Composite Material in U.S Coast Guard Aids to Navigation

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Abstract

- Common occurrences for Aids to Navigation (ATON) Structures:
  - Corrosion of metal
  - Concrete and timber deterioration
- Failures occur at various rates and are dependent upon the environment in which the structures reside
- Fiberglass Reinforced Polymer (FRP) has superior ability to withstand harsh marine environments

Introduction

- ATON correctly mark navigational channel for mariners designating safe water
- Traditional materials for constructing ATON consist of
  - **Steel**
  - **Timber**
  - **Concrete**

- Rate of degradation of materials in marine environments results in failure and replacement of vital aids
- A US Coast Guard primary mission is to design and maintain the ATON system for the United States

Looking ahead…

- The U.S. Coast Guard is selecting ATON designs based on lifecycle cost of a structure vs. a best initial value design
- Intended design life for new ATON is moving from a 25-50 year to a 75-100+ year design life
- Metal coatings, concrete mix admixtures and timber preservative treatments prolonged lifecycles
- Difficult to meet >75 year lifecycle in harsh conditions

Corrosion

- Advancements in FRP = corrosion resistant, strong, lightweight and cost effective
- Structural material degradation from corrosion – large factor in engineering design
- 2014 - estimated worldwide corrosion cost to be $2.2 trillion (>3% of the world’s GDP)

Steel

- Steel used in ATON structures for many years
- An ideal candidate for large ATON structures; rigid and abrasion resistant
- Steel is not as cost effective as in the past

  Increasing material cost +

  Amount of steel used in aids diminishing

  = Shorter ATON lifespan

- Protection from Corrosion

  1. Cathodic Protection
  2. Alloyed Metals
  3. Coatings

TIMBER

- Used for hundreds of years due to its affordability and workability
  - Renewable, low in cost, easy to manufacture, can be recycled, flexibility
- Lifecycle is dependent on the species, treatments, coatings and the environment of its intended use
- Highly susceptible to abrasion damage from boats, ice and other floating debris
- Increase in labor and fuel costs throughout lifecycle due to the need for frequent replacement, timber does NOT provide a low lifecycle cost option
- If timber ATON **NOT** knocked over, timber aids can have a lifecycle from 20 to 40 years, sometimes longer

Concrete

- The use of reinforced concrete in ATON occurs on a case by case basis.
- Used as channel markers not advisable in areas with high knockdown rates although proven to be an excellent material for ATON IF constructed properly
- Primary issue is the difficult and costly repair or removal once it has reached the end of its useful life
- Most concrete ATON structures are often built and demolished using private contractors, which can be very costly

Fiber Reinforced Polymer (FRP)

- Fiber Reinforced Polymers (FRP) have been around since the beginning of the 20th century
- Extend the expected lifecycle beyond that of using traditional materials and cost effective in certain instances
- Utilize thermoset polymers to enhance the resistance of ultra violet degradation and abrasion
- USCG CEU Miami has implemented an initiative to use FRP in ATON to lower lifecycle cost and increase aid availability
- FRP ATON much safer alternative due to its ability to absorb high impact loads without permanent deformation or failure

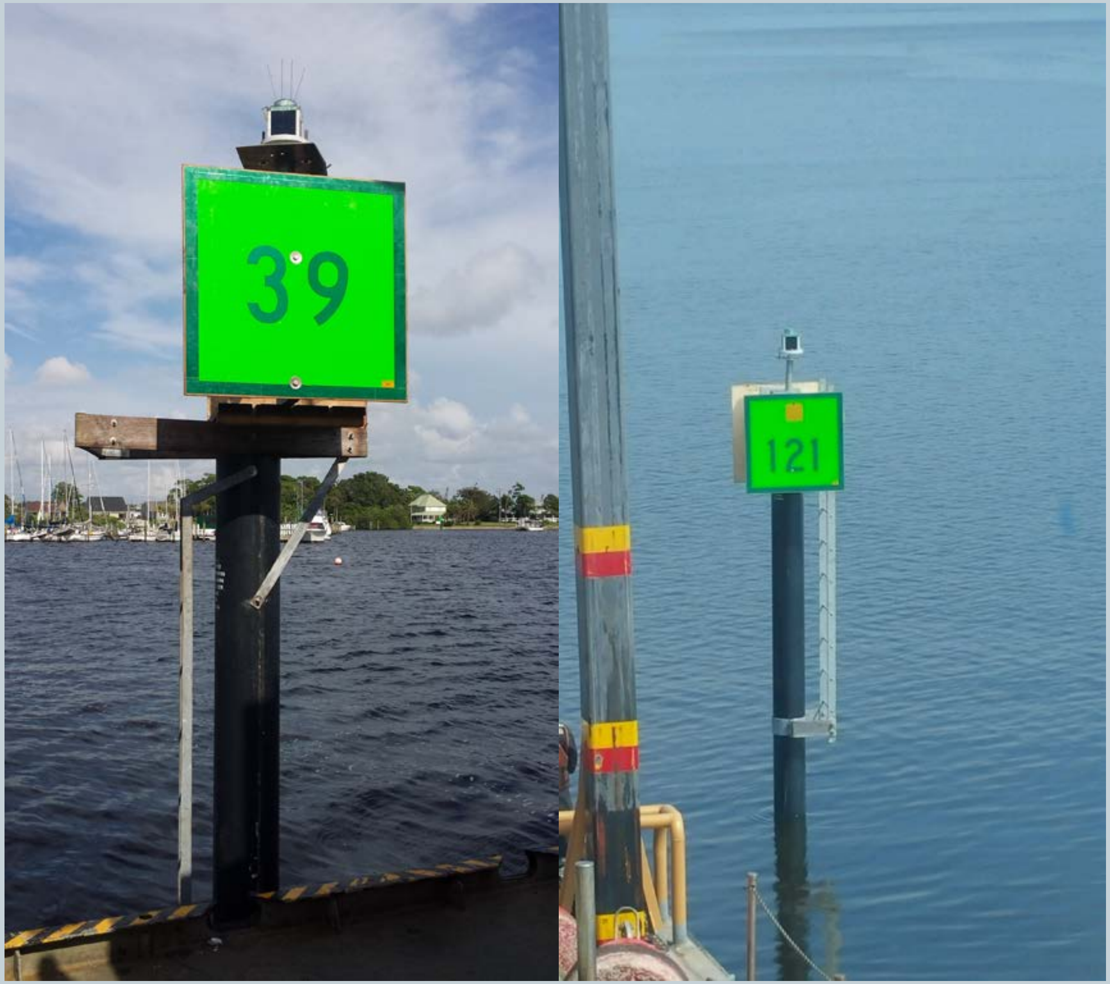

Figure 1:USCG Aids to Navigation (ATON)
Built Using FRP Piles

Successes of FRP

- Approximately 25 FRP ATONs have been installed in high knockdown areas since 2014
- Only ONE reported knockdown within the last year
- Cutter construction crews have found the FRP piles to be lightweight and easy handle on deck; cuts and drills efficiently

Challenges of FRP

- Specific blades required for cutting
- The smooth surface of the piles requires some adjustments in handling
- In areas with hard soils, the top and tip of the pile may become damaged when driven
    - Many FRP piles used for ATONs ordered with cast iron driving tip for hard bottoms where steel normally used
- There are many variations in the FRP manufacturing process therefore making it a challenge to use FRP materials across suppliers

Benefits of FRP

- Despite some growing pains, FRP benefits outweigh costs
- Very high resistance to degradation in marine environment
  - Primary mechanism of ultraviolet breakdown has been addressed with coating and admixtures to the resin mix
- Material is lighter than steel with very high strength-to-weight ratio; compatible with most existing on-board equipment
- High strength and low modulus allows it to absorb impacts making it less susceptible to damage

Ultra Violet Resistance Testing

- FRP structural elements not used long enough to prove a 75-100 year design life
  - Performing UV accelerated weathering tests (ASTM G154) predicts long term strength
- Engineers utilize factor of safety to meet the 75-100 year lifespan requirement from accelerated UV testing
- Use of UV resistant coatings help delay degradation in strength

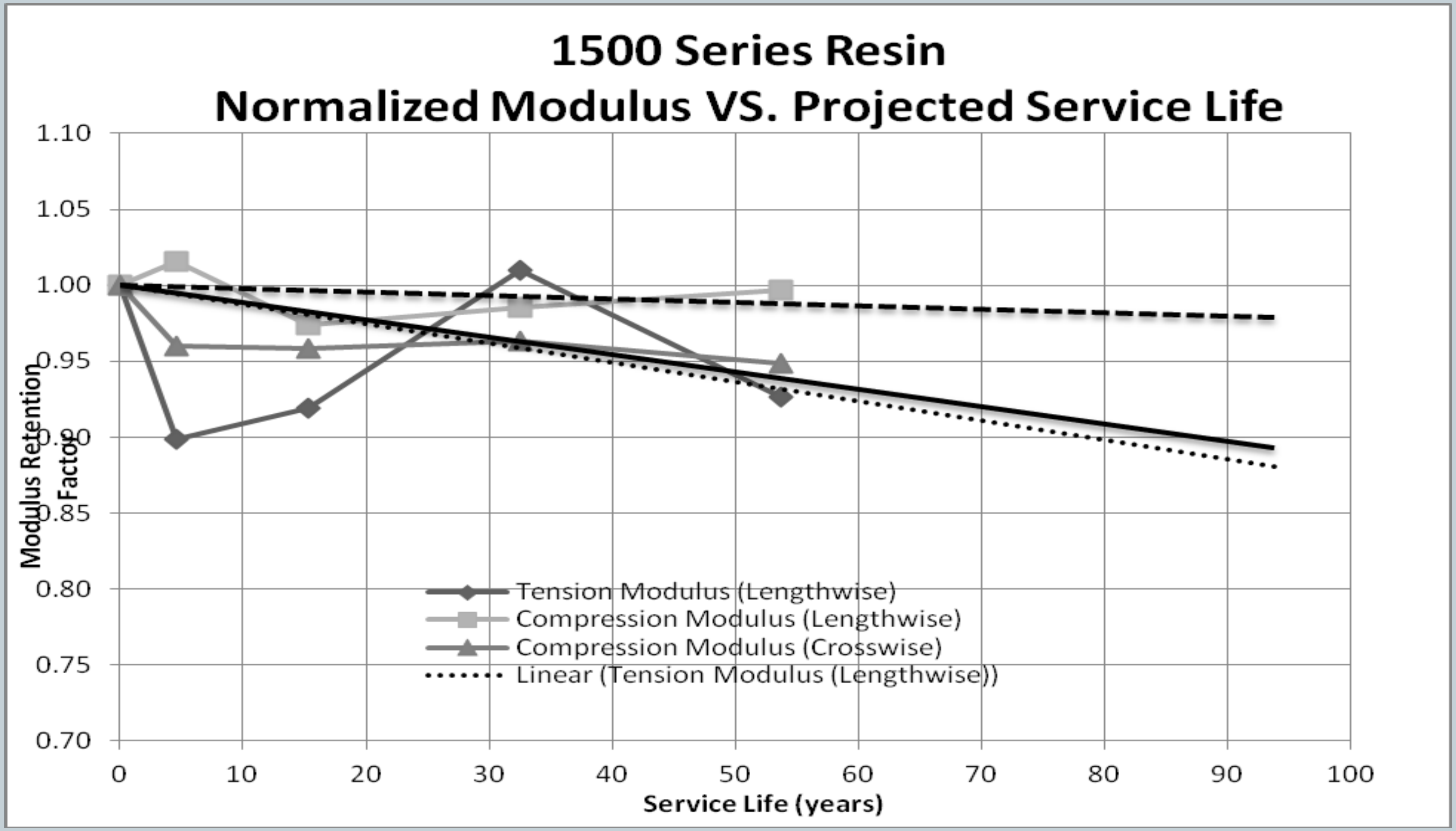

Figure 2: Example of UV Accelerated Weathering to Predict Long Term Strength (Courtesy Creative Pultrusions, Inc.)

Fatigue Resistance

- FRP, when placed at high temperature extremes i.e. >50°C/122°F will have more deflection.
- Studies have proved that fatigue testing performed at extreme temperatures show little to no fatigue damage apparent

Abrasion Resistance

- High density polyethylene (HDPE) pipe bonded over an FRP pile for additional abrasion resistance.
- Bonded HDPE pipe also offers the FRP pipe a greater degree of UV protection.

Bending Stiffness

- If design requires minimizing deflection, FRP bending stiffness may require use of a hybrid design to reduce the deflection
- FRP has about one-fifth the bending stiffness as compared to steel
- FRP is an anisotropic material; direction of the forc applied has much to do with how the material bends

Lifecycle Co$t

- Must consider construction/demolition/re-construction costs along with associated maintenance costs required to achieve the designed/predicted lifespan.
- Most manufactured materials have a point of diminishing returns where they are no longer cost effective to maintain.

100 Year Lifecycle Cost Analysis of 60 foot long pile in Key West, Florida (interest - 5 percent)				
	Steel Pile	**Treated Timber Pile**	**Reinforced Concrete Pile**	**FRP Pile**
Size	12 in dia X 3/8 inch wall	Varies ~ 12 inches	12 inch x 12 inch square	12 in dia x 1/2 inch wall
Material Cost at year 0 ($)	$3,908.09	$527.82	$1,135.20	$3,407.42
Installation Cost at year 0 ($)	$25,000.00	$25,000.00	$25,000.00	$25,000.00
Service Life (estimated)	50 years	25 years	50 years	100 years
Disposal Cost (Present Value)	$2,500.00	$500.00	$8,500.00	$1,500.00
Replacement Cost at year 25 ($)		$88,139.31		
Replacement Cost at year 50 ($)	$360,169.13	$298,471.42	$397,175.69	
Replacement Cost at year 75 ($)		$1,010,730.27		
Disposal Cost at year 100 ($)	$328,753.15	$65,750.63	$1,117,760.71	$197,251.89
PV yr 0, 100 year service ($)	$62,814.84	$104,108.37	$69,268.92	$29,907.42
Year 100 LC cost ($)	**$717,830**	**$1,488,619**	**$1,541,071**	**$225,659**

Figure 3: Lifecycle Cost Analysis of Piles Constructed of Various Materials

Disposal and Recycling

- FRP's disposal needs to be considered so environmental concerns are mitigated through use of new technology.

Conclusion

1. Pilot program for FRP ATON structures proved a viable, cost effective alternative to traditional materials from both a performance and lifecycle cost standpoint.
2. Use in Coast Guard ATON structures makes for safer waterways and higher aid availability.
3. Continued use yield much less annual maintenance costs and reduce wear and tear on aging Coast Guard construction tender fleet.

Questions