

Getting ducts in a row with corrosion-resistant FRP

Composites are effective in providing corrosion protection in significant volume for industrial processing systems worldwide. Vicki P. McConnell examines corrosion market influences and system ductwork applications.

There's not much call for advanced exterior aesthetics in corrosion-resistant reinforced plastics used for pipelines, storage tanks, flue gas desulphurisation (FGD) stacks, or exhaust and cooling towers. Maybe that's because these systems are used primarily by the chemical, water treatment, pulp and

paper, mineral recovery and mining, food processing, electronics, semiconductor and power industries, as well as in bridge and highway infrastructure. What surface and interlaminar content in these fibre reinforced plastic (FRP) components must endure is a tough array of corrosion agents – from extreme acids and abrasive

slurries, to cyanide, lead elements, ozone, raw sewage and more.

The real beauty of FRP for corrosion protection is low cost, long life, low maintenance materials from which components can be fabricated to handle these aggressive environments. This may be in new build systems or refurbishment and replacement of corrosion-damaged metals or other materials. The corrosion-fighting FRP components can be impressive, such as 37 m (120 ft) diameter jet bubble reactor shells, 305 m (1000 ft) tall scrubber stack liners or 190 000 litre (50 000 gallon) underground petroleum storage tanks. Complementing almost all these industrial systems is FRP ductwork that must endure the same conditions as the primary system elements, and deliver comparable benefits.

Corrosion resistant market

Key factors affecting the market globally for corrosion-resistant FRP products include growing demand for power and water, fluctuation in international economies, changes in government regulations, and the price of competing materials. Consider the following:

- The 2010 estimated global cost of metallic corrosion: US\$15 trillion (€10 trillion)



That's no Space Shuttle exhaust, that's large spool FRP ductwork made with Ashland's HETRON epoxy vinyl ester resin and glass for a North Dakota FGD system. Ershigs filament wound the 21-30 ft diameter components.

equating with 3.1% of gross national product. Of this, the US cost is approximately \$465 billion (€322 billion) (Det Norske Veritas).

- Worldwide revenue for 2011 of total FRP components used in the corrosion-market replacement segment: \$691 million (€478 million) (McIlvaine Co, 2010).
- Demand on world water resources by 2050: more than 5000 km³/year. By 2015, spending of over \$80 billion (€55 billion) is expected in the US and Canada to upgrade and expand municipal wastewater treatment facilities (World Water Council and University of Michigan, 2000).
- Demand globally for electricity by 2030: double today's rate, to 2.7 million MW, resulting in a possible \$10 billion (€6.9 billion) increase in the market for FGD systems. FRP component replacement revenues in these systems could double to \$400 million (€277 million) by 2020 (*FGD World Markets*, McIlvaine Co, June 2011).
- Estimated growth by 2015 in the market for FRP storage tanks in North America: \$712 million (€493 million), with polyester resin expected to be the dominant choice for composites (*Opportunities for FRP Tanks in North America 2010-2015*, Lucintel, 2010). Estimated annual cost of corrosion in the 8.5 million tanks in the US: \$7 billion (€4.8 billion) (Owens Corning).
- Addition of pipelines for crude oil, petroleum product and natural gas over the next two years: could reach 95 000 km (59 030 miles) in North America, Asia Pacific, Middle East and Africa (*Global Planned Oil and Gas Pipelines Industry to 2013*, reportlinker.com).
- World consumption of copper in the next 30 years: comparable to consumption over the last 10 000 years (*Ashland Corrosion Chronicle*, Spring 2011).

Where FRP fits in

Suppliers of resin and glass and FRP component fabricators offer their perspectives in assessing the place FRP holds within the larger corrosion resistance market.

Thomas Johnson, Corrosion Industry Manager for Composite Polymers/Performance Materials at Ashland Inc, Dublin,



Minerals processing is a growth area for FRP. At the sulphuric acid plant that is part of Votorantim Metals' zinc refinery in Cajamarquilla, Peru, FRP scrubbers, tanks, piping and ductwork are made using Ashland's Derakane epoxy vinyl ester resins.

Ohio, USA, states: "The corrosion market is project driven. As such, recessionary economic effects may manifest later but last longer than with other composite markets. Once the capital markets tighten, project monies become scarce and future projects are not funded."

The corrosion market is project driven.

Regulatory upheaval has also taken its toll. In 2007, the Clean Air Interstate Rule (CAIR) affecting US coal-burning power plant projects was vacated. Chaun Trenary, Vice President of Marketing and Sales for Houston-based Denali Inc comments that "the FRP industry that served the FGD industry from 2005 to 2009 experienced growth as a result of CAIR. However, after the vacatur and with a delay in the proposed Transport Rule by the US Environmental Protection Agency (EPA), the demand side dwindled due to this regulatory uncertainty. As such, the previous growth rate hasn't been sustainable in 2010 and 2011."

Johnson also points out that competing materials prices have increased, compared to the price for FRP in industrial components.

"Currently, stainless steel is running about 200-300% the price of FRP, and Hastelloy C-276 is up to six times the cost of FRP, based on epoxy vinyl ester resins. Moreover, the price of corrosion resistant alloys is much more volatile than FRP."

Trenary adds that "even though competing metals prices have increased, we are also seeing cost increases in FRP raw materials and excess FRP industry supply-side capacity resulting from the previously robust market. The composites industry will likely struggle to improve pricing and margin levels until the excess capacity is consumed and end-users are willing to accept raw material price increases. This said, based on my knowledge of the FRP corrosion industry, US growth is on a hopeful horizon but one that will come primarily after full economic recovery and regulatory certainty relative to EPA rules."

Positive signs

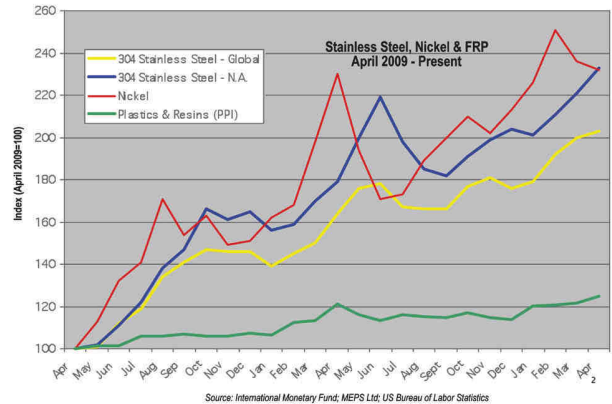
Kevin McDonald, USCA and EMEA General Manager of Reinforcements for PPG Fiber Glass, Pittsburgh, Pennsylvania, USA, is of the opinion that "the composites industry has always been responsive to market changes with the ability to redefine itself based on market and economic conditions.

CONSTRUCTION MATERIAL COST COMPARISON

Construction Material	Cost*	Cost Ratio
Shop Fabricated FRP	\$50 / Sq. Ft	1.00
Field Fabricated FRP	\$70 / Sq. Ft	1.40
2205 stainless steel 3/8 in plate	\$225 / Sq. Ft	4.50
C-276 clad carbon steel	\$330 / Sq. Ft	6.60

*Cost obtained from 2011 Ashland North American survey

Stainless Steel & Nickel Prices vs FRP



Source: International Monetary Fund, MEPS Ltd, US Bureau of Labor Statistics

Competitive materials to FRP for corrosion protection are currently showing significantly higher costs, with recent spikes in stainless steel and nickel while composites have remained relatively price-stable. (Source: Ashland.)

Also, the forces that affect corrosion applications in the US and Canada may have little or no affect on the markets in Europe and Asia. While the US is recovering from recession, markets in China and the Middle East are rapidly expanding. If one looks at specific applications such as pipe, the penetration of composites is very low – by some estimates only 3% – so that despite overall negative market or economic conditions, growth is still likely.”

PPG’s Richard Heilman, Global Business Director, Direct Draw, elucidates.

“We currently place approximately 20-25% of our global direct draw volume into the corrosion market, and expect growth of more than 6% annually for at least the next five years.”

Ashland’s Johnson cites a growing sub-market for corrosion protection.

“Mining and mineral processing are on a global upswing. Copper and nickel prices are high. Both of these metals use acid extraction processes that are a perfect fit for epoxy vinyl ester resin-based FRP

equipment. So too is the mineral extraction process used to harvest rare earth minerals from raw ore. Very large projects in Newfoundland, Mexico and in California are procuring hundreds of processing vessels and tanks, plus miles of abrasion-resistant composite piping. All of these projects are specifying Ashland’s Derakane epoxy vinyl ester resins in the construction of glass-reinforced processing equipment.”

The corrosive environment of ethanol processing in Brazil is benefiting from FRP. Rick Pauer, Product Manager for Epovia Vinyl Ester and Specialty Resins, Cray Valley/Cook Composites and Polymers (CCP), based in North Kansas City, Missouri, USA, reports that Epovia RF5101 resin has been formulated to operate within the 90-100°C (194-212°F) temperatures for ethanol processing, “which can cause chemical attack even in conventional bisphenol A and novalac epoxy vinyl esters. We’ve hybridised vinyl ester and urethane in RF5101, which helps protect the ester linkages from this chemical attack by the small ethanol organic molecule. The resin also demonstrates 140°C (284°F) HDT and improved toughness.”

CCP’s 2011 year-to-date sales of Epovia resins in the US have grown 23% over last year. Some 78% of this growth has been in chemically resistant and structural applications fabricated via infusion, and another 18% in protective chemical



For a New Jersey odour control system, FRP ductwork built by ECS using AOC Vipel vinyl ester resin and Owens Corning glass helps move 3400 m³ per minute of air and saved the end user 60% in component costs compared to stainless steel equipment.

resistant coatings. Two Epovia vinyl ester infusion resins – RF1001L-00 in glass fibre structural applications and its rubberised partner, KF3202L-00 for both glass and carbon fibre applications – have generated significant interest from the corrosion sector by showing improved performance over infused epoxy resins.

In Cray Valley's Korea operations, Pauer says "we're seeing a sales increase this year of approximately 13% over 2010, with much of this growth in FRP vinyl ester ductwork and chemical resistance applications due to expansions by large electronics companies such as Samsung, LG and Hynix. Growth can also be attributed to Korean FGD applications."

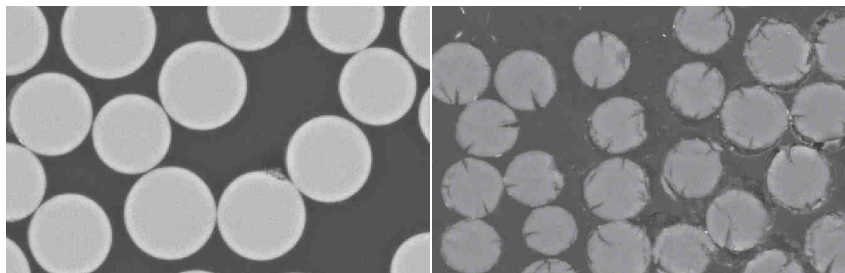
Another potential growth area is identified by Ben Bogner, Corrosion Specialist for resin supplier AOC of Collierville, Tennessee, USA.

"Composites continue to grow in cooling water equipment because the material is longer lasting and more environmentally friendly than wood in these applications."

The company's Vipel polyester and vinyl ester resins are competing in corrosion resistance applications such as high strength HVAC [heating, ventilation and air conditioning] ductwork, sewage pipe and wastewater ductwork, water filtration plant storage tanks, and in large diameter pipe for cooling water recirculation, desalination and gasification systems.

Schaffhausen, Switzerland, headquartered DSM Composite Resins supplies its Atlac vinyl ester resin portfolio to the corrosion resistant equipment market, particularly in FGD and water system applications. Wilfrid Gambade, Business Director of Composites Resins Europe, says performance in the corrosion market in the last two years has been in recovery mode from global economic downturn.

"That said, we experienced considerable regional variations, with high growth economies remaining buoyant and markets in northern Europe bouncing back, arguably stronger than those in southern Europe. We



Scanning electron microscopy photographs show comparative response of glass fibres to 10% sulphuric acid after three months time. Advantex E-CR glass on the left show no degradation, while traditional E-glass on the right shows definite negative effects from the acid. (Pictures courtesy of Owens Corning.)

are also experiencing growth in desalination plants and food processing applications. Our Atlac resins for tanks, pipes and relining continue to generate traction in corrosion applications, and we will roll out additional products compliant with good manufacturing practices (GMP) standards through this year. "

In April DSM launched Atlac 5200 FC vinyl ester, which is fully compliant with European regulations (EU 1935/2004, European Food Contact Directive 2002/72/EC) and GMP (EU 2023/2006) relative to FRP components used in direct contact with food or drinking water. Atlac 5200 FC also has initial approvals from the UK BS6920/WRAS and the French ACS.

"Components based on Atlac 5200 FC resins outperform components made from steel in terms of corrosion and chemical resistance, increasing component life time and therefore reducing cost of ownership," Gambade observes.

Guide to glass selection

Manufacturing its trademarked boron-free Advantex corrosion-resistant E-CR glass, Owens Corning of Toledo, Ohio, USA, estimates about 30% of its total glass fibre production is supplied to corrosion submarkets. These are identified as industrial factories (chemical, food, and more); roads and bridges; energy exploration; transportation; power plants and distribution; refineries; potable water; and sewage operations. Advantex E-CR glass products were initially manufactured specifically to resist acid and alkali exposure, and as an E-CR glass

reinforcement that meets ASTM D578, ISO 2078, and DIN 1259-1 standards.

Selecting the right glass fibre is a key factor in corrosion resistance and can lower the risk of failure.

In March, Owens Corning published its *Glass Fibre Reinforcement Chemical Resistance Guide*.

"We believe selecting the right glass fibre is a key factor in corrosion resistance and can lower the risk of failure," explains Ashish Diwanji, Vice President of Innovation for the Composite Solutions Business. "After spending a lot of time with end-users, fabricators and engineers, we learned that some did not have success with FRP in part because they did not specify a glass type. We created the guide to address this knowledge gap regarding the important role that glass fibre plays in the performance of FRP in corrosive environments. We believe its contents particularly help explain the properties of glass in field performance, which is key to making optimum materials selection decisions and to building composite structures with longer useful life."

The guide contains test results of the effect of various chemicals on different glass fibre types, examples of glass fibre specifications, and information about



Ductwork can encompass transition and extension joints, dampers, flanges, and hoods that provide complex geometries, sound dampening, and weight reduction. (Picture courtesy of ECS.)

industry standards for glass fibre compositions used in FRP applications.

Ductwork challenges

In most industrial processing systems, ductwork connects primary system components in order to move or direct air or vapour from processing operations. Besides exposure to corrosive agents and operating temperatures, ductwork often has to accommodate custom geometries to go up, over and around existing architecture or other structure.

To get a handle on distinguishing ductwork from piping, *Reinforced Plastics* asked Jeff Jones, CEO of Engineered Composite Systems (ECS) in Belton, Texas, USA, for his definition.

"Piping is typically designed for internal pressure from liquids, and can be a commoditised product. Ductwork is quite a different

animal, in that it typically operates as a negative pressure application since liquid is usually not conveyed through it. We also find that design requirements of ductwork under negative pressure are actually more stringent than for pipe with internal positive pressure."

In business since 1986, ECS fabricates some 25% of total its FRP components annually in ductwork, which Jones indicates represents around \$5 million in revenue for 2010.

"Every ductwork system we fabricate – which can include transition, elbow, air intake/exhaust, stack and control damper components – utilises a combination of round or square and straight geometry created on one of our computerised filament winders. We also manufacture all fittings by chopper gun or hand lay-up. One of our strengths is the ability to supply a complete ductwork package, which guarantees materials, design and fabrication continuity between components, along with cost savings."

In 2010, ECS worked on a large municipal biofilter odour control system project for the Camden County Municipal Authority in Camden, New Jersey. The system includes two stacks and all ductwork, and was designed to move 3400 m³ (120 000 ft³) per minute of air. ECS offered a rebid on the ductwork package for the system that had been originally slated for manufacture from 304 stainless steel.

According to Jones: "We were able to save Camden County about 60% on the

ductwork components and installation with less infrastructure required than would have been needed to support the stainless steel equipment."

Using composites, the two stacks were also designed to be free standing.

"I consider these stacks a form of ductwork," Jones says, "since they convey air."

Fabrication of the 250-plus FRP components, made from AOC's Viprel K022 bisphenol A epoxy vinyl ester resin and continuous glass from Owens Corning, took six weeks. In addition to corrosion resistant performance in the highly acidic operating environment of the odour control system, the resin formulation maximised exotherm control to accommodate laminate thickness to beyond 1 inch. ASTM E-84 Class 1 flame spread and smoke requirements are also met with this material, though no smoke limit was necessary for the parts. Jones estimates the FRP material value alone was \$1 million.

He adds that: "Our relationship with AOC is important beyond words, and has been crucial in achieving efficient, cost-competitive operations at ECS and increasing the quality of our final products."

ECS can fabricate FRP components from 5 cm to 3.6 m (2-144 inches) in diameter with its two dual-stage filament winders, helical tank winder, four chopper stations and five vacuum infusion stations at the 96 000 ft² facility in Belton. Jones reports that the company also makes conductive liners for ductwork used to convey combustible gases.

"Dissipation of static electricity is crucial in such components so we typically use a carbon veil and mix graphite powder with the liner resin," Jones relates.

ECS is currently building ductwork to 42-inch diameter for a US textile facility that will use 350 000 lbs of FRP.

"Part of the package will also be several hoods that will be 12 ft in diameter and average 50 ft in length. We are saving the customer a substantial amount of weight



Success story for FRP: Ashland's glass-reinforced resins offer corrosion protection in the scrubber and ductwork equipment that is part of one of the largest jet bubbling reactors in North America, installed at a 950 MW power plant.

by designing the hoods with FRP skins over honeycomb core."

Conveyance complexity

Ershigs' Trenary considers ductwork design as complex as that for primary system components.

"Every FRP component in a system needs to be designed correctly, and we consider ductwork a primary component in an industrial system in which critical fumes are conveyed."

The speciality FRP contractor formed a successful team on an FGD system project with end-user Minnkota Power Cooperative Inc and installation contractor Pullman Power in Center, North Dakota, USA. FRP components were built on time by the team for a chimney liner and ductwork installed last year at Minnkota Power's Milton R. Young station.

According to Trenary, the design temperature for the FRP components is ~145°F, with upset temperature at 200°F. Some 1400 linear ft of 21-30 ft diameter components were fabricated from Ashland's HETRON FR992sb epoxy vinyl ester with an MEKP cure system for corrosion resistance that meets ASTM E-84 flame spread requirements. He adds that Ershigs applied an inch-thick, 2 lb density urethane foam during the filament winding process as insulation to the exterior FRP ductwork. Structural reinforcement in both the chimney liner and ductwork is provided through E-glass continuous strand, chopped strand, unidirectional and woven roving. For the corrosion liner, Ershigs used carbon veil, C-glass veil and chopped strand E-glass.

What made the ductwork fabrication unique, Trenary says, was that his company manufactured all the components onsite, "where the external temperature reached -37°F and sometimes -57°F with wind-chill. So we had to minimise the total amount of outdoor laminating and deal with unique challenges in transport, rigging and lifting of these components."

Further, the new ductwork had to be constructed around both existing scrubber elevations and significant elevation changes



Replacing metals, FRP materials can extend the lifetime of infrastructure such as bridges, in new builds and refurbishment. (Picture courtesy of Owens Corning.)

from the scrubber outlet to the chimney liner inlet.

"Two scrubber outlet lines were transitioned into one chimney liner inlet on the outside of the stack," Trenary explains. "Typical configuration on other projects would have a chimney liner for each outlet duct, or multiple breaching inlets into one chimney liner. The FRP transition section increased the complexity of the design."

Almost all the ductwork was preassembled in maximum lifting dimensions at grade after fabrication onsite. Terminating ends for duct sections were mostly flanged or fitted with expansion joints.

"Careful planning between Pullman and Ershigs allowed for the lifting of extremely large duct spools (one spool was ~88 ft long by ~40 ft wide) and the elimination of external FRP joint laminating at the install elevation," Trenary says.

Critical FR properties

"Duct components bring up the double challenge of in-process chemical vapours and fire retardance (FR)," CCP's Pauer notes.

Cray Valley-Korea has launched Epovia RF2000SEHA, the supplier's most fire

resistant resin to date for ductwork.

This formulation eliminates antimony or aluminium trihydrate (ATH) fillers, and registers a LOI rating of 33-34.

"LOI stands for 'limiting oxygen index' or the minimum amount of oxygen needed to ignite a composite sample," Pauer explains. "Higher LOI means it will take longer for an FRP component to ignite in a fire. Major semiconductor systems now being planned will use Epovia RF2000SEHA to achieve maximum FR performance in glass-reinforced composite laminates, including ductwork."

According to AOC's Bogner: "Ductwork continues to grow in odour control systems at wastewater treatment plants. It can easily handle hydrogen sulphide (H₂S) vapours that can quickly attack standard steel ducts."

Scott Lane, AOC Corrosion Product Leader, explains that "current resins for FRP duct components are selected primarily on a cost-performance basis, with corrosion and fire resistance being the primary requirements. Viprel K022-AAA-00 fire retardant vinyl ester meets the need in applications requiring a combination of fire, heat, and corrosion resistance. In cases where low smoke density is the primary driver, Firepel K133 modified polyester (which utilizes ATH fillers) is selected



The chemistry of corrosion worldwide can affect thousands of miles of metal piping for water and petroleum products. (Picture courtesy of Owens Corning.)

for its combination of low cost and low smoke properties.”

“Design-wise, if you look at air handling ductwork for HVAC systems, FR properties are the key,” adds Ashland’s Johnson. “Ductwork for corrosive gases requires design to Class I ASTM E-84 fire resistance as well as top notch corrosion resistance. Class I fire resistant epoxy vinyl ester resins like Derakane 510A-40 and Hetron FR 998/35 fit for these applications.”

Ashland has recently introduced Derakane 510B-400 epoxy vinyl ester resin, with an HDT value of 227°F (108°C), and which eliminates antimony in FRP laminate so that inspection for imperfections in Class 1 E-84 components is easier. Where even higher temperature performance is desired, Ashland offers Hetron FR 998, which can also deliver Class I E-84 fire resistant laminates as well as an HDT value of 275°F (135°C). Outside of North America, high temperature laminates are typically designed with Derakane 455-400 which provides similar performance.

“We continue to push the temperature performance envelope for ductwork environments,” notes Johnson. “Part of the challenge in designing resins for high temperature

service is keeping the robust corrosion resistance and mechanical properties that epoxy vinyl esters are known for, while improving the Tg or glass transition temperature. New laboratory data is under development for high temperature laminates based on Derakane 470 epoxy vinyl ester resin and Derakane 470HT epoxy vinyl ester.”

Changing materials mindset

There’s another important factor influencing the growth economics of FRP in corrosion protection, known commonly as “metal mentality,” or the “if it ain’t steel, it ain’t real” attitude. This is demonstrated by project engineers and material specifiers involved in building industrial systems who are not knowledgeable about the properties and effective use of composites as an alternative to metals. This is ironic considering the current surge in demand for FRP components to answer metal processing equipment needs.

“The ‘education gap’ for engineers is ever present when it comes to composites,” states CCP’s Pauer. “That said, as the use of composites goes up in large markets such as in aerospace, oil and wind energy, and of course in corrosion resistant applications, this gap is getting smaller. We also fully expect a resurgence of composite usage to occur in automotive, as has happened in aerospace, due to the new 34.1 mpg (14.5 km/l) CAFE requirements upcoming

by 2016. If lighter weight materials win over smaller vehicle size, engineers will need to understand and be able to design in composites, as they do in metals today.”

Both Ashland and AOC devote resources to bring the gospel of FRP to the corrosion design engineering community. This includes global participation in programmes with the National Association of Corrosion Engineers (NACE) to demonstrate best practices in corrosion control with polymers. Recently Ashland organised corrosion seminars, Managing Corrosion With FRP and FRP in Mineral Processing. AOC’s team of corrosion specialists conducted NACE FRP Corrosion Education Sessions on the topic of Inspection and Repair of FRP Corrosion Resistant Equipment.

Ershigs’ Trenary believes “the FRP industry will likely always be in the position where we need to educate engineers who have more experience and comfort level with metals and concrete.”

It does seem, however, that based on the market factors examined here, FRP is gaining more ground as a ‘go to’ materials option. Especially as all engineers involved in fighting the battle of corrosion must get their ducts in a row and come to terms with the reality stated by the World Corrosion Organisation: “Corrosion knows no national boundaries.” ■

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