Reinforced Glass Fabric Epoxy Linings with Leak Detection for Storage Tanks

Here's a way to prevent leaks from storage tanks using linings that have their own leak detection systems.

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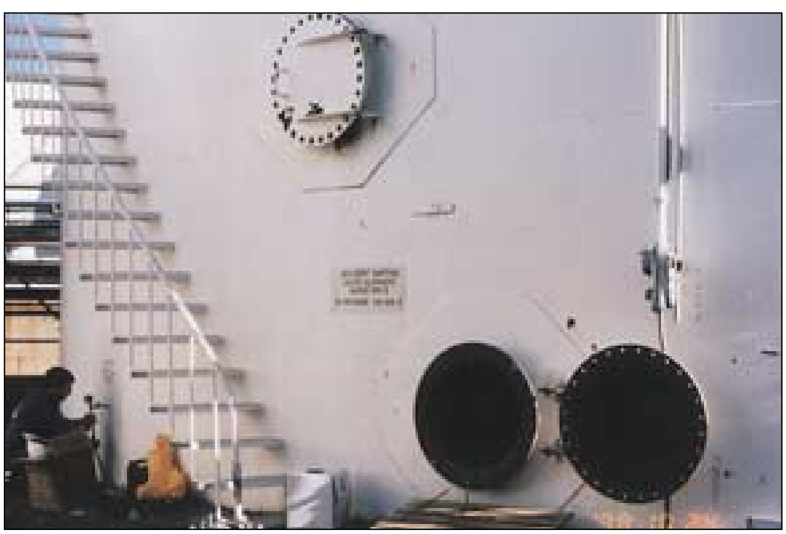
This article describes a relatively new approach to prevent the accidental leakage of cargo from both aboveground storage tanks (ASTs) and underground storage tanks (USTs).

According to the American Petroleum Institute (API), North America houses over 700,000 petroleum tanks.[1] Also, the U.S. Environmental Protection Agency (EPA) states there are 1.5 million ASTs.[2] Several government officials and state legislators stipulate that leak control monitoring systems are the only acceptable way to prevent tanks from leaking into the water table and navigable waters.

Leak detection system installed on AST
Courtesy of ICI Devoe Coatings Company



The cost of even small and undetected leaks is significant: up to 8,700 gallons/year/tank (33,060 liters/year/tank) for a one-gallon/hour (3.8-liter/hour) leak that is almost impossible to detect with traditionally available equipment.[3] The Resource Conservation and Recovery Act (RCRA), the Oil Pollution Act (OPA 90), and the Clean Water Act all have regulations on ASTs.[4] If industries do not become more proactive with spill and leak concerns, large fines may be levied and offenders may be closed down.

In the "EPA Liner Study: Report to Congress"[5], four liner systems were investigated with respect to enhancing secondary containment under and around ASTs and USTs: soil, synthetic geomembrane, coated concrete, and steel. The report recommends a broad voluntary program be developed for controlling and preventing contamination from ASTs.[6] Comprehensive AST regulations have been developed by the states of Florida, New York, Rhode Island, South Dakota, Virginia, and Alaska. Canada's G-55 Health and Safety Regulations govern the prevention of chemical waste, spillage, and leakage of potentially hazardous cargoes into the environment.

At a recent conference in Florida[3], these four liner systems and other ways of addressing secondary containment issues were brought to the foreground. In a state where 90% of the drinking water comes from the ground, the Florida DEP organized a technical advisory committee to investigate various secondary containment options. Confronted by impending new legislation and the requirement for the responsible operation of both ASTs and USTs in conjunction with secondary containment areas, owners and legislators alike are seeking secondary containment systems that are corrosion-resistant and integrated with continuous leak detection monitoring devices for the interstice.

U.S. regulatory agencies have advocated the double steel floor or "steel tank-in-tank" approach in place of lining tanks for retrofits or for new tanks. With retrofits, new steel floors are separated from old steel floors by concrete or sand and they themselves become a sacrificial anode. Ironically, once a double steel floor is installed, it still requires a liner (dielectric) to stop the galvanic action; otherwise, the new double bottom will corrode approximately 4 times faster than the old bottom.[7]

European countries such as Austria, England, Holland, Germany, Sweden, and Switzerland have embraced newer technologies that provide secondary containment within the tank structure. In Canada, too, recent research and field applications have shown that secondary containment inside the tank structure can be accomplished with a composite consisting of epoxy-impregnated three-dimensional (3-D) glass fabric that is bonded to tank floors. The system allows for permanent leak detection, secondary containment inside the primary structure itself, and a chemical-resistant corrosion barrier. This article will explain how the approach combines lining and leak detection technology in new or existing tanks and how this system can provide more comprehensive leak protection than either lined tanks or double-bottom storage tanks with leak detection equipment. The discussion also addresses how the system can be installed, and it gives an applicator's perspective on the system's strengths and limits.

Fig. 1 - End view of 3-D glass fabric design
Courtesy of Parabeam

Components of the Glass Fabric-Epoxy System

The 3-D Glass Fabric and Leak Detection System

Otherwise referred to as a glass yarn 3-D glass fabric, this material was developed in Europe in 1989 using a velvet weaving technique that dates back to 200 BC.[8] The 3-D glass fabric design consists of two identical plain fabric decks (upper and lower) woven integrally and mechanically together by means of vertical pile threads. Figure 1 shows the end view of the design.

The resulting fabric has a pre-set (interstitial) space between the two deck surfaces. Although the fabrics are available in various thicknesses ranging from 3 to 25 millimeter (0.12 to 1 in.), the 3-millimeter (0.12-inch) version is most commonly employed today. Providing a foundation for a higher shear and compression strength laminate, the 3-millimeter glass fabric is also

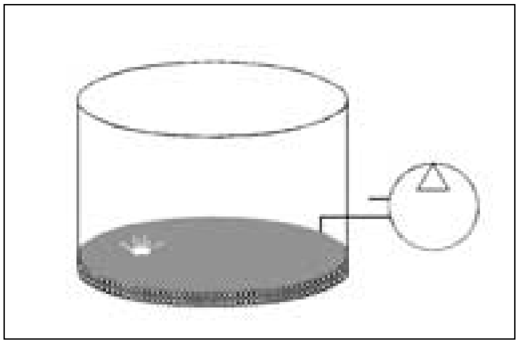


Fig. 2 - Schematic of leak detection system that monitors interstitial space
Figures 2-5 courtesy of ZCL Composites

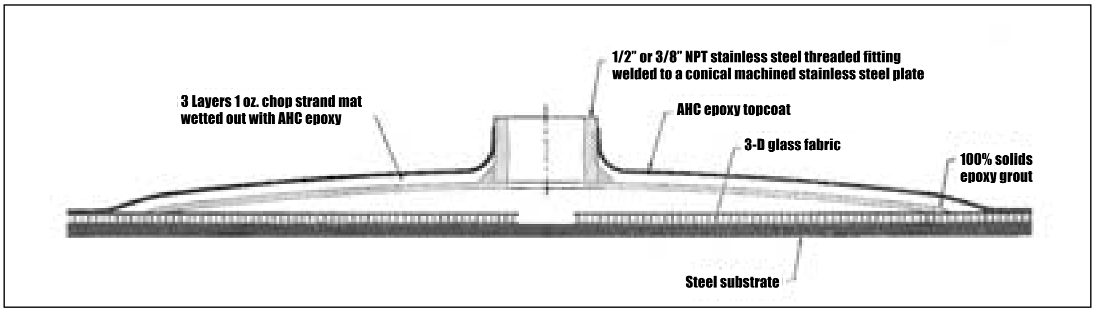


Fig. 3 - 'Butt' edges of installed glass fabric and seal with stitch-mat

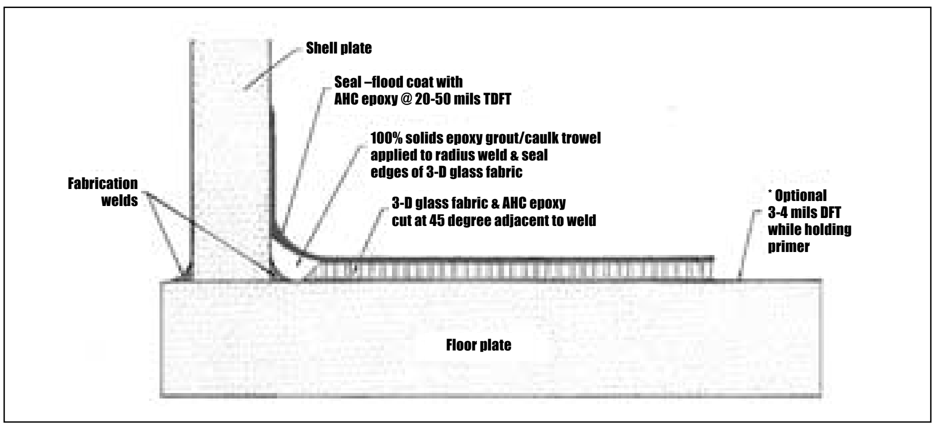


Fig. 4 - 3-D glass fabric AHC epoxy laminate at the critical zone of an AST

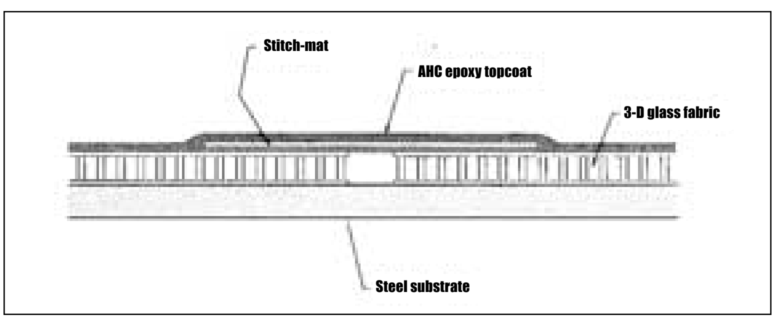


Fig. 5 - Interstitial space monitoring attachment

noted for its flexibility on critical deflection surfaces. In addition, the flexibility of the epoxy-impregnated 3-millimeter fabric ensures adhesion to itself and the substrate because it readily conforms to the contours of curved or irregular shapes. Both the amount of epoxy resin required and the fast impregnation caused by the capillary action of the vertical fibers in the 3-millimeter fabric help reduce material and labor costs. Each fabric deck weighs approximately 280 g/m^2. The weight is distributed equally over the warp (lengthwise) and weft (sideways) direction. The weight of the vertical pile threads that connect the upper and lower decks depends on the thickness of the fabric and the number of vertical piles per square meter.

Cycloaliphatic Amine-Cured Epoxy Technology

Internal tank linings such as two-component epoxies have provided over 40 years of success in combating corrosion. In the last decade, tremendous strides have been made in the development of epoxies based on Modified Mannich base (MMB) and modified cycloaliphatic amine converters (referred to here as advanced hybrid cycloaliphatic, or AHC, epoxies).

So what exactly are AHC epoxies? First, here's a little background on aromatic and cycloaliphatic converters that are used to cross-link epoxy resins. Aromatic amines (where an amine is attached to a benzene ring) offer excellent chemical resistance when combined with epoxy phenolic resins. However, they are very slow to react and normally need a catalyst or accelerator to speed up the reaction. In contrast, cycloaliphatic amines have rings similar to the benzene rings except that they are fully saturated. These cycloaliphatic amine converters have much better molecular mobility and better speed of reaction compared to aromatic amines. With the AHC, more than one converter is employed to cross-link an epoxy phenolic novolac resin, yielding a balanced speed of reaction and high cross-link density.

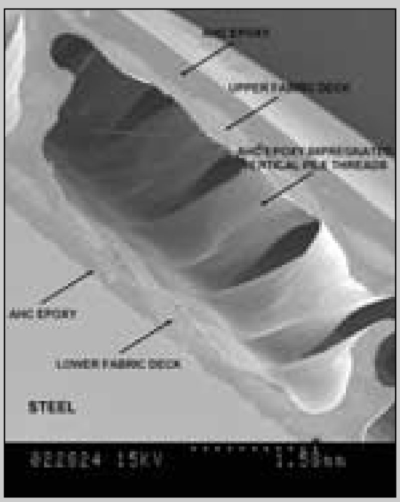


Fig. 1 - Photomicrograph of 3-D glass fabric/AHC epoxy laminate. Note how the vertical pile threads have been thoroughly wetted by the epoxy resin system.
Courtesy of Bacon Donaldson Engineers

Table 1
Chemical Resistance* of the Glass Fabric-AHC Laminate

Aromatic/high flash naphtha	Ethyl benzene
Aviation gasoline	Fuel oils—all type
Ballast water	Gasoline—leaded, unleaded and aviation
Bunker fuel	Gasoline—15% max. MTBE or TBA
Caustic solutions	Glycols and glycerols—all types
Condensates	Jet fuels—all types
Crude oil—all types	Paraffins
Cumene	Potassium chloride
Diesel fuel	Sodium chloride
Diethyl or dimethyl benzene	Toluene
Dipentenes—Turpentine	Xylene
Ethanol/gasoline blends (30% max. EtOH)	

**Some of the cargoes listed may operate between ambient temperature and 275 F (154 C).*

With the advent of modified cycloaliphatic technology, coatings are available with eight key properties:

- compatibility with 3-D glass fabrics,
- penetration,
- high degree of wet and dry adhesion,
- cure reaction without accelerators,
- rapid cure,
- self-priming,
- water and chemical resistance, and
- high temperature resistance.

Rapid cure AHC epoxy coatings are 100% solids by volume and, in the absence of glass fabrics (and depending upon service requirements), ultra-high thick-film applications can be spray applied in one coat, between 20 and 125 mils (0.6 to 3.8 mm) DFT without runs or sags and without compromising performance. They are designed for immersion in aggressive environments and services. Thus, any steel, concrete, or fiberglass tank lined with unreinforced AHC epoxies can be returned to service in as few as eight hours from the time of application. As with all coatings, the most important criterion for curing a coating is time-at-temperature.

All surfaces of the glass fabric have a silane sizing to provide compatibility and unimpeded wetting by a specially formulated epoxy system. During the wetting out process, the fabric has an inherent rebound, or spring resilience, which forces the upper deck to rise to a height dictated by the length of the vertical pile threads. These threads look like a multiple series of miniature I-beams.

The spring resilience and compressive strength of the 3-D glass fabric is derived from four factors:

- 500,000 vertical pile threads per sq m,
- capillary forces during and after impregnation with a resin system,

Table 2
Technical Data: 3-D Glass Fabric-AHC Epoxy Laminate

Fabric type		85136 (width =1500 mm [60 in.]) 87136 (width = 750 mm [30 in.])	
Roll quantity	87136	(m^2)	30
	85136	(m^2)	50
Laminate thickness		(mm)	3.3
Face thickness		(mm)	0.35
Core thickness		(mm)	2.6
Fabric weight		(g/m^2)	755
AHC epoxy weight		(g/m^2)	855
Laminate weight		(g/m^2)	1610
Glass type		E	
Yarn finish		silane	
Thermal conductivity	[λ]	W/m*K)	0.06
Thermal resistance	[R]	(m^2*K/W)	0.06
Perpendicular to the faces:			
Compressive strength	[σ_c]	(MPa)	3.8
Compressive modulus	[E_c]	(MPa)	38
Parallel to warp direction:			
Core shear strength	[τ]	(MPa)	0.6
Core shear modulus	[G_c]	(MPa)	3
Tensile strength	[σ_t]	(MPa)	175
Tensile modulus	[E_t]	(MPa)	11,000
Compressive strength	[σ_c]	(MPa)	70
Compressive modulus	[E_c]	(MPa)	8,000
Flexural modulus	[E_b]	(MPa)	4,500
Parallel to weft direction:			
Core shear strength	[τ]	(MPa)	1.3
Core shear modulus	[G_c]	(MPa)	16
Tensile strength	[σ_t]	(MPa)	190
Tensile modulus	[E_t]	(MPa)	12,000
Compressive strength	[σ_c]	(MPa)	110
Compressive modulus	[E_c]	(MPa)	17,000
Flexural modulus	[E_b]	(MPa)	6,000

1MPa = 145 psi

Careful modifications of some of these AHC epoxies enable them to thoroughly impregnate (and be reinforced by) 3-D glass fabrics (Fig. 1).[1] After installation of a 3-D glass fabric-AHC composite laminate, depending upon project specifics, a tank can be returned to service in as little as 12 to 24 hours from the time of application.

These AHC systems were developed in the 1990s. The benchmark chosen for optimum chemical resistance of this technology was satisfactory long-term immersion in methanol and other aggressive, petroleum-based chemicals. Formulations with only single converters have limited effectiveness, whereas properly formulated multi-converter AHC epoxies can withstand constant immersion in methanol, as well as a whole range of solvents, fatty acids, and mineral acids such as glacial acetic, hydrochloric, and concentrated sulphuric acid.

Complete cure even at low temperatures can be achieved with liquid epoxy resins utilizing multifunctional diluents, two or more converters with high secondary amine content, and certain mobilizing agents. For highly aggressive immersion resistance such as acid service, post cure (at elevated temperatures up to 150 F [60 C]) drives the reaction to completion, increases the glass transition temperature (T_g), and increases film strength and chemical resistance (Table 1). The AHC epoxy developed for USTs is third-party certified and meets API 653 criteria in independent laboratory tests.[2] Table 2 highlights technical data on one of the epoxies.

Elastomeric versions of AHC epoxies have been developed for secondary containment systems and other concrete containment structures that require crack bridging. They are also suitable for the critical zone on AST tank floor perimeters and for USTs. Some flexibilized AHC epoxies have elongations up to 120% and exhibit no shrinkage or cracking. Thus, they can also be used to fill pits and radius welds on tank floors subject to considerable flexing. ❍

References

1. *A. Lacis, Private Communication, Bacon Donaldson Engineers, Vancouver, B.C., 1998.*
2. *API Standard 653, Tank Inspection, Repair, Alteration, and Reconstruction (Washington, DC: American Petroleum Institute, 1991).*

- the firmness with which the vertical piles are woven into the plain fabrics, and
- the composition of the glass fabric.

When the glass fabric is impregnated with epoxy and then fully cured, a continuous cavity is formed between the upper and lower deck in the laminate. The cavity looks somewhat like the end view of corrugated cardboard. While the lower deck is tightly adhered to the floor, the upper deck is flood-coated with solventless epoxy. This process leaves an interstitial space to be continually monitored by a leak detection system (schematically shown in Fig. 2 on p. 27). This system is permeable in all directions. In the event of a cargo side leak, the

Table 1
Added Value of Early Warning External Leak Detection*

• Fail-safe backup to preventative controls
• Minimizes product value loss
• Minimizes environmental damage remediation
• Mitigating factor in liability claims
• Supplements inventory reconciliation
• API Standard 653 considerations - internal inspection intervals - bottom plate thickness requirements - may minimize required repairs - may help avoid expensive hydrostatic testing - can minimize out-of-service time
• May limit impact of "financial responsibility" requirements
• May limit regulatory penalties

*See Reference 10.

interstice contains leaking cargo and the specific alarm will detect a breach before the cargo reaches and contaminates the environment. (The alarm will also sound if a ground-side leak occurs.) Appropriate repairs can then be carried out. Besides the leak-warning feature, the system also provides corrosion protection for steel, concrete, or fiberglass.

Several companies in North America make systems that utilize the 3-D glass fabric-epoxy technology to upgrade USTs, converting them into new double wall tanks. The result is 360-degree double wall protection with an interstitial sandwich system that combines high strength with a high degree of bending stiffness.[9]

Leak Detection

Many permanent leak detection techniques can be applied in this composite laminate for constant leak surveillance. Several combinations of techniques are possible, which together can increase detection reliability. In principle, any one of the following techniques can be employed: hydrostatic, pressure, vacuum, liquid sensor, or gas sensor. Table 1 lists some key advantages of external leak detection.

On the basis of a theoretical model, the appropriate laminate construction can be calculated. In practice, a continuous pressure load on the seams up to a maximum of 10 psi (0.67 bar) appears possible. The work of the authors with the system suggests the maximum practical overpressure is 2 psi (0.13 bar).

Mechanical Properties

Aside from its leak detection attributes, when a 3-D glass fabric is being made into a composite laminate with an epoxy, the result is a fast-curing sandwich structure with several properties not found in standard fiberglass mats.

- The 3-D glass fabric creates a pseudo I-beam structure. The interstitial air space keeps the majority of the resin mass at the extreme surfaces of the laminate, which is separated by capillary support beams. In this way, a laminate is produced with a high tensile strength and a flexural modulus compared to that of traditional mat/roving laminates.
- The 3-D glass fabric air space helps absorb impacts that may otherwise cause a fracture or holiday in the internal lining.
- The air space insulates the substrate/interface laminate from thermal shocks. This helps eliminate differential thermal expansion failures.
- The air space provides insulation from numerous environments, such as heat, cold, and noise.

In marked contrast to a polymeric resin system that has been reinforced with a 3-D glass fabric, typical polyester and vinyl ester linings are often damaged by mechanical impact. The damage can produce fluid wicking to initiate osmotic pressure pockets or corrosion cells. The laminates eliminate the osmosis failure mechanism in two ways. First, any fluid that finds a path through the primary containment membrane will be contained in the air cavity. This air space is vented to permit fluid to flow easily to the liquid sensor. Therefore, leaked fluid cannot develop increased pressure and will be detected. Second, the relatively rigid laminate would require much higher differential pressure to induce delamination by osmosis.

Chemical and Physical Properties
Until recently, the 3-D glass fabrics were usually used in conjunction with thermoset resins other than epoxy, especially isophthalic polyesters and vinyl esters.[11] The latter have better chemical resistance than regular unsaturated polyesters and they possess good tensile and flexural strength characteristics.

Care must be exercised with selection of anticorrosive resins because certain systems cure partially or not at all in a given 3-D glass fabric. The reason is a thin layer of polyvinyl ester on the vertical pile thread may generate only a very low peak exotherm and therefore be insufficiently cured. Due to the configuration of the glass fabric, there is a large interface of resin and air. This means, on the one hand, oxygen inhibition can occur, and, on the other hand, a large amount of styrene evaporates from the vertical pile thread (so the styrene concentration in the resin is significantly reduced). Hence, a “low-styrene emission resin” was normally recommended.

Epoxy Resin
Ideally, an epoxy coating would solve these problems but it has not been an easy task to develop a suitable candidate material. However, recent research and molecular engineering led to the development of a new class of solventless epoxies described as advanced hybrid cycloaliphatic epoxies (AHC).[12] Further refinements of this technology have enabled a critical balance to be achieved among viscosity control, thixotropy, wetting, reaction rate, chemical resistance, thermal resistance, and recoatability. At the same time, those refinements have produced the clear resin system needed for visual inspection as the resin optimally wets out glass fabrics. Utilizing this epoxy chemistry with 3-D glass fabrics offers significant performance and application advantages compared to polyester, vinyl ester, and standard epoxy-based laminates (Table 2). The AHC technology is described in the sidebar. Table 3 summarizes the key properties of the entire system.

AHC epoxies are best applied with heated twin feed plural-component spray equipment
Courtesy of ICI Devoe Coatings Company

Application

Application Equipment
Ease of application is a requirement for desired performance of most coatings and linings, including AHC epoxies. AHC coatings are best applied using heated twin feed plural-component spray equipment. They may not be particularly easy to apply unless the contractor is properly set up with appropriate spray equipment and has experience with this type of equipment and technology. The mixing ratios of these coatings are typically 2:1 and their pot lives at 77 F (25 C) are normally in the range of 6 to 45 minutes.

Viscosities are temperature-dependent, and viscosity control is very important for good application. For example, an AHC epoxy can have a viscosity like honey at 77 F (25 C), a viscosity similar to skim milk at 100 F (38 C), and a viscosity like molasses at 40 F (4 C). One AHC epoxy coating gave viscosity values of 19,000, 29,000, and 100,000 cps at 100 (35 C), 70 (21 C), and 40 F (4 C), respectively.

Some experienced applicators can and do routinely and successfully apply

An Applicator's Perspective

On any AST steel floor, a leak can develop from corrosion of the top side or the bottom side. As an applicator, we had several questions about the 3-D glass fabric epoxy laminate.

- How strict were the surface preparation requirements?
- How easy to install was the 3-D fiberglass weave/epoxy system?
- What was the mechanical integrity of the joints between adjacent rows of woven material?
- How was it tested before being placed in service?
- How did the tank owner know the system was working, and was the monitoring system subject to interpretation, or was it simple to evaluate?

In our first two installations of this system, these questions were addressed.

First of all, the preparation of the steel floor was no more stringent than that required for any normal internal epoxy floor coating—abrasive blast to White Metal, SSPC-SP 5, before applying an epoxy primer.

Second, the installation of the fiberglass itself presented some challenges because of the tank size and the particular width of the 3-D glass fabric. The two tanks were small (i.e., 16 ft [5 m] diameter), so we couldn't install more than a few feet of the system at a time without some interruption, whether it was a baffle, a floor fitting, or the tank shell. Using the 5-foot-wide (1.5-meter-wide) roll of 3-D glass fabric, our workers could not avoid stepping on the saturated laminate, although it would be preferable not to do so. Fortunately, this proved not to impede our ability to install the laminate with relative ease.

One pleasant surprise was the small amount of effort required to work in the resin to the laminate. This process is faster and requires less labor than normal fiberglass lining with polyester resin.

Third, the strip over the joints proved to be easy to install and was integrated into the laminate system with no problems.

Fourth, once the laminate was floodcoated and the monitoring connections were made, testing the integrity of the laminate was straightforward. A small amount of air pressure easily located holidays. Holding pressure for a period of time was a reliable indicator of total system integrity.

Fifth, we found that once a tank is put in service, it can be monitored in various ways. Although it sounds sophisticated to talk about electronic remote monitoring to control rooms, our experience is that such approaches can unnecessarily complicate monitoring. Electronic monitoring software or hardware can easily malfunction, requiring troubleshooting of the monitoring system and risking undetected leaks. As applicators, we are not against utilizing remote monitoring technology, but there has to be a real advantage (such as remote tanks or tanks scattered across a large area). In normal situations, where operators are close to the site, a quick glance at a liquid trap or pressure gauge is simple. Monitoring can be done simply with a small container on top of the tank holding antifreeze, connected to the annular space with a flexible hose. If the liquid leaves the container, with the head pressure in the container always higher than the pressure on the floor caused by the weight of the liquid cargo, then there is no doubt—there is a leak.

Repairs

We also learned that repairs depended on the type of breach in the system.

Leak Detection

If the laminate has been damaged, or the pressure applied to the interstitial space cannot be stabilized at the pre-determined value, the following options can be used if the leaking section is not visually identifiable.

- Option 1: Fill the interstitial space with compressed air; stabilize the pressure at 2 psi to 10 psi (14 kPa to 70 kPa); and wet down the area with a soapy water solution using a mop or low pressure spray gun application. Bubbling of the soap solution will identify the breach.
- Option 2: Apply a vacuum to the interstice. Spray the tank floor with gaseous helium, which is a low atomic weight, inert gas. Even the smallest pinhole will register a loss of vacuum.

Small Area Repairs

All repairs can be carried out with cold techniques, thus reducing risks to workers in confined spaces. Once a leak is located, 4 to 6 in. (10 to 15 cm) of the surface around the breach should be feathered back using a 24-36 grit abrasive disc on a power grinder. The technique should create a uniform profile and remove all gloss. The exposed and prepared surface is vacuumed clean.

Depending on the size, the damaged area can be repaired with either a fast-set patch version of the specified epoxy or two to three layers of 1-oz/sq ft (300-g/sq m) fiberglass reinforcing mat that has been uniformly wetted with the epoxy. The fast-set repair patch should be allowed to cure and then pressure tested to check for integrity. Once its integrity is confirmed, the repair patch should be scuff sanded and sealed with the same epoxy finish described in the original project specification. With the second approach, the wetted mat is rolled with an aluminum-ribbed roller to remove entrapped air from the laminate, produce an aesthetically acceptable surface, and remove excess resin in the interstice. In either case, the repaired area must be properly cured before the tank is returned to service.

Large Repair Areas

Damaged areas are abrasive blasted or ground out, including 6 to 8 in. (15 to 20 cm) of the periphery of the damaged area. Ideally, the lower deck of the previous 3-D glass fabric-AHC epoxy installation will be left firmly adhered to the substrate. A power grinder fitted with a 24-36 grit abrasive disc can be used to feather the perimeter of the removed area 2 to 3 in. (5 to 8 cm). A uniform profile must be maintained. The feathered and exposed edges are sealed off and filled with a flexible 100% solids AHC epoxy caulk. While the latter is still wet, 2 to 3 layers of 1-oz/sq ft (300-g/sq m) fiberglass reinforcing mat is applied to the epoxy caulk and to exposed ground/abrasive blasted surfaces.

The wetted mat is rolled with an aluminum-ribbed roller to remove entrapped air from the laminate and obtain a uniform and aesthetically acceptable surface. While this area is still wet, the complete section is covered with the glass fabric and uniformly wetted out, rolling into the wet underlay and backrolling during spray application of the epoxy. As soon as the area is cured, it should be uniformly scuff sanded and vacuumed. At 12 in. (30 cm) intervals around the perimeter of the newly applied laminate, holes are drilled through this new application and into the previously installed laminate. A Forstner bit is used on the drill. The holes are vacuumed to remove all residuals and covered with clear shipping tape. Next, 2 to 3 layers of AHC-impregnated 1-oz/sq ft (300-g/sq m) fiberglass reinforced mat is applied to the entire repaired section. The wet mat is rolled as described above. After curing, the repaired area is pressure tested to confirm integrity. It is then scuff sanded, sealed with the epoxy finish specified for the whole project, and cured properly before the tank is placed in service.

Ultrasonic Testing, Vacuum Box Testing

When a glass AHC epoxy laminate is to be installed inside a previously used tank, it is highly recommended that ultrasonic testing be conducted by a qualified independent third-party inspection company. The substrate should be deemed acceptable by local authorities for the intended service environment of the lining system. All welds on the entire surface to be coated must be vacuum box tested to confirm integrity. This requirement actually applies to new or used tanks. A pinhole in a weld will not hold air, and it will cause a breach that is impossible to detect after the application of the glass fabric epoxy system.

It should also be noted that equipment currently available can ultrasonically test the integrity of a steel floor after a 3-D glass fabric epoxy system with interstitial space has been installed. Tank floors can thus be inspected non-destructively to confirm substrate integrity after the system has been in service for several years.

Cathodic Protection

As an applicator, I advise that all cathodic protection systems be designed, certified as adequate, and installed by a corrosion specialist. All corrosion protection systems should be tested within six months of installation and at least every three years thereafter, in accordance with the code of practice developed by a nationally recognized organization. Impressed cathodic protection systems should also be inspected every 60 days to ensure that the system is operating properly. In the U.S., the cathodic protection system should be operated and maintained according to requirements specified in Title 40 of the Code of Federal Regulations, Part 280.31, or according to requirements of the implementing agency, whichever is more stringent.

Holiday Testing

Holiday testing in accordance to NACE-RP 0188-90, Discontinuity (Holiday) Testing of Protective Coatings, is not the optimum test for acceptability of a 3-D glass fabric epoxy laminate application. The preferred test method to confirm integrity of the laminate is to pressurize the interstitial space with compressed air and stabilize the pressure at 2 psi (0.13 bar) (maximum 5 psi [0.33 bar]) for a predetermined amount of time (usually 4 to 6 hours) without loss of pressure. If constant pressure is not maintained, repair guidelines must be consulted and repair procedures undertaken. However, if dry spark holiday testing procedures are requested for verification of integrity, the testing equipment should be set at 100 volts per mil. ❍

AHC epoxies with high ratio standard airless spray equipment utilizing pre-heat and in-line heater viscosity control.

With or without 3-D glass fabric reinforcement, these solvent-free epoxy coatings reduce safety hazards (source of ignition) and VOC concerns. In addition, their light colors (including a clear primer) facilitate easy inspection when applied to ASTs and USTs.

Application (Lay Up Sequence) to an AST Floor

The tank condition and structural integrity must be carefully determined before accepting it as a candidate for a 3-D glass fabric-epoxy lining. API standards 653 and 652 will apply.

New or retrofitted tanks must be blast cleaned to a minimum SSPC-SP 10, Near White Metal Standard, and a 2- to 4-mil (50- to 100-micrometer) jagged profile obtained. For heavily pitted and corroded areas, weld seams, radiuses, and overlaps, a 100% solids epoxy caulk should be carefully worked into these areas after applying the optional holding primer, and immediately before applying the initial coat of epoxy. This procedure is extremely important to produce a more friendly radius and a uniform substrate that assists in installing a void-free application of the laminate. The epoxy reinforcement is to be applied while the caulk is still wet and workable. Since columns or supports in AST tanks are on corrosion allowance pads (re-pads), the 3-D glass fabric is made to butt up to the re-pads and is grouted in place with the 100% solids epoxy caulk.

When applying AHC epoxies in conjunction with 3-D glass fabric, the initial application of the clear AHC epoxy should be 20 to 30 mils (500 to 750 micrometers) WFT, immediately followed by placing the 3-millimeter 3-D glass fabric into the wet epoxy. Rolling must begin immediately, using a napless serrated aluminum roller, and the epoxy must be worked up into the 3-D glass fabric. This procedure should remove any entrapped air, eliminate wrinkles, and uniformly embed and wet out all the fibers of the 3-D glass fabric.

Spray application of the epoxy should be carried out simultaneously with back rolling, using a mohair roller to eliminate dry fabric, pinholing, or air entrapment. Depending on the specified system, when the initial lay up is complete, the system should be no less than 90 to 125 mils (2 to 3 mm) DFT, including one layer of 3-D glass fabric.

The 3-D glass fabric should be laid down in parallel courses ensuring edges/seams are butted tightly together (maximum space of about ¼ in. [6 mm]) and not overlapping (Fig. 3 on p. 27).

Immediately after each parallel course of fabric has been effectively rolled out, a 4-inch- to 6-inch-wide scrim of stitch mat should be laid down, uniformly wetted, and rolled out over the butted seams of the glass fabric (Fig. 4 on p. 27). This 1 oz/10 oz combination fabric is required to encapsulate and seal off the glass fabric joints.

After the application has had sufficient time to cure (when it can be walked on without damage), any anomalies, protruding strands, rough edges, or seams must be ground or sanded smooth. At this time, all edges adjacent to the chime, clips, and projections should be either ground back smooth or razor cut to a 45-degree angle to accommodate the 100% solids flexible grout/caulk application to seal off the interstitial space. Also at this time, the monitoring plates should be installed into the 3-D E-glass application (Fig. 5 on p. 27). Final repairs, including filling air pockets and stitch mat seams with 100% solids epoxy grout, should also be completed now.

Next, the entire floor area should be vacuumed using a bristle brush attachment to remove all loose particles. Sweep or blow-down cleaning alone is not acceptable. It is recommended that at this time, prior to the application of the final flood/topcoat, an additional 8- to 12-mil (200- to 300- micrometer) DFT application of AHC epoxy be applied to the entire surface.

This process has proven to mitigate tiny, difficult to detect pinholes in the glass fabric reinforcement application. Once this application has been allowed to sufficiently cure to the state it can be walked on without causing damage, a final visual inspection should be performed to confirm integrity prior to the application of the final flood coat (minimum 25 to 40 mils [≈ 1 mm] DFT). The final flood coat of the specified system can be applied while the 100% solids flexible grout or epoxy caulk is still wet.

Table 2
Advantages of 3-D Glass Fabric-AHC Epoxy Laminate Linings vs 3-D Glass Fabric-Polyester and Vinyl Ester Laminate Linings

1. Improved safety and environmental considerations
   - Solvent-free formulation (100% solids systems)
   - High flash point
   - Lower odor—no strong styrene odor
   - NIOSH cartridges—not air-supplied respirators
   - Does not require toxic MEK peroxide catalyst
2. Superior cargo and heat resistance
   - Poly/vinyl ester systems limited to 150 F (84 C) wet service—AHC epoxy novolac can resist up to 275 F (154 C) wet service depending on cargo
   - Poly/vinyl ester systems require fiberglass reinforcement. Damage to the outer layer may expose fiberglass hairs. Cargo is then allowed to wick down along the fiberglass through to the substrate causing premature failure
3. Superior adhesion, impact, compressive and flexibility characteristics
   - The coefficient of expansion of poly/vinyl ester systems is markedly different than that of steel. Cyclic temperature changes often induce delamination from the tank
4. Greater film build
   - Up to 80 mils (2 mm) in one coat
5. Superior and stable shelf life—more than 2 years
6. Superior Cathodic Disbondment test results
   - (CAN/CSA-Z245.20-M92) (1.5V SCE, 80 C [144 F], 48 hrs, 3% NaC1) = 5 mm [0.2 in.] (avg) disbondment for AHC epoxy
7. Superior Electrochemical Impedance Spectroscopy results
   - Log Z (ω-sq cm) = 10.5 for AHC epoxy

Table 3
Key Properties of the 3-D Glass Fabric-AHC Double Floor System

• Composite corrosion barrier and interstitial 3-D glass fabric
• Composite monolithic system that is chemically/mechanically bound together
• Completely adhered system consisting of a 100% solids AHC epoxy phenolic novolac
• Epoxy: greater thermal coefficient of expansion compatibility between steel/epoxy compared to steel/poly-vinyl ester
• High adhesion and cohesion values
• Attached to 100% cleaned and uncontaminated substrate
• Radius in critical zone—system tightly adhered; flexible caulk in critical zone
• In event of tank shift/settling—minimal damage/repair
• No fittings and mechanical fasteners
• Custom-made installations; not pre-assembled
• Split lap welds radius; lap welds all caulked with 100% solids flexible epoxy
• Broad spectrum of chemical resistance
• High-temperature resistance
• User-friendly—no peroxides/solvents
• Electronic detection probes—or simple detection techniques
• Years of tank lining experience worldwide in oil patches, marine, aerospace, waste water, rail cars, other petrochemical services etc.

The preferred test method to check for positive cure is time-at-temperature as outlined on the manufacturer's product data sheets. A less favorable but acceptable test for positive cure can also be determined using the destructive sandpaper test method to test panels prepared at the same time as the tank application. Positive cure can be established by sanding through the top/flood coat to the 3-D glass fabric (using 100 grit wet and dry sandpaper) and producing a powder. No gumming will be evident on the sandpaper from the uncured epoxy.

Depending on the technology of the specified finish/top coat and the system's recommended dry film thickness, Durometer or Barcol hardness testing can be used to confirm through-cure. Appropriate readings referencing cure level can be made available from the coating manufacturer.

To be acceptable, the application should be free of obvious defects such as sags, runs, blisters, pinholes, air-entrapment, fish-eyes, overspray, and any other foreign matter entrapment. It should also be pressure tested.

Inspection

The last person to leave the vessel before installing all manways or covers should be a coating inspector, who can conduct a final inspection of system integrity (through pressure testing). The inspector should also examine the vessel for mechanical damage caused by removing equipment or installing internals. If the vessel is damaged, repairs will be required. The second sidebar gives an applicator's view from the field on application, inspection, and repair techniques. Table 4 summarizes the lay up sequence.

Finally, it should be noted that although the system can be applied to sumps in AST tanks, most owners are welding in the sumps and placing the 3-D glass fabric epoxy directly over them.

Summary

The 3-D glass fabric-AHC epoxy laminate provides:

- leak prevention, leak detection, and leak monitoring;
- corrosion protection in aggressive chemical and thermal environments;
- secondary containment within the primary structure such as an AST or UST. (Therefore, the steel floor can be considered the secondary containment structure and the laminate/interstice the primary containment structure.);
- extremely sensitive leak detection monitoring without risk of soil or groundwater contamination; and
- cost-effectiveness, extended service life, and inspection/maintenance requirements. (That is, the number of API 653 inspections may be reduced since this system is under constant surveillance.) ❑

Table 4
Application (Lay Up Sequence) at a Glance

1. Apply 20-30 mils of clear 100% solids AHC epoxy to a clean and prepared surface.
2. Apply 3 mm (120 mils) 3-D glass fabric in the appropriate size configuration to the wetted out area and roll in with an aluminum ribbed roller.
3. Apply additional 20-30 mils (500-750 micrometers) of clear 100% solids AHC epoxy to ensure that there is full saturation and wet out of the 3-D glass fabric. Simultaneously back roll with a mohair roller during spray application.
4. Cover seams with 6 in. (15 cm) wide stitch-mat and wet out with AHC epoxy.
5. Install interstitial space monitoring attachment.
6. Test lining with a 2 psig air pressure test to ensure the lining's integrity.
7. Flood coat the entire lining with the designated AHC epoxy finish at approximately 80-100 mils. Simultaneously back roll with a mohair roller during spray application.
8. Post-cure if necessary.
9. Again test at 2 psig air pressure to ensure the lining's integrity.

References

1. *Philip E. Myers,* Aboveground Storage Tanks, *(McGraw-Hill, New York, NY, 1997) p. 2.*
2. *P.E. Del Vecchio, Jr., "An Overview of Legislative and Regulatory Activities on Aboveground Storage Tanks and Terminals," presented at the National Institute for Storage Tank Management 1st Annual Conference on Aboveground Storage Tanks, May 27-29th, 1998, Tampa, Florida.*
3. *M. Mott-Smith, "Florida's Approach to AST Regulation: Chapter 62-761, F.A.C. Storage Tank Systems," presented at the National Institute for Storage Tank Management 1st Annual Conference on Aboveground Storage Tanks, May 27-29th, 1998, Tampa, Florida.*
4. *P.E. Del Vecchio, Jr., "An Overview of Legislative and Regulatory Activities on Aboveground Storage Tanks and Terminals," presented at the National Institute for Storage Tank Management 1st Annual Conference on Aboveground Storage Tanks, May 27-29th, 1998, Tampa, Florida.*
5. *EPA Liner-Study: Report to Congress, Publication 9380. 0-24.*
6. *K. Kapsanis and P. Markle, "The Debate over Tank Linings: Protecting Aboveground Storage Tanks and the Environment,"* JPCL *(July 1997), 53.*
7. *A.R. Watson, "Aboveground Storage Tank Foundations and Relocations," presented at the National Institute for Storage Tank Management 1st Annual Conference on Aboveground Storage Tanks, May 27-29th, 1998, Tampa, Florida.*
8. *K. Swinkels, "Parabeam Double Wall Lining for Above and Underground Tanks," Technical Conference, JEC 96, CNIT, Paris, France, 1996.*
9. *D. Bolianatz, Private Communication, ZCL Composites, Edmonton, AB, 1998.*
10. *D. Wien, AST External Leak Detection, presented at the National Institute for Storage Tank Management 1st Annual Conference on Aboveground Storage Tanks, May 27-29th, 1998, Tampa, FL.*
11. *T.W. Cowley, "Recommended FRP Inspection Procedure for the End User," presented at NACE-Canadian Region Western Conference, 1997, and CORROSION NACExpo '97, Managing Corrosion with Plastics.*
12. *M. O'Donoghue, R. Garrett, V.J. Datta, P. Meli, L. Meilus, "Optimizing Performance of Fast-Cure Epoxies for Pipe and Tank Linings: Chemistry, Selection, and Application,"* JPCL *(March 1998), p. 36.*

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