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HOW TO USE FRP MATERIAL TO LOWER CORROSION COSTS

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ABSTRACT

As metal prices rise, engineers and end-users are replacing traditional materials with fiberglass-reinforced polymer (FRP) in corrosive environments across diverse industries including power and energy; chemical processing; mining; water and sewage treatment; and food processing. In many cases, using FRP materials lowers costs, offers outstanding performance, and often provides superior quality over traditional materials such as stainless or coated steel, wood, and alloys. When using FRP, specifying the right material is critical and depends on the chemical environment the equipment will be facing. This paper discusses the various types of glass fiber and resin available and shows how to specify the correct materials for different chemical environments. In addition, the construction of an FRP laminate, including the veil layer of the corrosion barrier, the mat/chop portion of the corrosion barrier, and the important structural layer is discussed. And, ways of selecting the proper materials for each layer using the tools available are also shown. Finally, this paper illustrates the benefits of specifying the correct FRP materials and reviews the standards available to ensure the proper construction, installation and inspection of FRP equipment. The information provided in this paper is presented in five key steps.

Key Words – Corrosion, FRP, composite, tanks, pipe, ASTM, fiberglass, inspection, Advantex®, corrosion barrier, E-CR, ASME, plastic, polymer

INTRODUCTION

Corrosion is the term used to describe the deterioration of a material as it reacts with its environment and is a natural process that occurs when materials such as refined metals return to a more stable compound. During the process of corrosion, an engineered material actually disintegrates into its constituent atoms as a result of chemical reactions with its surrounding environment. Corrosion can be concentrated locally to form a pit or crack or it can extend across a wide area, almost uniformly corroding the surface.

Corrosion-related damage is costing developed and developing nations trillions of dollars annually in repair and replacement costs. This cost not only relates to infrastructure but also to private industrial companies that spend billions of dollars annually repairing many processing system components. A recent estimate of the worldwide direct cost of corrosion – for prevention as well as repair and replacement – exceeded $1.8 trillion.[1]

New material solutions such as fiberglass-reinforced polymer (FRP) have been developed since much of the corroding material was originally installed. FRP material consists of a mix of glass fiber reinforcements and a polymer system. The combination equals an engineered material system resulting in unique attributes replacing traditional materials such as stainless or coated steel, wood, and alloys. An estimated 25 to 30 percent of the annual cost of corrosion-related damage can now be avoided if optimum corrosion management practices are employed.[1] One such practice includes using FRP material in corrosive environments where traditional materials do not perform as well.

There are many ways to fight corrosion including using costly metals and coatings, surface treatment, and other special procedures to protect materials. In many situations, a better solution can be achieved by using modern FRP materials. Applications made using FRP are safe and reliable solutions able to face harsh conditions in many different corrosive environments and outperform traditional materials. With more than 50 years of field experience, FRP is now a proven material technology.

Understanding the properties of FRP and the environments in which it is best used will help end-users and engineers lower corrosion costs and improve performance when compared to using traditional materials. Glass fiber and resin selection is as important in using FRP material as it is when choosing a metal to fit a chemical environment. There are five key steps involved in ensuring quality, securing long-lasting results, and reducing risk when considering using FRP for applications in corrosive environments. These are discussed in detail in Using FRP Material – Five Key Steps.

These five key steps are:

1. Identify suitable applications for FRP material
2. Implement company FRP material standards
3. Use existing governing standards to have FRP equipment made for use in corrosive environments (ASME, ISO, ASTM, etc)
4. Specify proper materials (glass fiber, resin, corrosion barrier) to construct the FRP application
5. Implement proper inspection protocols

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MAIN DISCUSSION

As metal prices rise, engineers and end-users are replacing traditional materials such as stainless or coated steel, wood, and alloys with FRP in corrosive environments. Diverse industries have been impacted including power and energy; chemical processing; mining; water and sewage treatment; food processing; and other industries around the world. In many cases, the FRP equipment is lower in cost, has outstanding performance, and provides equal (if not superior) quality over higher cost alloys.

FRP material is lightweight, durable, non-conductive, and corrosion resistant. It is also high in strength, fatigue resistant, and offers significant design flexibility; radio frequency signals can travel through FRP as well. Its many properties make it a material of choice for numerous kinds of equipment/applications. The use of FRP is strongly recommended if an application requires two or more of these properties (i.e. lightweight and corrosion resistant).

Table 1 FRP corrosion and strength

Corrosion Performance	FRP	2205 SS	C-276 Alloy
Hydrochloric Acid	90° C to 15% concentration	60° C to 1% concentration	80° C to 15% concentration
Acid Chloride Salts	100° C in all concentrations	65° C with 2,000PPM @ low pH levels	65° C with 50,000PPM @ low pH levels

When comparing the performance between FRP material and metals for corrosion resistance and strength properties, FRP performs well (Table 1). For corrosion performance in common acids like hydrochloric and sulfuric, FRP outperforms the stainless steel and alloy. Even in acid chloride salts, FRP performs much better when compared to stainless steel and alloy.

Regarding strength properties (Table 2), FRP is stronger than conventional steels and C-276 because of the uniformity of fiber alignment. Conventional steels and C-276 are both initially stiffer than FRP, but yield and begin elongating early. FRP is significantly lighter than other corrosion resistant materials, with a density lower by a factor of four.

Table 2 Strength properties of FRP

Property	Unit	Steel (includes 304, 316L, 2205, carbon)	C-276 Nickel-Molybdenum-Chromium Alloy, annealed	FRP Fiber-Reinforced Polymer Composite
Ultimate Tensile Strength	ksi (MPa)	70-90 (485-620)	100-120 (690-830)	160 (1100)
Tensile Modulus	Msi (GPa)	28-29 (190-200)	30 (205)	7 (48)
Elongation at Break	**%**	35-50	50-70	3
Poisson's Ratio		0.27-0.30	0.31	0.33
Density	**lb/in3 (g/cc)**	0.28-0.29 (7.8-8.0)	0.32 (8.9)	0.08 (2.1)

Cost of FRP Compared to Steel

When using FRP material in certain corrosive environments, not only will it outperform steel, its upfront costs can be considerably less than stainless steel and other alloys. For many years, the up-front costs of FRP were normally higher than traditional materials. However, in recent years FRP has proven its value because it is lower maintenance and performs longer than other materials. After 2004, the global price of steel started to dramatically increase due to high demand in developing countries as the world's economies grew at a high rate. During this phase, FRP material started to compete head-to-head with stainless steel solutions. Since the spike of steel prices in 2008, FRP has become consistently competitive with stainless steel and alloys. Future forecasts for nickel, which is used to make stainless steel, favor the use of FRP as forecasted prices of nickel to supply stainless steel continue to rise (Figures 1 and 2).

Figure 1 Nickel price forecast

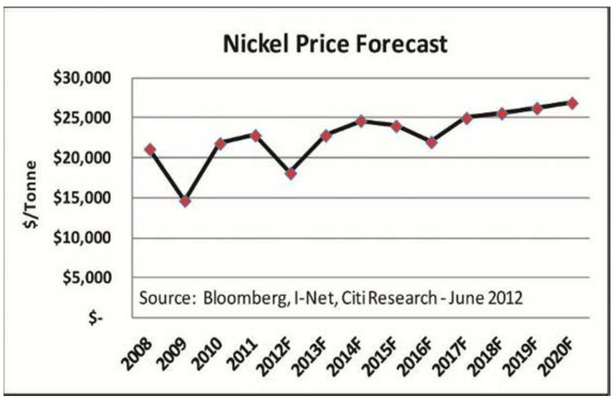
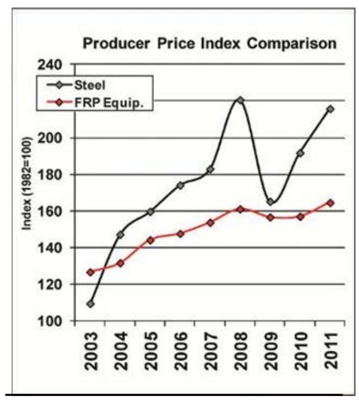


Figure 2 Producer price index comparison



An Example Where FRP Material Can Lower Corrosion Costs

When coal power owners in the United States were faced with tougher federal pollution limits, power companies spent the last several years installing large scrubbers at their coal-fired power plants. The cost of each scrubber system was between $200 million and $500 million. These scrubbers are mainly used to catch sulfur dioxide. A scrubber can hold as much as 1 million gallons of lime slurry, a solution that captures the sulfur compounds in hot power plant smoke before it goes up the stack.

Figure 3 Example of a 2205 stainless steel scrubber tank

Figure 3 is an example of a 2205 stainless steel scrubber tank being installed at a coal-fired power plant. Approximately one year after scrubber tanks were installed, inspections found aggressive corrosion occurring in tanks across the United States. In some cases, the corrosion extended completely through the steel tank. One power company has spent more than $5 million in short-term repairs.

Because of corrosion-related issues, several United States power companies have switched to using FRP material not only for external sections of these large scrubber tanks but also for internal components of the scrubbers, as well as numerous other parts of these large pollution control systems. To date, the material is performing well, thus lowering the costs associated with corrosion repair. Other components made with FRP material include lime-slurry pipe; support beams; inlet/outlet ducting; spray headers; and wastewater treatment mist eliminators and stack liners.

Using FRP Material – Five Key Steps

As mentioned in the Introduction, when considering using FRP for applications in corrosive environments, there are five key steps involved in ensuring quality, securing long-lasting results, and reducing risk. These steps are discussed in detail in the following text.

Step 1: Identify suitable applications for FRP material. When using FRP, it is important to validate that the material will perform in the environment considered. To do this, you will need to:

a) Understand the temperature range the FRP application will face. Higher temperatures have a greater effect on how the resin will perform and little to do with the performance of the glass fiber reinforcements. Depending on the environment, FRP can perform in temperatures up to 100°C. It is important to work with the resin supplier to confirm temperature capabilities depending on the type of environment.

b) Determine what the chemical environment will consist of and the concentrations of each type. In addition, learn the cleaning process between batches and the chemicals used that will be in contact with the FRP equipment.

c) Consider the methods of processing the chemicals and how they are combined either through agitation or other types of mixing processes.

d) As you identify the suitability of FRP, verify that the mechanical properties are aligned for use of FRP. Confirm the strength requirements; FRP can be designed to meet a specific strength requirement.

e) Finally, verify that the FRP has a proven history of performing better than traditional materials in the particular environment and validate the overall lifetime costs will be lower using FRP. If FRP is found suitable, maintenance costs should also be favorable for the application.

An example of FRP pipe being selected as the best material of choice for a project is the National 9/11 Memorial Fountains at New York City's World Trade Center (Figure 4). When engineers considered using either 316L stainless steel or FRP, they found FRP delivered better performance in three areas. First, using FRP material saved over 677,000 pounds (307,082 kg). Second, this provided a lower installation cost, and, finally, the FRP pipe provided a projected service life of 50 years. Thus, FRP was the suitable solution for this project.

Figure 4 FRP pipe used in National 9/11 Memorial Fountains at New York City's World Trade Center

Step 2: Implement an FRP General Usage Standard. A company usually has specific methods or standards set in place to ensure proper usage and maintenance of the various materials used to make equipment. The goal is to make sure the same high quality FRP assets are being used consistently at each company site and that there is not a mix of various FRP materials used for similar conditions, causing varying performance issues. When using FRP, a company should set in place an internal FRP General Usage Standard to ensure consistent performance throughout. The Standard should include the following key information:

A. Drawings and calculations
B. Fabrication methods
C. FRP laminate properties
D. Governing standards
E. FRP laminate sequences
F. FRP laminate testing
G. Inspection protocol
H. Shipping methods

If an engineering group inside a company needs support in developing a company FRP General Usage Standard, there are many skilled FRP engineering firms and consultants throughout the world to provide the necessary support to implement such a standard.

Step 3: Use existing governing standards to have FRP equipment made for use in corrosive environments. As with steel, there are many governing standards to instruct FRP fabricators on how to construct FRP used in corrosive environments. When learning more about this material, take advantage of these standards, making sure fabricators follow them to ensure high-quality performing FRP assets are installed. Below is a list of some of the more commonly used FRP standards to help ensure proper construction and installation of FRP equipment.

- **ASME RTP-1-2007** – Reinforced Thermoset Plastic Corrosion – Resistant Equipment
- **ASTM D3299** – Standard Specification for Filament Wound Glass Fiber Reinforced Thermoset Resin Chemical Resistant Tanks
- **ASTM D4097** – Standard Specification for Contact Molded Glass – Fiber Reinforced Thermoset Resin Chemical Resistant Tanks
- **ASTM D3681** – Chemical Resistance of "Fiberglass" (Glass–Fiber–Reinforced Thermosetting-Resin) Pipe in a Deflected Condition
- **ASTM D 3567** – Standard Practice for Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings
- **ASTM D2996** – Standard Specification for Filament-Wound Reinforced Thermosetting Resin Pipe
- **ASME Section X** – Fiberglass reinforced plastic pressure vessels
- **ASME Section 10** – ASME FRP Boiler and Pressure Vessel Code
- **API Specification 12P** – Specification of Fiberglass Reinforced Tanks
- **ISO 24817** – Composite Repairs for Pipework — Qualification and Design, Installation, Testing and Inspection
- **ASTM D4097** – Standard Specification for Contact Molded Glass Fiber Reinforced Thermoset Resin Chemical Resistant Tanks
  STI ACT-100 – Qualification Procedure for ACT-100 Composite Tank Laminates
- **ASTM D 3754** – Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe

Referencing these standards for fabrication in a company FRP General Usage Standard, which was described in Step 2, will help an end-user or engineer who is ordering or using the FRP equipment clarify what quality and methods to follow to make the equipment. For example, some of the standards listed above include the following details:

A. Materials
B. Test methods
C. FRP laminate composition
D. Design for external and internal pressure
E. Fabrication of flanges, manways, shell joints, drains and other items
F. Inspection responsibility, conditions for inspection

Other standards/instructions (best methods) are available for pipe and other applications made using FRP material. Relying on the standards will take the pressure off the end-user to develop their own methods.

Alloy Comparisons for selection in various environments			
Levels of Corrosion Resistance	**Chloride Stress Corrosion Cracking**	**Sulfuric Acid**	**Oil Field Environments**
Outstanding	Nickel or Cobalt - Base Alloys -C 276	Nickel or Cobalt - Base Alloys -C 276	Nickel or Cobalt - Base Alloys -C 276
Excellent	Duplex Stainless Steel - 2205		
Good	Austenitic Stainless Steel 316	Duplex & Austenitic Stainless Steel 316, 2205	Duplex & Austenitic Stainless Steel 316, 2205

Step 4: Specify proper materials (glass fiber, resin, corrosion barrier) to construct the FRP application. When selecting the proper steel/alloy to use for a specific environment, there are many choices to consider. These are presented in Table 3.

Similar to selecting the best steel/alloy for a corrosive environment, selecting the best FRP material for a specific environment is just as important. FRP material used in corrosive environments is made of two sections (corrosion barrier and structural) and can be made of different materials.

FRP material is a combination of reinforcements, resins, and possibly other additives. Glass fiber is the primary reinforcement used in almost all (98%) FRP equipment. There are many different types of glass and resin available today. By combining these materials, an engineered material system is formed with unique attributes that can replace traditional materials used in corrosive environments. The system can be designed to withstand either low pH or high pH conditions. Figure 5 shows the components of an FRP laminate.

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The corrosion barrier faces the chemical environment and can range in thickness from 100 mils (2.54 mm) to 500 mils (12.7 mm) depending on the chemical, temperature, and other conditions. The corrosion barrier consists of the Inner surface veil (Yellow Section) and the chopped/Chopped Strand Mat portion (Orange Section) as shown in Figure 5.

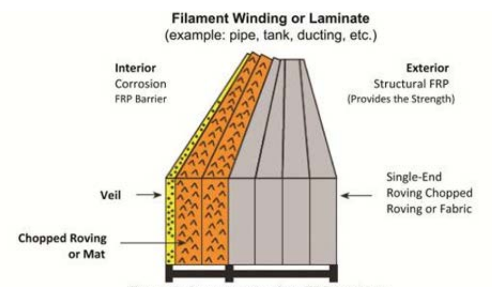


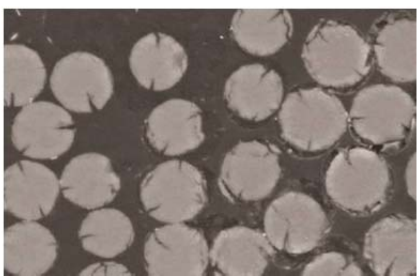
Figure 5 Components of an FRP laminate

The corrosion barrier does not provide any mechanical properties of the laminate and is only used to protect the structural portion against the corrosive environment. There are many selections for the type of veil used and is dependent upon the corrosive environment. Some veil types include: C-Glass, Advantex® E-CR Glass, Polyester, and Carbon. The glass type for the chopped glass fibers/Chopped Strand Mat is normally an Advantex® E-CR glass. In some cases, however, specifying a PVAC free Advantex® E-CR glass Chopped Strand Mat will improve the performance.

The structural portion of the laminate shown in grey in Figure 5 consists of 65% – 75% glass fiber reinforcements. The glass reinforcements provide the strength of the laminate and optimize the performance of the corrosion barrier. In corrosive environments, the use of Advantex® E-CR glass is highly recommended and supported by ASTM D 578 and ISO 2078.

To show the importance of the proper selection of glass fiber reinforcement type used for FRP used in corrosive environments, Scanning Electron Microscopy (SEM) pictures of a pultruded FRP rod that was placed in 10% sulfuric acid for three months are displayed in Figure 6. This is from a study conducted in April 2010.[3] When viewing the SEM of the E-glass, the glass fibers (white circular spheres) are starting to crack and de-bond from the resin. If a similar selection of glass were used in the field, there is a high probability the performance of this FRP equipment would not perform as well as one made with Advantex® E-CR glass. The SEM pictures of the Advantex® E-CR glass fibers experiencing the same environment and time (3-months) show no signs of deterioration and remain fully bonded with the resin. Similar to metal selection, it is important to work with industry experts who can help recommend the glass type for use in corrosive environments to gain the greatest performance at the lowest cost.

E-Glass

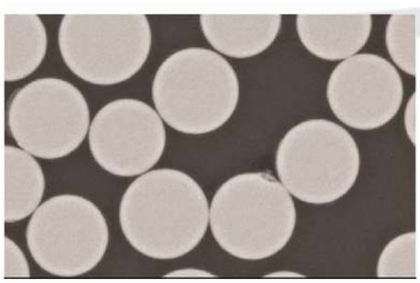


E-glass starts to break down, with leaching, and cracking causing de-bonding from the resin which could lead to the potential failure of the application.

The resin selection is also important and will depend upon the environment as well. Normally, the same resin is used throughout the laminate, including the corrosion barrier and structural portion. Both well-established glass fiber and resin suppliers can recommend the proper material selection (glass fibers and resin types) for any environment. It is recommended to use these resources for each new environment for the proper glass and resin selection. A record of the FRP material used for each environment should be kept so that the same material can be specified in the future for similar conditions.

Step 5: Implement proper inspection protocols. One you have the FRP assets installed, similar to steel or other materials, inspecting and maintaining these FRP assets are important for safety and long-term performance. There are several different methods used to inspect FRP equipment, and selecting the best method will depend upon the severity of the chemical service, temperature, or other factors.

Advantex® Glass



E-CR (Advantex®) glass continues to perform after three months with no leaching, cracking or weakening. It maintains its strength in a corrosive environment.

The various methods of inspection include:

A. Visual Inspection – The condition of the FRP equipment should be visually inspected by looking at the internal corrosion barrier, all joints and flanges, and all other connections. ASTM provides best practice to follow for visual inspection. ASTM D2563 – Standard Practice for Classifying Visual Defects in Glass Reinforced (FRP) Laminate Parts. This ASTM standard categorizes different inspection requirements for levels of product quality. The acceptance criteria shall be applied to the following: dimensions and tolerances, inserts, molded-in thread or cored holes, workmanship, critical area, allowable visual defects, repairable defects, surface finish, and surface appearance. Inspectors should look at the entire vessel for general appearance and note any discoloration that may be the result of improper wet-out of the glass fiber reinforcement or caused by overheating.

B.

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B. Acoustic Emission – ASTM provides a standard for acoustic emission testing titled: ASTM E1067-11 – Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels. This test method detects damage in FRP equipment including fiber debonding, resin cracking, delamination, and bond failure in joints (ex. Nozzles, manways, etc.). It is most effective when there is baseline information available. If using this method, it is important to conduct the first inspection soon after it is installed to establish the baseline. This type of inspection testing normally takes the longest to conduct and is the most costly.

C. X-Ray Digital Radiography – This method is good for inspecting pipe that is less than 30 inches (762 mm) in diameter while the pipe is in use. This method provides quality high resolution results that will allow an inspector to pick up and differentiate between the corrosion barrier and structural portion of the pipe. This method is also one of the most costly methods.

***D.* Ultrasonic Structural Characterization-** This method uses advanced procedures to analyze ultrasonic readings taken from one of the FRP surfaces. Readings can be taken from equipment while it is in service. The analysis provides information on the strength and condition of the entire FRP laminate thickness, as well as corrosion barrier condition and total thickness. This method is normally used to monitor changes in FRP vessels, pipe and structures throughout their lifetime and to calculate the remaining service life, as well as provide critical information for design of structural repairs

E. Destructive Testing – This process is used when a piece of the FRP equipment can be removed and examined by using SEM to evaluate the condition. As in Figure 6, the condition of the fibers and how well they are bonded to the resin can determine the condition of the FRP.

If necessary, perform any immediate repairs once an inspection has taken place, and then develop a future plan for preventative maintenance.

CONCLUSION

Corrosion-related damage is costing developed and developing nations trillions of dollars annually in repair and replacement costs. The use of FRP material can provide quality long-lasting performance and replace high cost stainless steels and alloys to help lower overall costs and maintain the high performance. Following the five key steps presented in this paper will help ensure quality, secure long-lasting results, and reduce risk when considering using FRP for applications in corrosive environments.

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