USE OF FIBER REINFORCED POLYMER LININGS FOR CONTROLLING CORROSION IN MINERAL AND CHEMICAL PROCESSING INDUSTRIES

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SUMMARY: Mineral processing and chemical processing industries often employ chemicals that are very corrosive to materials of construction such as steel and concrete commonly found in tanks, process vessels and piping. These construction materials need additional protection from corrosion. Past solutions have included rubber linings. Unfortunately, rubber linings are difficult to apply and require a great deal of maintenance over the life of the equipment. Fiber reinforced (FRP) epoxy vinyl ester resin linings have demonstrated excellent chemical resistance and require minimal maintenance over the life of the equipment. Choosing the proper resin for the corrosive environment is critical to liner performance. The method for determining the proper resin will be described in the paper and a comparison of performance will be shown using ASTM C581 test data. Proper construction of the FRP liner is equally important to insure a successful application. These linings can additionally provide outstanding abrasion resistance when formulated properly with additives such as silicon carbide. The affect of several potential abrasion resistant additives will be described with test data showing how each material improves the abrasion resistance in the FRP liner. Examples of equipment constructed with these epoxy vinyl ester linings such as mixer settlers, storage tanks, process vessels, etc. will be discussed.

1. INTRODUCTION

Many corrosive chemicals are used in the mineral processing and chemical processing industries that are very aggressive to standard materials of construction such as carbon steel and concrete.

The recovery of metals such as nickel, copper and uranium from ores is typically conducted through hydrometallurgical processes which employ acids to leach desired minerals from the ore. The acid most commonly used is sulphuric acid. At concentrations less than 90%, sulphuric acid is very corrosive to both steel and concrete. Another material that is very aggressive to steel and concrete in these industries is sea water. Sea water is commonly used for cooling water and process water for facilities that are situated close to the coast. As a result, both of these chemical services require steel or concrete equipment with added protection from corrosion or to the use of considerably more expensive corrosion resistant alloys. Many of these processes are also challenged with abrasion from solids in the process stream especially in the mineral processing industry. One of the most common materials to combat corrosion and abrasion problems in these processes has historically been rubber linings on steel or concrete. If the proper rubber is used, rubber linings can deliver reasonably good chemical resistance. The main draw back to rubber linings is that they require regular maintenance and repair. One reason for this is the permeation of chemicals through the rubber lining which then causes blistering of the lining [1]. Soft rubbers can then be quite susceptible to tearing. This leads to frequent repairs of the rubber lining and high maintenance costs over the life of the equipment.
Another material of construction often found in these industries is fibre reinforced polymers (FRP). These have been used successfully in both the chemical process industry and the mineral processing industry. FRP can be used to make the entire tank or pipe, or it can be applied as a lining on concrete or steel structures. Table 1 shows a comparison of the chemical resistance of FRP made from an epoxy vinyl ester resin to 316 and 2205 stainless steel as well as alloy C-276. FRP made from epoxy vinyl ester resin demonstrates superior performance to the 316L and 2205 stainless steels and equivalent corrosion resistance to alloy C-276 in sulphuric and hydrochloric acids. FRP is more corrosion resistant than even C-276 alloy when aqueous chloride salts are present. In fact, one of the first uses of FRP as a lining was to line the bottom half of crude oil storage tanks in order to protect the steel from acidic water that would settle to the bottom of these tanks. This is shown in Figure 1.

FRP abrasion resistance can be improved by the addition of hard fillers such as silicon carbide or aluminium oxide. This improvement in abrasion resistance is shown by ASTM D 4060 [2] Tabor Abrasion test results in Table 2. There were several types of epoxy vinyl ester resins used. The standard bisphenol A epoxy vinyl ester resin like HETRON™ 922 resin or DERAKANE™ 411 resin will be referred to in this paper as EVER. The epoxy novolac vinyl ester resin like DERAKANE™ 470 resin will be referred to as NEVER and the flexibilized epoxy vinyl ester resin like DERAKANE™ 8084 resin will be referred to as FEVER. The Wear Index in the table is an indication of resistance to abrasion. Lower Wear Index values represent improved abrasion resistance.

This paper will focus on the use of the FRP as a lining for concrete or steel structures in the mineral processing industry. Properly applied with the right resin, FRP linings have been shown to give a long service life with very little maintenance.

### Table 1. Chemical Resistance of EVER FRP Compared to Stainless Steel and Alloy C-276

<table>
<thead>
<tr>
<th>Materials</th>
<th>Sulfuric Acid</th>
<th>Hydrochloric Acid</th>
<th>Acid Chloride Salts</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRP Made with Epoxy Vinyl Ester Resin</td>
<td>100°C to 30%</td>
<td>80°C to 15%</td>
<td>100°C all concentrations</td>
</tr>
<tr>
<td>316L Stainless Steel</td>
<td>30°C to 5%</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>2205 Stainless Steel</td>
<td>30°C to 30%</td>
<td>60°C to 1%</td>
<td>65°C to 2000 ppm @ low pH</td>
</tr>
<tr>
<td>Alloy C-276</td>
<td>100°C to 30%</td>
<td>80°C to 15%</td>
<td>65°C to 50,000 ppm@ low pH</td>
</tr>
</tbody>
</table>

### Table 2. ASTM D 4060-01 Abrasion testing

<table>
<thead>
<tr>
<th>Laminate Resin Type</th>
<th>Wear Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVER</td>
<td>388</td>
</tr>
<tr>
<td>NEVER</td>
<td>520</td>
</tr>
<tr>
<td>FEVER</td>
<td>250</td>
</tr>
<tr>
<td>EVER with 20% silicon carbide</td>
<td>25</td>
</tr>
<tr>
<td>EVER with 40% silicon carbide</td>
<td>10</td>
</tr>
</tbody>
</table>

Corrosion & Prevention 2012 Paper 40 - Page 2
2. DESCRIPTION OF LINING STEEL AND CONCRETE WITH FRP

There are two ways that an FRP lining can be applied to a tank or a large vessel like a mixer/settler. The first process that will be discussed is a standard FRP lining. The recommended process for applying an FRP lining to steel is to first prepare the surface by steam cleaning or washing the metal with 1% sodium triphosphate solution to remove any grease, oil or other contaminants. Once the surface has dried, grit blast it to a bright metal finish. Don’t wipe the surface with solvent; brush or (preferably) vacuum off the abrasive dust. The grit-blasted surface should have a 2- to 3-mil anchor pattern. Fill pits, cracks, holes and other irregularities with a catalyzed resin grout. Outside corners should have a 3 mm minimum radius, and inside corners should be filled to a 25 mm radius. FRP edges should be feathered by grinding. Allow resin grout to cure; then sand smooth and remove dust. The next step is to prime the steel surface by brush coating the clean metal with 2 to 3 mils of a coating formulated with catalyzed FEVER to provide an anchor for the lining. When this prime coat is dry to the touch, check the surface with a test patch to verify that a good bond can be obtained as described in the DERAKANE™ Resin Fabrication Tips [5]. The laminate is then laid up on the primed surface of the steel to the desired laminate thickness.

Using the same sequence of operations, apply two layers of surfacing veil with resin. The lining should now be at least 3 mm thick. The surface veil is applied on top of the mat layers. The lining should be inspected for defects such as voids, dry glass or exposed fibres before the final top coat is applied. A spark tester can be used for this inspection. The final laminate layer is applied which is a mixture of catalyzed resin with a small amount of wax to prevent air inhibition of the resin.

The procedure for lining concrete is similar to the procedure for lining steel. Concrete must be well cured before applying the FRP lining. Otherwise the inherent moisture in under cured concrete may interfere with resin cure and the laminate bond to the concrete. The surface is prepared by grit blasting to obtain a good profile for the resin to bond. The surface of the concrete is coated with 0.05 to 0.08 mm of FEVER-based coating as a primer. The laminate is then applied to the desired thickness and then the veil layer is applied. The lining is inspected before applying the final top coat of resin and wax.

These general guidelines can help insure a reliable lining for protecting steel and concrete substrates from corrosion.

3. DESCRIPTION OF LINING STEEL AND CONCRETE WITH PREFABRICATED FRP SHEETS

Another common method for lining large steel and concrete equipment is to use shop fabricated FRP sheets that have been shipped to the site for installation. A common application for this type of lining would be CCD (Counter Current Decantation) Thickeners. This process requires less labor at the job site since the FRP panels are fabricated beforehand. The general process for installing these FRP panels is to prepare the surface of the concrete or steel by cleaning and sand blasting just as was described above for lining steel or concrete with FRP. The surface of the clean steel or concrete is brush-coated with 0.05 to 0.08 mm of a catalyzed FEVER-based coating to seal the surface of the concrete or steel. The FRP panels are pre-fabricated at a shop and shipped to the job site for installation. The pre fabricated FRP panels are mechanically attached to the coated concrete or steel walls. This is generally done using screws to anchor the panels to the steel or concrete substrate. Once anchored to the substrate, the seams between the FRP panels are laminated with the same resin used in their original fabrication.

4. CORROSION TESTING OF FRP

The choice of resin to use for making FRP linings is based on several factors. The first factor is the chemical environment to which the lining will be exposed. Leading suppliers have conducted corrosion tests for more than fifty years on resins in thousands of environments in order to determine how FRP linings will perform in various processes. The standard method for testing FRP is ASTM C 581: Standard Practice for Determining Chemical Resistance of Thermosetting Resins used in Glass Fiber Reinforced Structures Intended for Liquid Service [6]. Test Coupons are designed to simulate the lining material by fabricating the coupon with a layer of veil on each side and chopped strand glass in the middle at about 3 mm in thickness. This coupon is immersed in the test liquid for 12 months. Since the coupon is exposed on both sides instead of just one side, it is considered an accelerated test. Samples are evaluated at one, three, six and twelve month intervals for visual and mechanical property changes. Properties retention values should exceed 50% of their initial results after 12 months of exposure to be considered acceptable for a given chemical environment at a set temperature.
This test data is commonly accepted to generate the recommended temperatures and chemical concentrations for FRP using various resins. Chemical Resistance Guides are available from resin suppliers to determine which resin is most appropriate to construct an FRP lining for a given environment [7, 8].

5. DISCUSSION

One of the major problems with rubber lined equipment is the requirement for ongoing maintenance to repair tears and blisters in the lining. This experience has been communicated from a number of engineers at several chemical and mining companies interviewed by the authors. It is also discussed in a recent paper by Wolfgang Berger [1] comparing rubber linings to epoxy vinyl ester resin based linings in limestone slurry piping used in flue gas desulfurization systems at coal burning power plants. The main issue is the difference in corrosive chemical permeation between rubber linings and FRP based linings on carbon steel. Since the rubber allows greater permeation of water vapours, more blisters tend to be formed. The soft rubber lining then has a greater tendency to tear. Epoxy vinyl ester resin based FRP linings tend to have far less corrosive chemical permeation. Lambrych et. al. [4] showed that the standard theory of permeation does not hold for thermoset material like EVER. It appears that most chemical permeation travels a set distance into the FRP corrosion barrier and then essentially stops. In rubber linings just as in thermoplastic linings corrosive fluids will continue to permeate at a set rate throughout the lining. That is why EVER based linings tend to show less blistering.

The chemical resistance of EVER linings is very good over a wide range of chemical environments, especially mineral acids, caustic and aqueous salts. EVER laminates are essentially inert to aqueous chloride salts. FRP has been used extensively for sea water piping and tanks as well as for lining large sumps and tanks.

FRP technology has been successfully applied in a variety of mineral processing applications. Figure 2 shows a concrete uranium flotation tank lined with an EVER based laminate. This tank contains uranium ore in sulphuric acid and kerosene and has been in service since 1992. Figure 3 shows a lining based on a novolac epoxy vinyl ester resin (NEVER) in a concrete digester tank at a waste water facility in France.

Figure 4 shows a reactor at a chemical plant in Nova Scotia lined with EVER based FRP. This reactor vessel was used for mixing chemicals into hydrochloric acid at temperatures up to 80°C. After 11 years of service, the lining remained in excellent condition.

In 1980, the first large diameter concrete CCD thickener was lined with FRP panels at Keylake in Alberta Canada [3]. These thickeners are still in service today. The process of lining large diameter equipment with prefabricated FRP panels has become common practice for building modular solvent extraction plants.

A more recent application for FRP sheets to line multiple large diameter concrete vessels was the Ambatovy Nickel processing plant in Madagascar [3]. This project consisted of 2 tanks, 80 meter in diameter and 4 tanks, 55 meter in diameter, each with side walls about 4 meters tall. More than 450 metric tons of FRP were required to line the 6 vessels. Figures 5 and 6 show some of the vessels that were lined for this project. This project was completed in 2010.

There have been several other successful mineral processing projects using FRP linings for mixer settlers in solvent extraction facilities including the Salton Sea solvent extraction plant in the United States. In Tintaya, Peru four 33 meter x 38 meter settler units were lined with FRP sheets. Another site in Spence, Chile had 26 settlers lined with FRP sheets. All of these installations have operated with no major maintenance. Two more recent projects using FRP linings in their mixer settlers are the Vale Long Harbour project in Canada and the Baja Mining El Boleo project in Mexico.
6. CONCLUSIONS

Mineral processing and chemical processing applications typically employ chemicals that can be very corrosive to concrete steel and even corrosion resistant alloys. There are several ways to combat corrosion in these chemical processes. The first is to use very expensive exotic alloys. A lower cost option would be to apply corrosion resistant lining. Rubber linings are one
option. A more durable and cost competitive option would be an FRP lining based on an epoxy vinyl ester resin. These can be applied directly to the substrate or prefabricated in sheets and attached to the substrate at the job site. Both of these FRP liner solutions provide excellent chemical resistance to acids, bases and aqueous chlorinated salts. FRP linings have demonstrated service lives in excess of 10 years in mineral processing environments with little maintenance.

7. REFERENCES

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5. DERAKANE™ Resin Fabrication Tips, Section 8, page 28
8. HETRON™ Epoxy Vinyl Ester Resins Resin Selection Guide for Corrosion Resistant FRP Applications
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8. AUTHOR DETAILS

M. Stevens is a Principal Scientist with Ashland Performance Materials. He has a Bachelors degree in Polymer Chemistry from Virginia Tech. He is responsible for technical support for the use of FRP in corrosion environments. He is Vice Chairman of NACE STG-10 Committee for the management of corrosion with non metallic materials of construction. He has over 30 years of experience in this industry.

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