TC 114 Marine Energy – Wave, Tidal and Water Current Energy Converters

PT 62600-2 Design Requirements for Marine Energy Systems

Composites for Marine Energy Systems

Florida Atlantic University
Sea Tech Auditorium
Dania Beach, Florida
November 17, 2009

Clark Little photo

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What Are Composite Materials?

- A composite is the combination of materials that results in a greatly improved structure.
- Resin matrices transform from liquid to solid during fabrication to “tie” the structure together.
- Fiberglass, Aramid, and carbon laminates with resins are examples of composites, as is plywood and other “engineered” wood products.
- Resin matrices are either “thermosets” that cure to solids through a non-reversible chemical process called “crosslinking” or “thermoplastics” that can be reformed when heated.

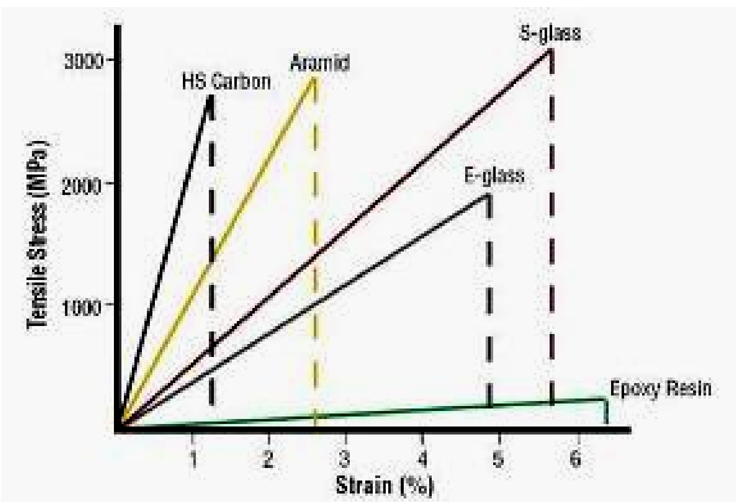
Why Use Composites for Marine Energy Systems?

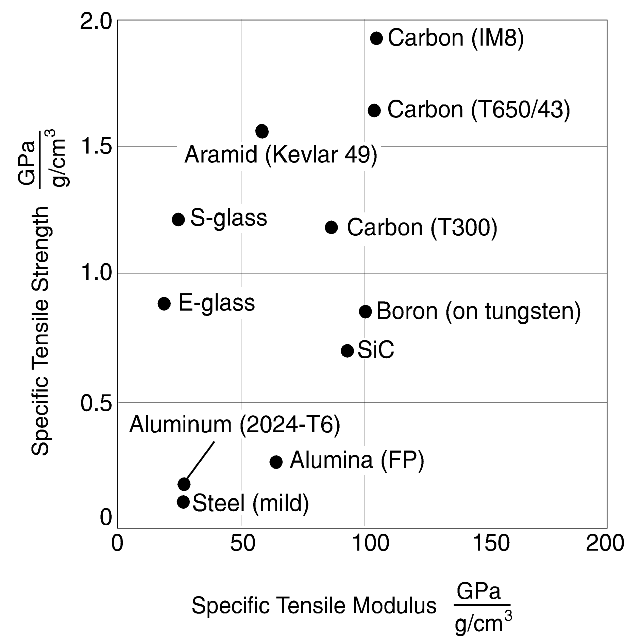
- Composite materials are not subject to corrosion degradation.
- Complex shapes are easily formed with composites.
- Lightweight composite structures are easy to handle and require smaller control machinery.
- Sandwich laminates are ideal for resisting hydrostatic loads.
- Composite laminates have excellent fatigue characteristics.

Fibers

	Density gm/cm^3	Strength MPa	Modulus GPa	Specific Strength MPa*	Specific Modulus GPa*
E-glass	2.60	3450	72	1327	28
S-glass	2.49	4589	87	1843	35
Aramid	1.44	3623	124	2516	86
Carbon (commercial)	1.76	2415	227	1372	129
Carbon (high performance)	1.76	4830	393	2744	223
Polyethylene	0.97	3000	170	3093	175
Basalt	2.66	2950	90	1109	34
HT steel	7.86	750	210	95	27
Aluminum	2.66	310	75	117	28

* Strength or stiffness divided by density





Resins

	Tensile Strength	Tensile Modulus	Tensile Elongation	Heat Distortion Temperature	Shrinkage
	MPa	MPa	%	ºC	%
Ortho Polyester	41	3480	1.2	65	9.00
Iso Polyester	61	3380	1.6	97*	8.20
Vinylester	79	3380	5.0	105-120*	7.80
Laminating Epoxy	83	3680	9.0	110*	0.75
Multi-Purpose Epoxy	50	3170	10.0	54	0.80

* Post-cured data

from ATL Composites Pty Ltd

Polyester

- *Polyester* resins are the simplest, most economical resin systems that are easiest to use and show good chemical resistance.
- *Isophthalic (iso)* resins generally have better mechanical properties and show better chemical resistance.

Vinyl Ester

- Superior corrosion resistance
- Hydrolytic stability (blister resistance)
- Better secondary bonding properties
- Excellent physical properties, such as impact and fatigue resistance.

Epoxy

- Epoxy resins show the best performance characteristics of all the resins used in the marine industry.
- The high cost of epoxies and handling difficulties have limited their use for large marine structures to date.

Cores

End-Grain
Balsa

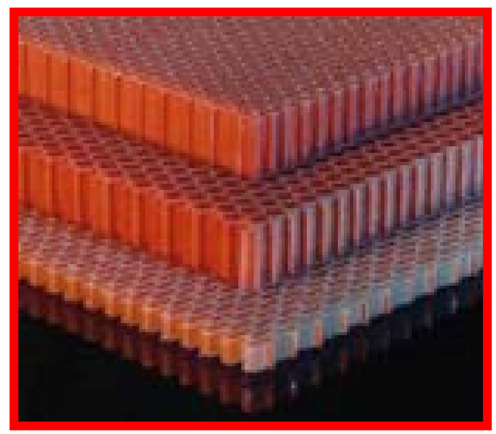
SAN Foam

Linear
PVC Foam

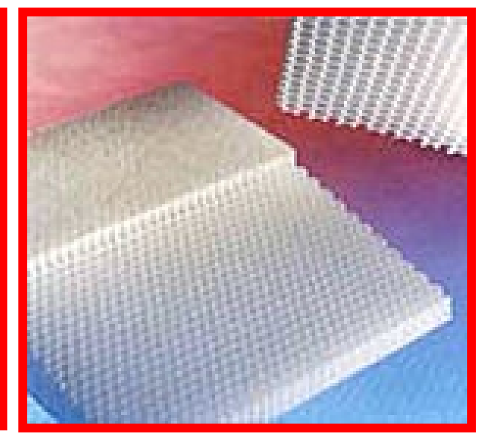
Aromatic
Polyester Foam

Cross-Linked
PVC Foam

PET Foam

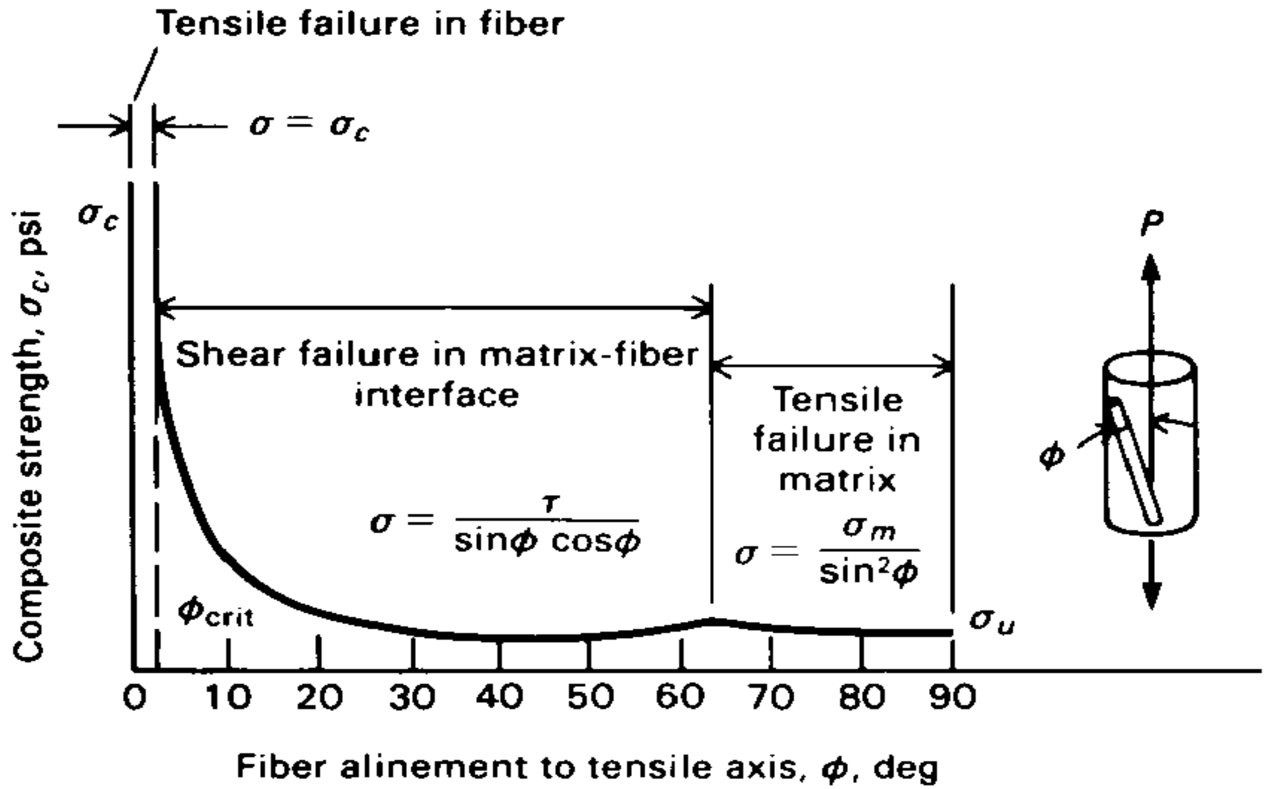


Aramid
Honeycomb



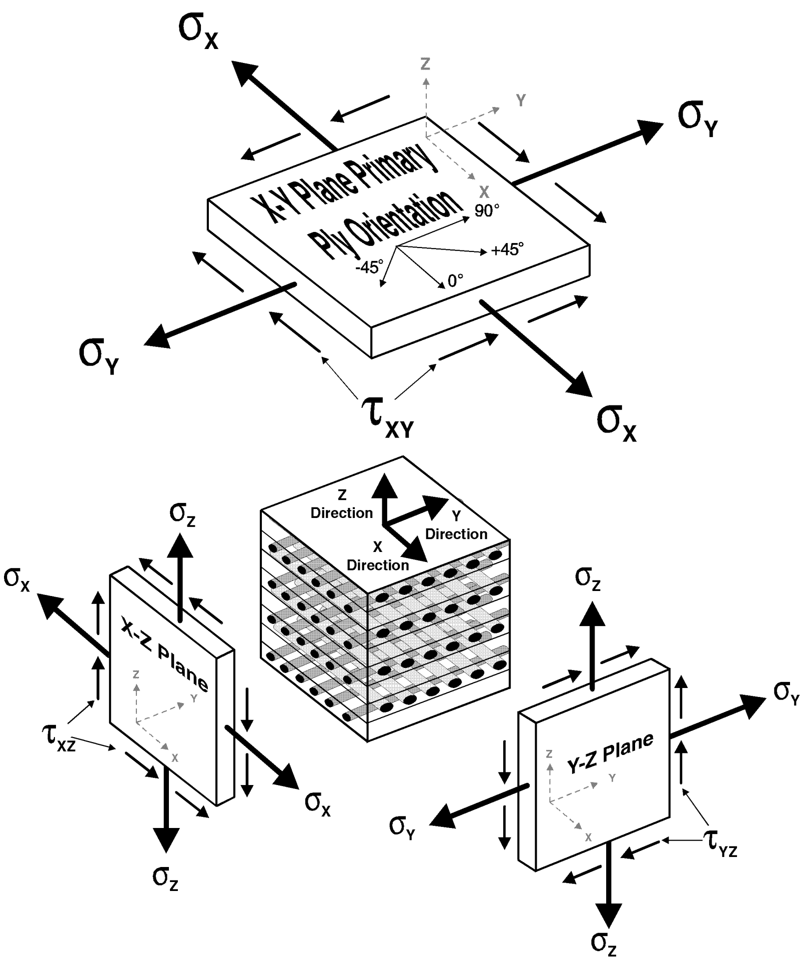
Polypropylene
Honeycomb

Directional Properties of Composite Laminates



The strength of composite fibers are dramatically reduced as the angle to the applied load is increased

Laminate Engineering Data



Stiffness	X	Longitudinal	Tensile Modulus	E_x^t	Compressive Modulus	E_x^c
	Y	Transverse	Tensile Modulus	E_y^t	Compressive Modulus	E_y^c
	Z	Thickness	Tensile Modulus	E_z^t	Compressive Modulus	E_z^c
	XY	Longitudinal/ Transverse	Shear Modulus	G_{xy}		
	XZ	Longitudinal/ Thickness	Shear Modulus	G_{xz}		
	YZ	Transverse/ Thickness	Shear Modulus	G_{yz}		
Strength	X	Longitudinal	Tensile Strength	$\sigma_x^{t\,ult}$	Compressive Strength	$\sigma_x^{c\,ult}$
	Y	Transverse	Tensile Strength	$\sigma_y^{t\,ult}$	Compressive Strength	$\sigma_y^{c\,ult}$
	Z	Thickness	Tensile Strength	$\sigma_z^{t\,ult}$	Compressive Strength	$\sigma_z^{c\,ult}$
	XY	Longitudinal/ Transverse	Shear Strength	τ_{xy}^{ult}		
	XZ	Longitudinal/ Thickness	Shear Strength	τ_{xz}^{ult}		
	YZ	Transverse/ Thickness	Shear Strength	τ_{yz}^{ult}		

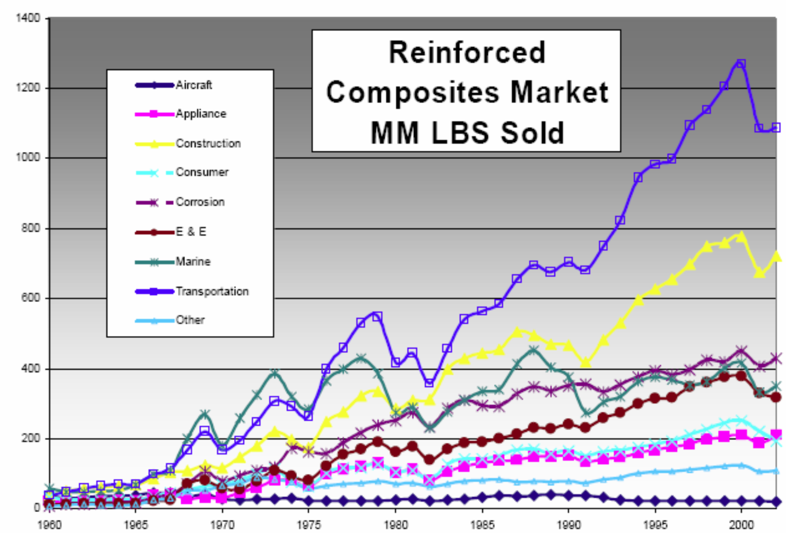
Poisson's Ratio				
Direction:	XY (Major)	YX (Minor)	ZX	YZ
Notation:	ν_{xy}^t, ν_{xy}^c	ν_{yx}^t, ν_{yx}^c	ν_{zx}^t, ν_{zx}^c	ν_{yz}^t, ν_{yz}^c

Engineering design parameters are more complex for a non-homogeneous material

Worldwide Use of Engineering Materials

Shipments, M-tonnes						
	1999		2004		2009 (est.)	
	Steel	Composites	Steel	Composites	Steel	Composites
North America	142.4	2.2	152.5	2.3	155.5	2.8
Europe	330.7	1.4	379.2	1.5	398.2	1.7
Asia	300.5	1.3	473.9	2.2	548	3.2
Rest of World	63.5	0.2	80	0.3	92.5	0.4
Total:	837.1	5.1	1085.6	6.3	1194.2	8.1
% Change:			29.7%	23.5%	10.0%	28.6%

Composites Use Breakdown by Industry in the U.S. Market



Examples of Large Composite Vessels

The ***Mirabella V***, the largest composite vessel and largest single-masted sailing yacht yet built, was launched in 2004 by VT Shipbuilding. The 75m long super-yacht displaces 740 tonnes

The ***VISBY*** displaces 600 tons (fully equipped), is 73 m overall length with a 10.4 m beam. Material of construction for the hull is sandwich construction carbon fiber reinforced plastic giving a quoted speed of >35 knots.

Examples of Large Composite Marine Structures

Composite Submarine Bow Dome Infused with Epoxy by Goodrich Composites

Advanced Composite Sail Envisioned for Virginia Class Submarines

Composite Drilling Riser Developed by Aker Kvaerner Subsea

Composites Design Considerations

Design Criteria:

- Strength Limits
- Deflection Requirements
- Buckling
- Vibration

Laminate Failure Modes:

- Microcracking of the Matrix
- Separation of the Fibers from the Matrix (debonding)
- Failure or Rupture of Individual Fibers
- Separation of Individual Lamina from Each Other (delamination)

Additional Sandwich Laminate Failure Modes:

- Core Yielding
- Ultimate Strength, Core Cracking
- Skin/Core Delamination
- Water Intrusion

Design Allowables

Partial Safety Factors:

- Location Partial Factor of Safety – accounts for the consequence of failure, that is, whether failure of the particular structural member in question results in total system collapse, or local failure
- Load Partial Factor of Safety – accounts for uncertainties in the accuracy, magnitude, nature, or location, of the loads applied to the structure
- Composite Material Failure Mode Partial Factor of Safety – accounts for uncertainties quality, or limitations in the ability to predict composite material failure modes with analytical tools and algorithms

$$F_s = F_s^1 \times F_s^2 \times F_s^3$$

Manufacturing Processes

Hand Layup

Resin Infusion

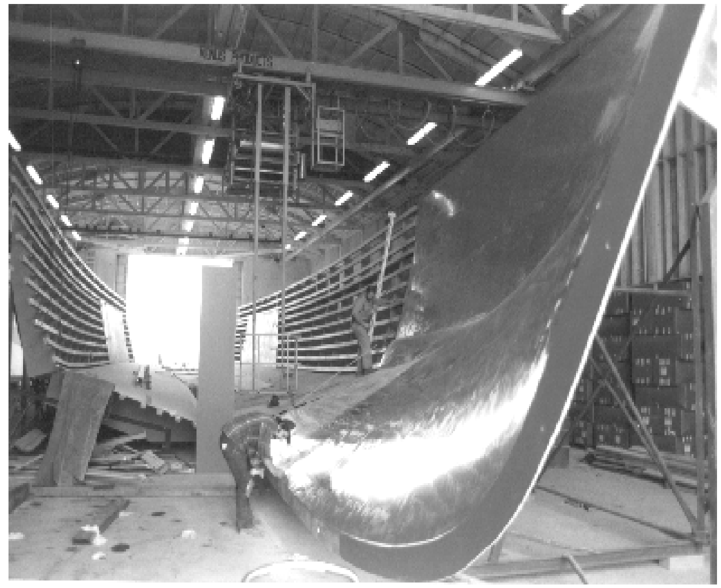
Filament Winding

Pultrusion

Prepreg

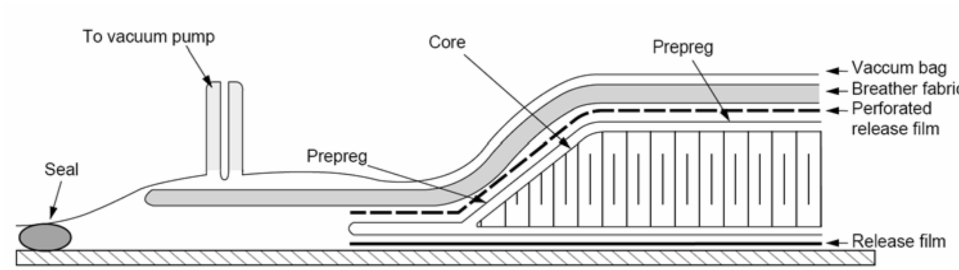
Key Processes Parameters

- Mold Production
- Material Handling
- Fiber Wet-Out
- Laminate Consolidation
- Curing Profile
- Inspection



Two Part Female Hull Mold

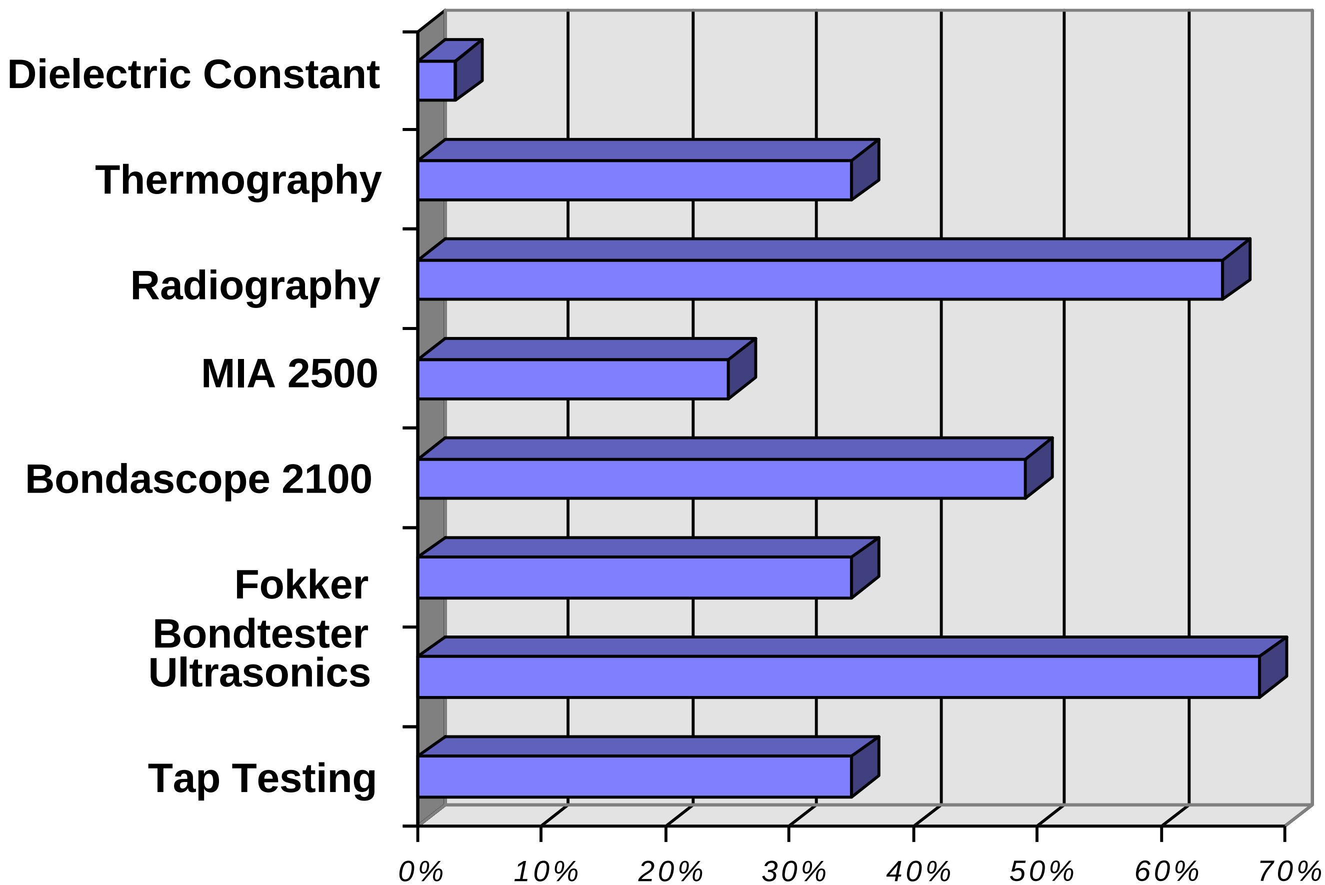
Impregnator on Overhead Gantry



Vacuum Bag Arrangement

Nondestructive Evaluation of Large Composite Structures

Effectiveness of Various Potential NDE Methods



Defects Considered:

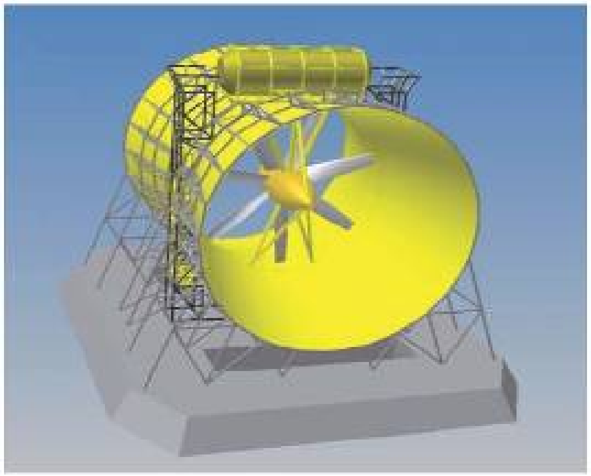
- Impact Damage
- Voids
- Dry Fibers
- Through Cracks
- Delamination
- Uncured Resin
- Excessive Core Filling
- Gap Between Stiffener and Web
- Sheared Stiffener

Bar-Cohen, *Nondestructive Evaluation (NDE) of Fiberglass Marine Structures,* US Coast Guard report CG-D-02-91

Rotors and Shrouds

Verdant Power

Ocean Renewable Power



Lunar Energy

OpenHydro

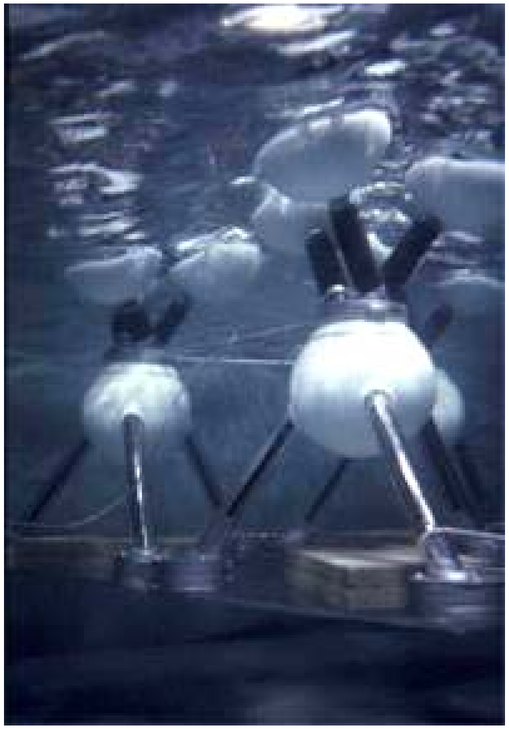
Marine Current Turbines

Hydro Green
Energy

Foundations

AquaBuoy

SEADOG Pump



OWEC Ocean Wave Energy Converter

Energetech

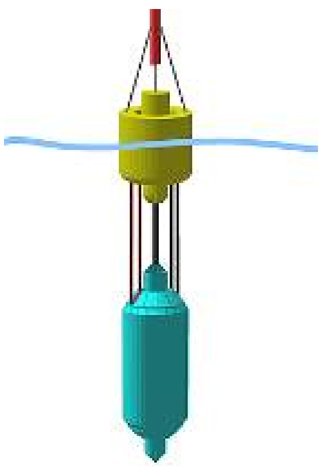
AWS Ocean Energy

Moving Parts

Aquamarine Power

Wavegen

Ocean Power Technology



Wavebob

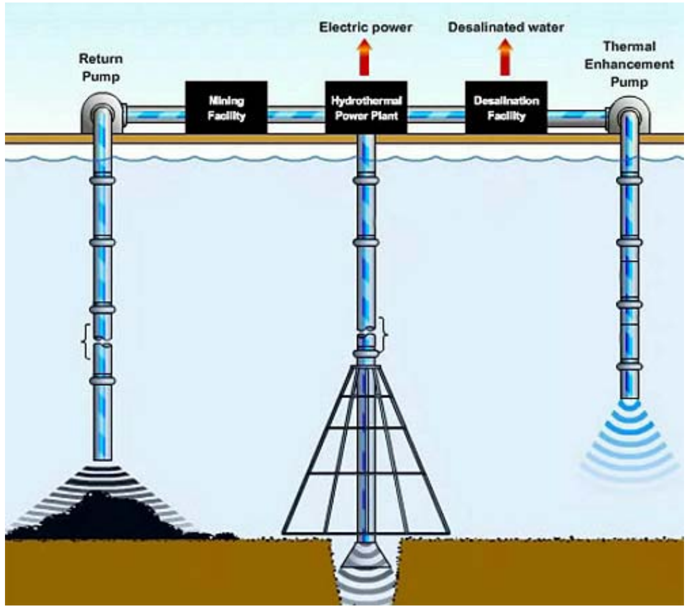
Pelamis Wave Power

Wavestar

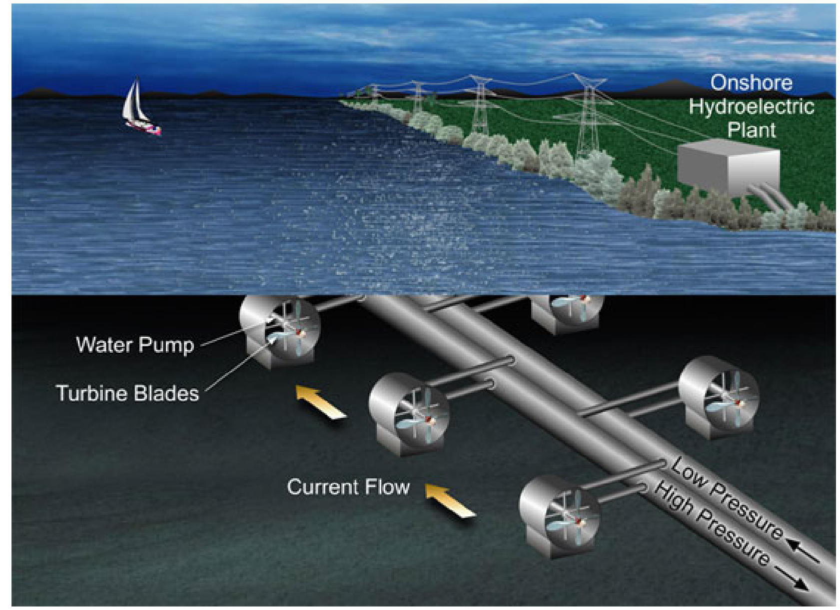
Sea Snail

Piping Systems

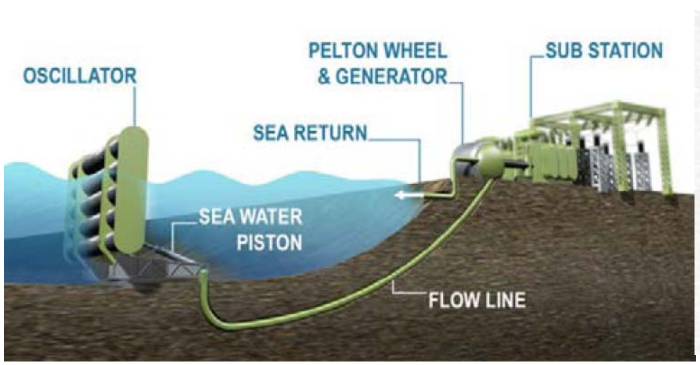
SEADOG Pump



Marshall Hydrothermal Recovery System



JPL/Caltech Hydrokinetic Energy System



Aquamarine Power

Gentec Venturi

Summary

- Composite materials are well suited for marine energy devices because they are non-corrosive and have good fatigue life.
- Directional properties of composites permit design optimization but loads, material properties and failure modes need to be defined.
- The physical properties of composite structures are defined during fabrication, so quality assurance procedures are paramount.
- Composites are especially attractive to build complex shapes, when weight is critical, and when manufacturing production quantities.