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The Application of Composite Materials to Eliminate Corrosion in Marine Environments

ABSTRACT

The battle against corrosion is relentless aboard maritime vessels, resulting in millions of dollars and thousands of man-hours applied each year. Shipboard equipment is designed to perform its intended function and these items have traditionally been made from corrosion resistant ("CRES") stainless steel or marine-grade aluminum to withstand the harsh, salt-laden marine environment.

This paper presents a simple, cost effective, alternate approach using fiber-reinforced plastic ("FRP") composite materials, instead of stainless steel or aluminum, to eliminate corrosion issues while maintaining essential performance characteristics. In certain military shipboard applications, cutting-edge features such as radar absorbing "stealth" technology have been incorporated.

Advanced composite manufacturing techniques are applied with interlocking parts that are bonded together with epoxy material to replace traditional welded structures. These FRP structural parts can be molded or pultruded to develop shapes with exacting tolerances commensurate with formed steel or extruded aluminum shapes. While FRP materials can be customized in a variety of colors, typical military applications require specific surface painting to conform to ASTM, MIL-spec or similar requirements to minimize fire spread and smoke generation. In some cases, a Product Design Assessment ("PDA") Certificate from the American Bureau of Shipping ("ABS") may be required as independent verification of specification conformance.

This paper will explain essential design considerations, performance improvements and cost benefits for air intake louvers from the perspective of the manufacturer and the end user. With installations across multiple US Navy ships, including both radar-absorbing and non-radar-absorbing styles, the use of FRP materials has demonstrated to reduce lifetime costs and offers an opportunity for both new ship construction and retrofit of systems aboard ships already in service.

INTRODUCTION

Air intake systems aboard maritime vessels include systems to remove saltwater and airborne particulates from the air that is being transferred into HVAC ventilation or gas turbine combustion air intake ducts. Other types of louvers are utilized to protect workspaces or cargo holds. These systems are typically located within the ship's hull or on bulkheads that are exposed to weather, bow waves and countermeasure washdown sprays. As such, exposure to a saltwater atmosphere presents a formidable corrosion challenge over the life of the ship. Historically, the most common materials of construction have been corrosion-resistant grades of stainless steel or marine-grade aluminum. In some applications, the base materials are treated with paint or anodized surface treatments that meet military specifications to extend service life. Despite these material selections and surface treatments, the natural marine environment imparts harsh attacks on base materials requiring regular maintenance operations such as grinding, abrasive blasting and re-painting. Eventually, the corrosion effects become so bad that sections of the equipment must be removed and replaced with costly new base materials or the entire piece of equipment must be replaced.

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SHIPBOARD CORROSION REALITIES

The following photos depict commonly occurring corrosion and the resultant unsightly effects aboard US Navy vessels.

Figures 1a and 1b: *Shipside discoloration from corroding steel louvers is evident below the orange lifeboats aboard USN Matthew Perry (T-AKE-9)*

Figure 2: *Close-up of a corroded steel louver blade with blistered paint*

Figure 3: *Shipboard view of chipped paint and corroded base metal within an air intake opening*

Figure 4: *Shipside louver blades experiencing severe corrosion aboard LSD-class*

To address this environmental challenge, several different manufacturing techniques have been developed to apply FRP composite materials for air intake moisture separators and shipside louvers in a cost-effective way. While the initial FRP composite material cost may be marginally higher than metals, the lifetime cost avoidance of reduced maintenance labor becomes the main decision driver for making the change from metal to composite parts.

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BASE MATERIAL CONSIDERATIONS

The selection of FRP composite base materials is focused on the type of resin and the type of glass fiber used for structural reinforcement. For military shipboard applications, the primary driver for material selection is the structural requirement to withstand shock and vibration impacts as qualified per US Navy requirements MIL-S-901D and MIL-STD-167-1, respectively.

Resins are available with different chemical compositions such as vinyl ester and the finished parts will be painted to provide a uniform final product that matches the ship's color. Special paint treatments to create an icephobic surface have been used to prevent ice buildup on ships that are deployed in cold weather conditions.

A unique crew safety challenge was met for US Navy ships by adding alumina trihydrate to the base resin. This chemical has fire-retardant properties and is compatible with the pultrusion process. The resultant parts are able to meet ASTM-E-162 flame spread, ASTM-E-662 smoke generation and ASTM-E-1534 time to ignition and heat release requirements specified by the US Navy.

Glass fibers are typically oriented so that the individual fibers provide adequate strength and stiffness in both the X- and Y-axes. However, a customized ply sequence can be used to adjust strength in only one direction when needed. Additional reinforcement can be applied by concentrating fibers in areas prone to excessive loads such as bolting locations, corners or along the edges of finished parts. E-glass fabric fibers were used for the marine applications reported in this paper.

FRP MANUFACTURING TECHNIQUES

Early manufacturing processes used molded parts where each different shape and size must be built with a specific mold. In addition to the excessive costs to make multiple molds, this process employs a laborious lay-up operation where multiple layers of fiber mat are placed by hand into a liquid resin that is then allowed to cure for several hours. Once cured, the part is removed from the mold and manually finished by grinding off irregular edges. Finally, this method is fraught with challenges to maintain consistent part thickness, uniform fiber deposits and the challenge of avoiding air bubbles within the resin. The bottom line of using molded FRP parts is excessive cost.

As an alternate to this costly approach, an advanced method of pultrusion was developed and applied for the US Navy LPD Amphibious Assault ships and the Military Sealift Command T-AKE replenishment ships. The pultrusion process is based on a continuous production of woven or non-woven fibers, impregnated with resin and pulled through heated die. As depicted in Figures 5a and 5b, this method produces 20- to 30-foot long parts of a consistent cross-section. To make these shipside louvers, only three different cross sections were needed: frames, vane blades and spacer bars. These shapes were cut to length, had their ends shaped using butted or tongue-and-groove connections, and finally fixed together with epoxy adhesive.

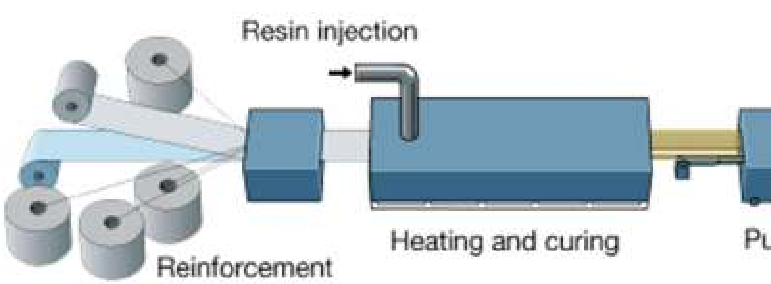

Figure 5a: *General Pultrusion Process*

Figure 5b: *Lengths of LPD louver frame parts depict the uniform cross section grooves*

FINDINGS

The pultrusion manufacturing method proved to be significantly more flexible and cost effective than molding as there were more than fifty different size louvers on the LPD ships, ranging from (18"H x 18"W) to (80"H x 80"W) and thirty-eight different size louvers on the T-AKE ships ranging from (24"H x 30"W) to (72"H x 108"W). The manufacturing process was executed in the following phases:

- Pultrusion of primary shapes: frames, vane blades and spacer bars
- Cutting primary shapes to length
- CNC machining for end shaping
- Kitting the required number of each primary shape for each louver
- Louver assembly and bonding
- Mounting flange bolt hole preparation
- Painting

LPD Class Louvers:

The LPD Class louvers utilized the tongue-and-groove assembly technique so the louvers could mount into bulkhead openings with radiused corner openings. A stainless-steel, perforated foreign object debris ("FOD") screen was mounted on the back side of each louver to protect the intakes while keeping the radar-absorbing material on exposed surfaces.

Figure 6: *Tongue-and-groove assembly of LPD louver frame radiused corner with epoxy adhesive*

Figure 7: *"Dry-Fit" pre-assembly of LPD louvers to confirm parts fit-up*

Figure 8: *Assembly of a "small" LPD louver before installing FOD screen and drilling mounting bolt holes*

Figure 9: *Assembly of a "large" LPD louver before installing FOD screen and drilling mounting bolt holes*

Figure 10: *Final assembly of LPD louver showing the perforated steel FOD screen on outlet (back) side and ferrule reinforced bolt holes on mounting flange*

T-AKE Class Louvers:

On the other hand, the T-AKE Class louvers utilized less expensive, square-cornered frames since these louvers will mount flush behind an opening in the hull. These louvers also used 100% composite materials by replacing the stainless steel FOD screens with a molded FRP grating. This grating was mounted to the front side of the louver, retained within the frame and supported by the vane blades. Alternate, back side, mounting to allow the grating to be removed during its operating life is also possible.

Figure 11: *Back side of T-AKE louver showing vane blades and interior corner reinforcing angles*

Figure 12: *Back side of T-AKE louver depicting vane blades and composite FOD grating*

Figure 13: *Front side of T-AKE louver showing composite FOD grating and square cornered frame*

TRADITIONAL vs. RADAR CROSS-SECTION ("RCS") FRP MATERIALS

Shipboard applications will benefit from commercially available composite materials. With FRP density approximately 32% that of steel, a ship's overall weight is reduced and its center of gravity can be lowered, leading to improved ship stability and maneuverability.

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A unique application of radar-absorbing materials was utilized for the shipside louvers on the US Navy's LPD-Class ships. This initiative by the Naval Surface Warfare Center, Carderock Division, developed louvers to integrate without compromising the stealth properties of this ship's composite hull structures. This patented design was developed to integrate special fibers into the pultrusions to achieve the required performance characteristics. Online testing of pultruded parts was evaluated by US Navy personnel to confirm consistent radar absorption characteristics before the louvers were assembled. A fuller description of these louvers is provided in reference 1.

SHIP INSTALLATION CHALLENGES

Manpower aboard ships is limited and sailors need to focus on their "day jobs." When ships come into port for availability service, time is of the essence to complete work and get the ships back out to sea. As such, labor is often applied at premium rates, especially as unscheduled work tasks become evident.

Metalworking tasks considered to be everyday business in a clean and spacious workshop become more difficult, time consuming and expensive when conducted aboard a ship. Tight access to the downstream side of louvers makes removal of full louvers difficult, if not impossible. Bulkheads, pipe racks, conduit raceways and manway access ports are commonly found to be "in the wrong place at the wrong time," hindering workers. In addition, the challenge of performing work aboard ships requires extra equipment, operators, work zone isolation, safety crews and detailed planning.

Figure 14: *Tools for welding and grinding require electrical cables and pneumatic hoses to be dragged through access ports aboard USN Charles Drew (T-AKE-10)*

Figure 15: *Shipside access to work on louvers requires a hydraulic lift platform and associated ground crew aboard USN Charles Drew (T-AKE-10)*

COST PERSPECTIVES

According to feedback from Military Sealift Command Port Engineer, Michael Zirpolo, the acquisition cost for a full shipset of thirty-eight new FRP composite louvers for the USN Cesar Chavez (T-AKE-12) was comparable to one maintenance cycle for half a shipset of painted steel louvers. The following review of just one typical louver provides a cost comparison of current maintenance operations versus a simple replacement.

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Steel Part Maintenance Cycle (~3 years):
Replace 50% of louver blades within one louver
Cost (labor and material) [2]: $38,000

- Paint removal by abrasive blasting
- Louver blade removal by grinding
- Louver blade parts manufacturing
- Louver blade installation by welding
- Re-painting

Composite Part Replacement (>10 years):
Complete louver replacement
Cost (labor and material) [3]: $40,000

- Louver removal by weld grinding
- Mounting frame and louver parts manufacturing
- Mounting frame installation by welding
- Composite louver manufacture
- Composite louver bolt-in-place

While the preceding example shows that a new FPR louver will cost slightly higher than a partial repair of a steel louver, a review of full shipset installation and multi-year operating maintenance costs presents an even more compelling argument for FRP composites. This review shows a balance of initial cost of goods for FRP louvers versus a much higher lifetime cost of maintenance for steel louvers.

Considering a 20-year operating lifetime and a shipset of thirty T-AKE class louvers of varying sizes, the following estimations were used:

- 2% annual inflation rate
- New steel louvers would need blast, paint and blade replacements starting in the 3rd year
- New FRP louvers would not experience corrosion but would require touch-up painting starting after 5 years
- A "maintain only" case of blast, paint and blade replacements on existing steel louvers is also presented.

Figure 16: *Lifetime cost comparison of FRP vs. Steel Louvers*

Compared to the option of installing new FRP louvers, both cases of using steel louvers result in additional lifetime costs starting in the fifth year. As shown in Figure 16, when comparing a 20-year operating life, the FRP louver option brings the following additional cost savings:

- **Existing steel louvers: $1,305,475**
- **New steel louvers: $1,695,475**

WEIGHT PERSPECTIVE

Current installations aboard T-AKE-14 and several LPD ships were able to realize the following weight savings per ship:

LPD-24 (89 louvers): 44,100 lb. (20,000 kg)
LPD-25 (130 louvers): 63,400 lb. (28,750 kg)
LPD-26 (51 louvers): 37,900 lb. (17,150 kg)
T-AKE-14 (38 louvers): 18,900 lb. (8,575 kg)

FUTURE DEVELOPMENTS

The application of FRP composite materials for shipboard louvers is still in its relative infancy. As such, product enhancements are being considered to innovate material shapes to reduce thickness while maintaining structural integrity. Developing thinner profiles is important for intricate cross-sections such as moisture separator vanes. As shown in Figures 16 and 17, pocketed moisture separator vanes have already been developed for applications in HVAC ventilation air intakes.

Additional developments are being considered to apply crafted surface finishes to further enhance moisture separator performance.

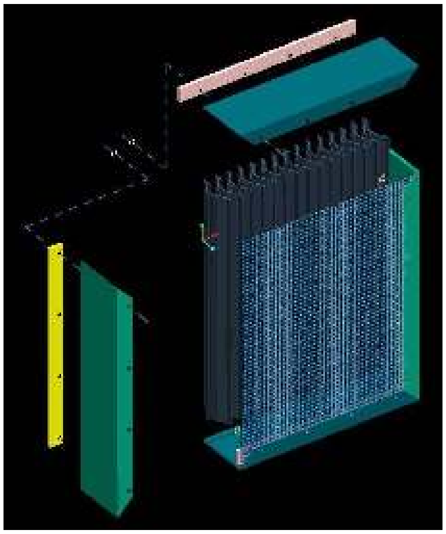

Figure 17: *Model of composite moisture separator vanes and framework with FOD screen*

Figure 18: *FRP pultruded moisture separator vanes (Peerless P2-XLP-C profile)*

Other exposed surfaces on ships such as stairs and ladders benefit from “anti-slip” finishes applied to stair treads and decks to replace traditional steel parts aboard ships and offshore platforms. Repair and re-painting are still the most common practice but replacing these stairs with FRP composite parts will extend the time between maintenance operations resulting in long term savings.

Figure 19: *Steel ladder treads aboard USN Charles Drew (T-AKE-10) require periodic repair, but will ultimately need to be replaced when the base metal corrodes*

Figure 20: *Freshly repaired and painted steel ladders aboard USN Charles Drew (T-AKE-10) may last for three years until the next maintenance cycle and will ultimately need to be replaced in full*

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CONCLUSIONS

FRP composite louvers have already been proven on two US Navy ship classes: LPD and T-AKE. Different approaches were taken on the base materials and the methods of joining parts together to meet the needs of each ship. In both cases, the application of pultruded parts proved that installing new composite louvers is the more cost-effective, long-term solution rather than repairing or replacing with stainless steel louvers. On every ship, there are many louver dimensions that need to be served to protect workspaces, cargo holds, ventilation ducts and combustion air intake and exhaust ducts. Accommodating for any louver size option is best served by the pultrusion manufacturing process.

Even more savings can be realized with advance planning to serve multiple ships. As with any type of continuous manufacturing method, the objective is to keep the machines running with the minimum number of setups. Louvers can be built in batches to serve multiple ships within a class and can be delivered in partial or full shipsets for installation when the ship is in port. For cargo hold applications such as on the T-AKE class, louver installation can be made while the ship is sailing at sea.

The direct comparison of composite vs. steel couldn't be more obvious than in the following photos. Not only does the ship with composite louvers (Figure 20) look better than the ship with steel louvers (Figure 21), but by installing FRP composite louver, ***the crew can be focused on their mission, not their maintenance!***

Figure 21: *LPD-23 with composite shipside louvers*

Figure 22: *T-AKE-9 with steel shipside louvers*

Photo Credits:

[1a, 1b, 21, 22] Created by: MC3 Dustin W, Sisco, US Navy, Public Domain

[2, 3] Shutterstock, Public Domain

[4] MEGARUST presentation, NAVSEA, Public Domain

[20] Created by: MC3 Ryan M. Breeden, US Navy, Public Domain

[5, 6, 7, 8, 9, 10, 11, 12, 13, 17] CECO Peerless: work in progress and engineering computer model for LPD and T-AKE louvers.

[14, 15, 18, 19, 20] Inspection aboard USN Charles Drew (T-AKE-10) conducted during ship availability at Vigor Shipyard, Portland, OR, April 2018.

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References:
[1] "*Composite Intake and Exhaust Louvers for Marine Applications*", *The 4th International Conference on Marine Technology, May 2001, The Technical University of Szczecin, Poland.* A. Macander, S. Han, D. Johnson.

[2] Based on labor rate of $74/hr and work scope estimate. Average cost of pre-planned work scope vs. unscheduled work order.

[3] Based on labor rate of $74/hr and work scope estimate. Composite louver cost in 2018.

David Taylor is Vice President at CECO Peerless (CAGE Code 46219: Peerless Mfg. Co.) and is responsible for sales and product development of the company's filtration business serving the Marine, Oil & Gas, and Nuclear Power sectors. Prior to his current role, he oversaw the development of the company's China operations and managed its business throughout Asia. Building upon an initial role in Peerless' R&D group, the author has held various positions in engineering, product development, manufacturing and business management. Mr. Taylor previously presented a technical paper on high-speed marine air intake filtration systems at the ASME-IGTI conference in Amsterdam. He received his BSME from Southern Methodist University in Dallas, Texas.