesively shear specimens



Composite

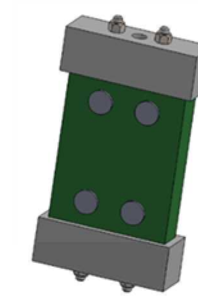
Adhesive bondline

Adhesively bonded inserts

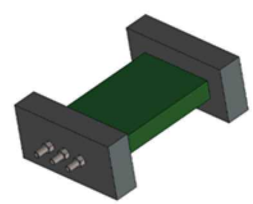


Metal Insert

T-bolt connections



Compression Relaxation specimens



MHK Databases

Wind & Water Materials and Structures

http://energy.sandia.gov/energy/renewable-energy/water-power/technology-development/advanced-materials/mhk-materials-database/

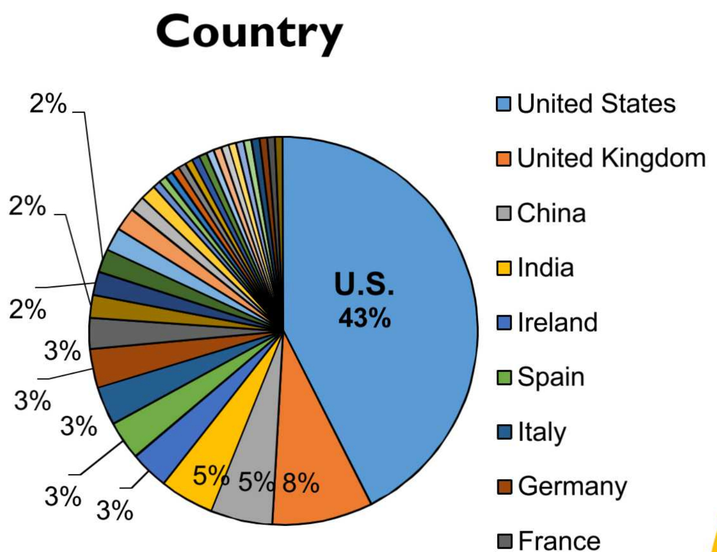
https://openei.org/wiki/Main_Page

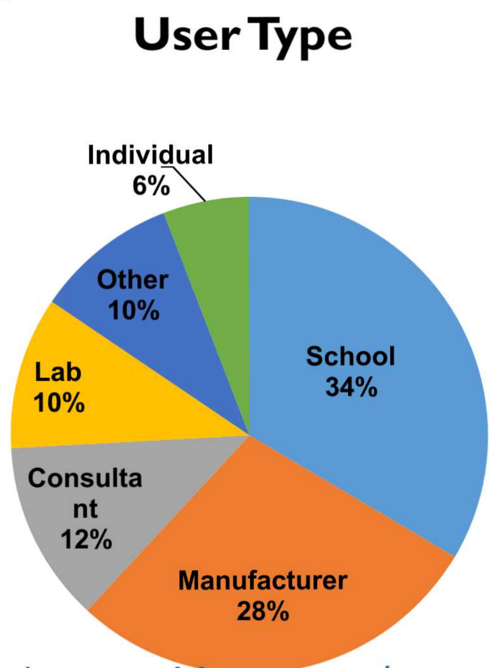
https://tethys.pnnl.gov/

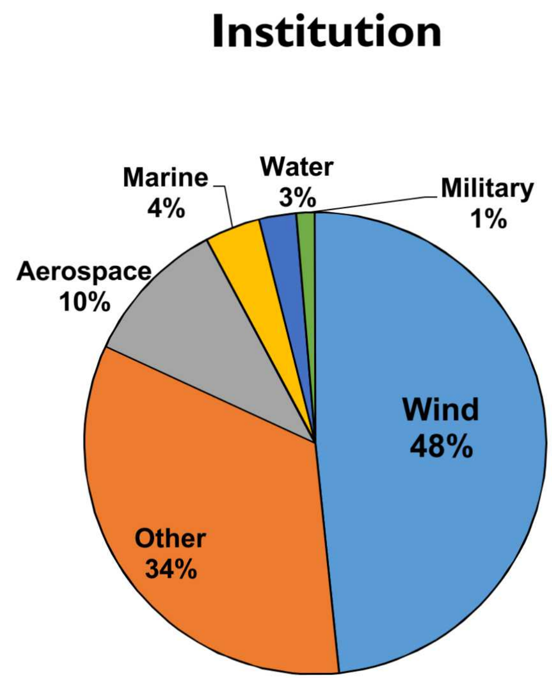
The MHK Composite Materials & Structures Database was born from discovery in wind energy.

U.S. DOE MHK Composite Materials & Structures Database:

Benefits: Open Source, Industry Advised, Backed with Publications.







- http://energy.sandia.gov/energy/renewable-energy/water-power/technology-development/advanced-materials/mhk-materials-database/

Current User Community of U.S. DOE Materials & Structures Database

Summary

- Our goal: "Provide a better understanding of the materials science and engineering of composites to avoid costly redesigns."
- Not all marine coatings work under MHK conditions
- Isolate Interconnects from carbon composite
- Composite performance can degrade-chose wisely
- Corrosion mitigation: Use a super-austenitic or super-duplex stainless steel; Use a more corrosion resistant Ni based alloy; Use a Ti alloy that performs well in sea water
- Substructure results coming soon!