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Evaluation of Composite Materials for Wave & Current Energy

Introduction to MHK Materials Program

Composites are promising materials that could provide lightweight marine durable structures for wave and current (tidal/instream) energy conversion technologies. However, some composite materials are expensive and unproven under marine renewable energy (MRE) conditions. To reduce uncertainty in using composites, Sandia National Laboratories along with Pacific Northwest National Laboratory, National Renewable Energy Laboratory, Montana State University, and Florida Atlantic University have partnered to investigate carbon and glass reinforced composites. Using samples provided by industry (U.S. Marine and Hydrokinetic (MHK), composites/coatings manufacturers), the effects of marine environmental exposure on performance was evaluated. Coupons were submersed in actual and simulated seawater to determine the effects of biofouling, metal-carbon fiber interconnect corrosion, and potential strategies to mitigate them. Tensile static and fatigue testing on 33 different laminates, from five suppliers, was also conducted. Testing was performed on unconditioned and simulated seawater conditioned coupons of each laminate. In addition, a larger scale testing effort at sub-component size to provide insight on the operational load challenges for composite materials is currently being designed with input from developers. It is expected that the outcome of this project will provide industry a better understanding of the materials science and engineering behind MHK composite structures, to optimize designs and avoid costly redesigns. Resulting data from this study can be found in the open source U.S. DOE MHK Materials & Structures Database. This poster focuses on the current results obtained from this program.

Summary of Current Activities and Future Directions

FY17

Salt Water Effects on Composite Performance Testing

Biofouling & Environmental Effects on Composites

Coupons provided by:
Composites Engineering Research Laboratory,
Composites Technology Development, Inc.
Hygrateck
Janicki Industries
Ocean Renewable Power Company
Polyone
Verdant Power

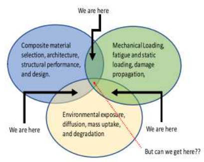
FY18

Metal – Carbon Fiber Composite Interconnects in Seawater

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

FY19

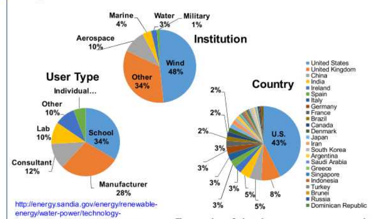
Industry directed full scale subcomponent testing (Simulated & Actual Seawater)



Goal: To reduce uncertainty in the performance, potential for manufacture, and providing validated resources on composite materials and structures to industry.

U.S. DOE Wind & Water Materials & Structure Database

To provide designers a tool to aid in materials selection, the U.S. DOE Wind & Water Materials & Structures Database was developed. The database is being utilized by multifarious users to fill knowledge gaps and to provide critical links between the materials science of composites, system & component design, and the performance of the materials & substructures.

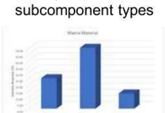


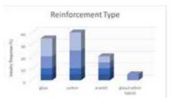
http://energy.sandia.gov/energy/renewable-energy/water-power/technology-development/advanced-materials/mhk-materials-database/

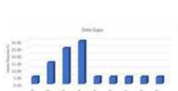
Example of database user community for marine composite Resources.

Industry Assessment

- Industry survey and assessment conducted to identify key materials and connections
- Identification of:
  - What materials are being used
  - Gaps in existing data
  - Design and manufacturing challenges
  - Components where composites may be used
- Survey results inform the development of subcomponent types





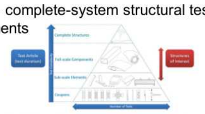


Data Gaps and Components:

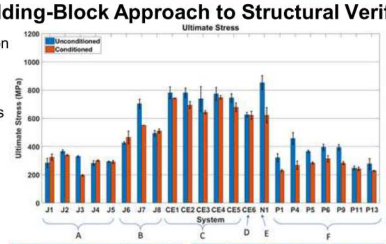
- Bonded and bolted joints frequently identified as key interface
- Bonded metal insert specimens
- T-bolt connection specimens
- Adhesive joint beam specimens
- Compression relaxation specimens
- Dry and saturated comparison
- Static strength and fatigue characterization
- Detailed inspection and instrumentation

Building-Block Approach to Structural Verification

- Intent – provide a pathway for structural verification of MHK systems using a building block approach
- Build upon coupon-level testing
- Establish design allowables including scale effects
- Include environmental effects that are difficult to include at component and full-system scales
- Inform development of MHK standards by advancing definition of a building block approach
- Minimize complete-system structural test requirements



Building block structural verification



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

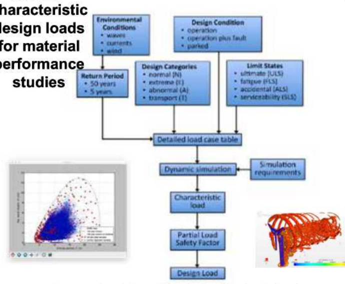
Group	Fiber	Matrix Type	Layup Type
D	Glass	Vinyl ester	[0/45/-45/0]
E	Glass	Elium	[0b]s
F	Glass	Thermoplastic	[0/90]n

Ultimate Stress for dry (blue) and conditioned (red) samples showing strength drop after saturation.

MSU Material	Layup	Average V_f for static tests %	% Moisture	Longitudinal Direction E, GPa	Longitudinal Direction UTS, MPa	Longitudinal Direction % strain	Transverse Direction E, GPa	Transverse Direction UTS, MPa	Transverse Direction % strain
CE1	$[V/(+/-45)g/0c]_s$	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

Table lists a hybrid thermoset made from both carbon and glass. Results illustrates how moisture diffusion within the laminate affects the longitudinal and transverse mechanical behavior. Similar degradations in strength and increase in failure strain was observed across almost all the 33 material systems provide by industry.

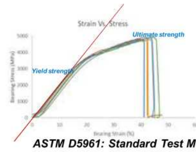
Marine characteristic design loads for material performance studies



Process for determining design loads via load cases

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

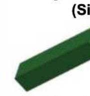
Industry directed sub-scale elements & joined coupon fabrication/testing (Simulated & Actual Seawater)



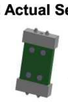
ASTM D5961: Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates

Testing of sub-scale joint coupons with fiber optic strain gages
- Dry testing has been performed
- Samples being conditioned
  - Biofouling (PNNL)
  - Corrosion (FAU)
  - Salt water absorption (SNL)

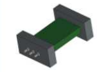
Industry directed full scale subcomponent testing (Simulated & Actual Seawater)



Metal Insert

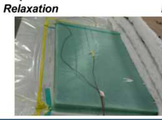


T-bolt connections



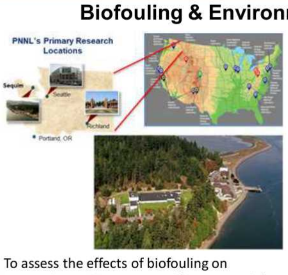
Compression Relaxation

Adhesive joint beams



Full-scale subcomponents
- Subcomponents designs have been selected from the industry assessment
- Specimens fabricated at MSU
- Biofouling at PNNL
- Corrosion at FAU
- Testing at NREL
- FBG Testing by SNL

Biofouling & Environmental Effects on Composites



To assess the effects of biofouling on composites, 500 coupons with commercial coatings and composites were examined.

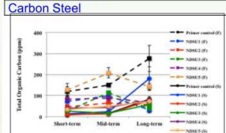
Controlled Velocity Raceway

"Static" Flow Tank

FRP Samples – 8 months Minimal algal growth

Edge failure, 6 months

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	



	Short-term	Mid-term	Long-term
Primer control (F)	119.48	149.78	275.71
NDSU1 (F)	71.93	98.46	32.19
NDSU2 (F)	46.46	65.71	56.01
NDSU3 (F)	24.75	112.78	38.45
NDSU4 (F)	82.71	86.74	66.64
NDSU5 (F)	126.64	207.25	142.07
Primer control (S)	8.35	16.51	83.28
NDSU1 (S)	13.62	23.95	181.05
NDSU2 (S)	10.37	12.22	78.73
NDSU3 (S)	25.80	16.44	56.57
NDSU4 (S)	39.90	43.79	77.17
NDSU5 (S)	33.15	48.51	71.32

Total Organic Carbon and Nitrogen (TOC/N) ; Wet and Dry Weight

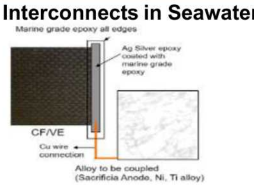
Durability
- Priming and adhesion of coatings failing
  - Improper preparation? (e.g., sanding to roughen)
- Failures on tapered and narrow edges (cracking, delamination)

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

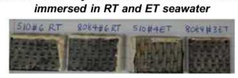
Metal – Carbon Fiber Composite Interconnects in Seawater

FAU-SeaTech Facility

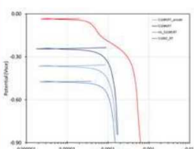
Using fresh seawater for corrosion studies. Carbon Fiber/Vinyl Ester samples were separately interconnected to sacrificial anode, nickel, and titanium alloys. Tests conducted at FAU



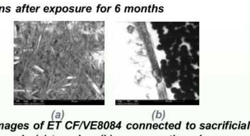
Carbon Fiber/Vinyl ester interconnected to metal immersed in RT and ET seawater



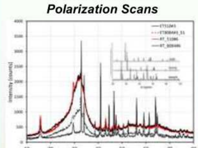
sections after exposure for 6 months



Selected Cathodic Polarization Scans



SEM Images of ET CF/VE8084 connected to sacrificial anode (a) top view (b) cross section view



XRD of CF/VE composites connected to sacrificial anodes

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

Crystalline structure identified
- Thicker calcareous deposits present on ET-CF/VE510#3
- No Vinyl ester peak visible

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

Conclusions

- Water absorption into composites impacts materials properties (composite performance, accelerated corrosion-carbon based)
- Not all antifouling coatings are created equal. MHK has its own conditions.
- Industry identified subcomponent for testing
- Corrosion: anode samples are corroding and calcareous deposits have formed on the interconnected composites.
- Load characterization and measurements testing are being conducted to advance understanding of MHK conditions on composite materials
- Results on samples from industry have been explored and will be downloaded to the database
- This public information is garnered to support design decisions