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Composites for Chemical Resistance and Infrastructure Applications

ABSTRACT

Composites are continuing to show utility in applications and systems that demand corrosion-resistant service as well as applications in infrastructure projects. This paper documents several applications where composites have produced structures that have better longevity and lower maintenance costs than the conventional products they replaced. The reasons for the continued growth of fiber-reinforced polymer (FRP) composites in infrastructure and corrosion-resistant applications are discussed.

INTRODUCTION

Unsaturated polyester and vinyl ester resin composites have proven successful in minimizing the effects of corrosion and chemical attack. Besides providing chemical resistance, these composites can be designed take high structural loads making them ideally suited for infrastructure. These composites perform well in applications requiring resistance to corrosion in damp soil conditions, acids, oxidizing agents, metal salts, reducing gases and sulfur gases. Quality infrastructure composite parts such as scrubbers, underground gasoline storage tanks and sewer liners have been successful in service for up to 40 years or more.

Corrosion-resistant resins include bisphenol-A epoxy vinyl esters, elastomeric bisphenol-A epoxy vinyl ester, epoxy novolac vinyl esters and chlorendic polyesters. Several of these resins have been developed since the 1960s and have undergone evolutionary enhancements in base resin and formulation chemistry to improve their process and end-use performance characteristics. Since it was independently established for a joint venture in 1994, AOC has been adding and improving on these advanced corrosion-resistant resin technologies. As a result, the AOC product line encompasses a greater capacity for withstanding harsher environments that the original product lines of AOC's two founding companies.

This paper will discuss a variety of successful applications of FRP composites based on corrosion-resistant resins. The discussion will concentrate on three specific application areas - corrosion-resistant equipment, underground storage tanks and bridge structures. Case histories will be used to show examples of how composites provide a longer life cycle than alternative materials such as metals, wood and concrete.

CHEMICAL-RESISTANT APPLICATIONS

Because of the demands of industry, a wide variety of applications has arisen that demand the use of chemical-resistant resins. By choosing from a range of resin chemistries, the specifying engineer can achieve the most cost-effective composite solution. In addition to resisting moisture and corrosive attack, the optimum cost-performance resin can address elevated temperature service, thermal cycling, structural properties, fatigue-stress, flame retardance, low smoke and other design and engineering requirements.

Market sectors that served by chemical-resistant composites include water and wastewater treatment, pulp and paper, food processing, chemical processing, mineral recovery and mining, microprocessor manufacturing, pharmaceutical production and power generation. Applications include piping, fittings, connectors, storage and holding tanks, scrubbers, weirs, baffles, flumes, domes, grating, ladders, walkways, enclosures, buildings and panels.

WATER TREATMENT

One recent example of chemical-resistant composite is a sophisticated stripper system that is part of a water treatment facility in Baldwin Park, CA, USA (Figure 1). 1,1-DCE, 1,2-DCE benzene, toluene and other solvents in the region's water supplies are attributed to waste discarded by aerospace companies before more stringent environmental standards were established. Funding for the clean-up is provided by the U.S. Environmental Protection Agency's "Superfund" for reclaiming sites affected by hazardous waste. The San Gabriel Valley Water District (SGVWD) selected U.S. Filter/Westates Carbon, of Santa Fe Springs, CA, to supply the equipment for the stage 1 treatment system for the solvent-contaminated water. U.S. Filter/Westates Carbon in turn came to Air Chem Systems, Huntington Beach, CA, to supply all the equipment prior to installation of carbon adsorption units.

Air Chem Systems provided a stripper system that uses four composite towers, composite fans with sound enclosures, heaters and interconnecting duct dampers and stacks. Each tower is approximately 9.1 meters tall and 1 meter in diameter (30 feet by 3 feet). The resin used to manufacture the towers and other composite components is Vipel® K022-C, a flame-retardant bisphenol A epoxy vinyl ester from AOC. Because of the resin's excellent resistance to solvents, it is also used for the ductwork, stacks, and fan blades of the water cleansing system. In addition to providing corrosion resistance, the resin meets critical specifications calling for a Class 1 flame and smoke rating per ASTM E 84. The rating is achieved with 1.5% antimony trioxide synergist. The composite towers and ancillary components have a longer projected engineering life than aluminum, which SGVWD was previously specifying for this type of application. Because composite is also a much lower thermal conductor than aluminum, composite use makes it is easier to control the process.

The treatment process starts when 28,390 liters (7,500 gallons) of water per minute are recovered from six wells. Water coming into the main header is split into four streams, one for each of the four scrubbers. As the influent water is injected into the towers, a high speed, high capacity fan pulls fresh filtered air through the towers to strip out the solvents from the influent water. The contaminated fumes are then pushed into and through the carbon filters supplied by US Filter/Westates Carbon. The solvent fumes are adsorbed by the carbon units and remaining contaminates in the effluent water are removed in a process that involves hydrogen peroxide and UV light. At the end of the system is potable water with no detectable amounts of contamination.

FOOD PROCESSING

The Abbott Laboratories' Ross Products Division plant in Casa Grande, AZ, USA, uses a unique composite rinse tank in a nutritional product manufacturing process. Composite is specified so that the complete vessel would be made of non-corrosive materials. There would be no potential of contamination by rust as would be the case in coated mild steel vessels. Compared to stainless steel, the composite vessel costs less while still complying with U.S. Food and Drug Administration regulation 1CFR177.2420. With a 1.3 million liter (350,000-gallon) capacity, the vessel is believed to be the largest composite tank ever built for U.S. FDA-approved food contact purposes.

The tank also meets strength requirements for seismic zone 2A construction, conforms to American Society of Mechanical Engineers (ASME) RTP-1 and American Water Work Association (AWWA) D120-02 standards for composites use with potable water and processed food, and provides continuous corrosion resistance while being subjected to three daily rinse cycles. In service, the tank handles more than 3.8 million liters (1,000,000 gallons) of potable water each day. Another critical design requirement for the tank was that it could be manufactured in sections that allow for oblation, a procedure of compressing cylindrical wall sections to give them a narrower footprint for shipping (Figure 2).

Plasticos Industriales de Tampico, S.A. (PITSA), Tampico, Mexico, fabricated the tank using Vipel® F737 isophthalic polyester, which performs to all the required codes and standards, especially FDA food contact. Vipel F737 resin's high tensile elongation of 4% was especially beneficial for the critical oblation procedure that lowered the cost of shipping over the 1,500 miles between the PITSA and Abbott Laboratory's facilities.

Composite design specialist Al Newberry of FEMech Engineering used Mathcad software to design the fiberglass-reinforced tank. The vessel's top and bottom designs were each divided into three open-molded pieces. The cylinder was divided into six filament-wound sectional "rings." Molded sections were post-cured with dry heat at 93°C (200°F) for two hours. Then, using power-pulls, chains and come-alongs, each ring was meticulously oblated from a round to a narrow racetrack profile for easier highway shipping. At the installation site, oblation of the ring sections was reversed. The rings and trisections for the tank's top and bottom were assembled and bonded together using fiberglass/resin composite lamination (Figure 3). The corrosion liner on the interior surface was finished off with C-veil in an FDA-approved vinyl ester. The tank is 10.03 meters in diameter by 16.85 meters high (32 feet, 10 inches by 55 feet, 4 inches). Wall thickness tapers from 53.6 millimeters (2.11 inches) near the bottom knuckle to 9.9 millimeters (0.39-inches) at the top. The thickness at the finished bottom knuckle is 108 millimeters (4.25 inches), including the laminate used to bond the knuckle to the wall.

After complete assembly, the vessel was steam-heated at 71° to 82°C (160º to 180ºF) for 16 hours to effect final cure and extract monomer. The composite structure was hydrotested to ensure its integrity, and stored water samples were tested to ensure there were no unwanted contaminants. Having passed both tests, the tank was put into service.

UNDERGROUND STORAGE TANKS: BACKGROUND

The needed for composite underground storage tanks came after steel underground storage tanks had been in service for over 40 years. The leaks caused by soil corrosion after years of service grew unacceptable because of the economic impact of fuel loss and the environmental impact of contaminated drinking water supplies. In the early 1960s, composite tanks based on isophthalic acid polyesters were starting to be installed in North America. There early growth was slow because users were reluctant to acceptant an initially higher cost tank. Once the superior performance of composite was demonstrated, engineers understood that the life-cycle cost of a composite tank was dramatically greater and its acceptance grew rapidly. Environmental requirements for safe, leak-free life tank performance have accelerated this growth. Today in North America, over 95% of new tank installations are all-composite tanks or composite-overwrapped steel tanks.

UNDERGROUND STORAGE TANKS: STANDARDS

Most underground storage tanks are covered by Underwriters Laboratories (UL®) listings. Tank manufacturers submit to a series of fuel resistance and physical property tests by UL inspectors who certify (UL calls it a listing) that the tanks can use the UL label. The UL standard used for underground fuel storage tanks is UL 1316. The testing is designed so the buyers of the tanks can have confidence they are getting a safe, quality built tanks that will provide years of trouble free service. Compliance with quality and performance standards also provides engineers with a measure of assurance that they are specifying a product that will perform as expected. When engineers learn of substandard products, their acceptance of composites declines and composites growth is negatively impacted.

The benefit of standards is emphasized in the performance of "UL-1," the very first composite underground fuel storage tank to be UL-listed. The tank was fabricated with an AOC isopolyester then buried under a service station in Schaumberg, IL, USA, in 1964. The tank was excavated in 1990 to accommodate new highway construction that overlapped the service station property (Figure 4). After an inspection and minor surface repair, engineers determined the tank was in good enough condition to return to service. The unit was buried again at another service station where the tank continues to resist internal and external corrosion (Figure 5).

A European Union underground tank standard was developed in the 1990s and finally approved in 1997. These standards are numbered EN 976-1, EN 976-2, EN 977 and EN 978 and were written under the direction of the European Committee for Standardization or CEN. These have only been used in Europe and do not have the long history of the UL standard. These EN standards, like the UL standards, are designed to provide the construction of safe and reliable underground storage tanks.

UNDERGROUND STORAGE TANKS: CURRENT STATUS IN ASIA PACIFIC

Underground storage tanks have been successfully used in several Asia Pacific countries. They have been used in

New Zealand, Australia, Australia, Japan and Singapore (Figure 6) for more than ten years. Composite underground tank installations are increasing in India, Malaysia and Korea; and the rapid growth consumer demand for automobiles in China is causing a parallel growth in demand for service stations with underground fuel storage tanks. Over the next ten years, the annual growth rate for composite underground fuel storage tanks in Asia Pacific is projected to grow at a rate exceeding 10 percent per year.

INFRASTRUCTURE

For civil and marine waterfront infrastructure, composites are specified for their high mechanical properties as well as their superior corrosion resistance that eliminates or significantly minimizes maintenance and replacement costs. Composites structures and products for infrastructure include bridges decks, bridge superstructures, bridge repair, concrete reinforcing bars ("rebar"), bridge and highway overlays, pipes for power station intake and output, sewer rehabilitation, utility poles and transmission towers, wind turbine blades, cooling towers, seawalls, piers and seismic-resistant systems for columns, beams and walls.

Key advantages of composites over traditional steel and concrete bridges are quicker and less costly installation, the capacity for an increased live life load, reduced maintenance costs and long-term durability. However, because the installed cost of a composite bridge is typically twice that of a bridge made with traditional materials, initial composites successes have occurred in "niche market" applications where composites advantages are more readily recognized. One such niche is the short-span "drop in" bridge, especially for rural areas where conventional construction usually requires detours that significantly add distance and time. A composite bridge can be factory built or assembled offsite, then installed in a matter of hours.

SHORT-SPAN BRIDGE

One of the first examples of a short-span composite bridge was a composite bridge installed in the autumn of 1996. That structure is still serving the people of Russell County, Kansas, USA. The bridge was load-tested immediately after its installation (Figure 7) and has been monitored by the Kansas State Department of Transportation. In almost yearly load tests, the bridge meets AASHTO standards for carrying an HS20 or 20 U.S. ton load (22 metric tons). The Russell County bridge is 7.1 meters long by 8.2 meters wide (23.25 feet by 27 feet).

This bridge uses a design that optimizes the ability to engineer FRP composites into an efficient structural system. The design is based on a composite construction that sandwiches a core with a sine wave cross section between two flat facing panels. The pattern is similar to the way cardboard uses corrugation to provide higher stiffness with less material. The difference with KSCI is that high strength engineered composites are used instead of paperboard.

KSCI manufactured the composite bridge components by hand laying resin-impregnated fiberglass materials in an open mold. The reinforcements are chopped strand mat for the sinusoidal core and a combination of chopped strand mat and bidirectional fabrics for the flat panels. The bridge wear surface is a polymer concrete mixture of thermoset resin and aggregate. Compared to conventional Portland cement concrete or asphalt surfaces, polymer concrete provides higher elongation, greater impact and abrasion resistance, and longer service life. For the Russell County demonstration project, KSCI used three different AOC resins: one for the core and face panels, another for bonding cores and face panels together, and the third for the polymer concrete.

Since the installation of the Russell County bridge, several bridge and bridge deck designs have been installed for composite vehicular and pedestrian bridges throughout North America and Europe.

CONCLUSIONS

Proven applications for composites in corrosion-resistant and infrastructure applications will provide a foundation for strong growth for similar uses in the Asia Pacific region. To eliminate economic losses due to leaking hydrocarbons and to better protect the environment, the use of composite underground fuel storage tanks will see a strong surge in growth. This growth will accompany the increase use of automobiles throughout the region. The use of composites for bridges and bridge structures and decks will grow because these products offer better longevity.

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BIOGRAPHICAL NOTE

Ben R. Bogner is a Market Specialist for AOC where he focuses on composites used in infrastructure and chemical resistant applications. He has over 25 years of experience developing composite materials with special emphasis in structural composites, composite processing and applications development. He is a Registered Professional Engineer in the United States and a Chartered Engineer in the United Kingdom. Mr. Bogner has authored seven patents and has presented more than 25 papers on composite materials and applications. AOC is the largest unsaturated polyester resin manufacturer in North America and one of the five largest in the world. The company manufactures polyester and vinyl ester resins for both open and closed mold processing of applications for a variety of industries, including but not limited to: transportation, marine, tub/shower, continuous panel, cast polymer, solid surface, pipes, tanks, corrosion-resistant equipment and consumer products.

Table I

Cast Casting Properties of Composite Resins

	Bis-A Vinyl Ester	Novolac Vinyl Ester	High Cross Link Bis A Vinyl Ester	Bisphenol-A Fumarate	Rigid Isophthalic Polyester	Flexible Iso Polyester	High X Link Iso Polyester
Tensile Strength, MPa	88	86	92	70	83	86	70
Tensile Modulus, MPa	3,034	3,655	3,172	3,034	3,793	3,379	3,517
Elongation,%	6.2	4	4.3	2.6	2.8	4	2.3
HDT°C	120	136	124	124	107	92	139
Barcol Hardness	39	40	42	40	43	39	51

Figure 1. Composites towers and ancillary equipment for scubbers at a water treatment facility in Baldwin Park, CA, USA.

Figure 2. Composite tank sections are oblated to reduce their footprint for shipping.

Figure 3. A composite rinse tank for processing nutritional products is installed.

Figure 4. UL-1, the first composite tank to earn a UL listing, is unearthed after more than 25 years of service.

Figure 5. UL-1 is buried for reuse and is still in service today.

Figure 6. In 1994, composite underground storage tanks are installed at Mobil service stations in Singapore.

Figure 7. A short-span composite bridge is load-tested shortly after its installation in 1994. The bridge is still in service today.