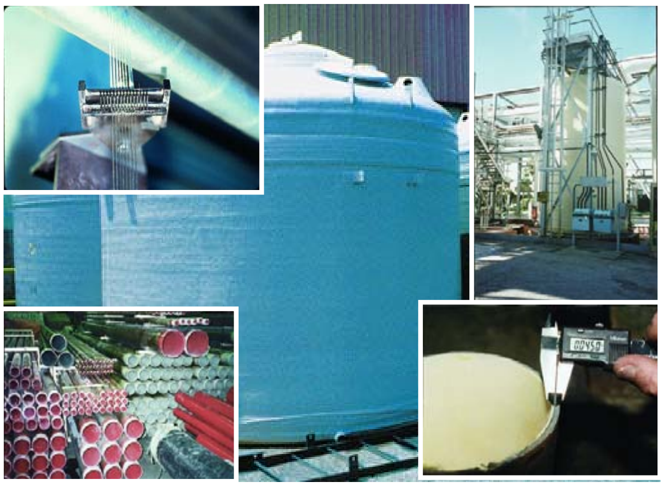

FRP Inspection Guide

An Inspection Guide for Fiber-Reinforced Plastic (FRP) Equipment

REICHHOLD

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The *FRP Inspection Guide* is to assist end users, engineers, and others interested in conducting quality assurance (QA) inspection and preventive maintenance (PM) inspection of fiber-reinforced plastic (FRP) equipment for corrosive industrial services..
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Statement of Purpose

The purpose of this document is to assist end users, engineers, and others interested in conducting quality assurance (QA) inspection and preventive maintenance (PM) inspection of fiber-reinforced plastic (FRP) equipment for corrosive industrial services. It is not intended to be an exhaustive instruction manual. We hope that it will encourage informed and effective use of FRP in corrosion-resistant applications.

Objectives

Quality Assurance (QA) Inspection

The objective of quality assurance inspection is to maximize the safety and reliability of new FRP equipment by confirming that equipment has been manufactured in accordance with the requirements of purchase documents and related specifications. This process requires a review of the manufacturer's internal quality control program and direct inspection of equipment by the owner or a designated representative.

Quality assurance demands familiarity with the unique characteristics of FRP and knowledge of the specialized tools and instruments used to inspect it. The inspector must be able to recognize manufacturing and material deficiencies and be prepared to negotiate effective, appropriate repairs that will ultimately enhance the long-term service life of the equipment.

Preventive Maintenance (PM) Inspection

The objective of preventive maintenance inspection is to reduce maintenance costs and the threat to safety and reliability caused by unexpected equipment failure. Properly conducted and applied, PM inspections will result in cost-effective and reliable repair decisions based on an accurate assessment of the equipment's condition and the rate at which that condition may be deteriorating. Preventive maintenance of FRP requires on going data collection through interior and exterior equipment inspections using specific tools and methods.

Inspection should be combined with an engineering evaluation of the findings, and documentation that retains correct information in the proper form for long-term trend evaluation. On the basis of current conditions and rate of change, the owner must decide between various options including repair, replacement, or continued use of the equipment. The decision maker must understand how FRP differs from metals and other, more familiar materials, and how those differences affect long-term safety and reliability.

If the owner decides to repair equipment in service, it is important to recognize the risks involved, specify the method and materials of repair, and verify compliance to the repair specification through inspection.

It is as important to inspect piping and critical ducting as it is to inspect tanks and process vessels. Pipe failure is a common cause of equipment down time, while vessel failure represents the greatest risk to life and property. There are fundamental differences in the inspection methods and tools required for inspection of piping and vessels.

Terminology

This manual assumes a basic familiarity with industry terminology. If additional information is required, please refer to ASME RTP-1, M-11 Glossary.

Fiber-Reinforced Plastic Technology

Resins

Resins can be divided into two broad classes: thermosetting and thermoplastic. This document discusses composite materials formed using thermosetting resins combined with fiber reinforcement. Thermoplastic resins have a definite melting point, whereas thermosetting resins cure to produce an infusible solid material that does not melt when heated. They soften when heated above their glass transition temperature, but do not reach a liquid state. Thermosetting resins used for FRP are typically purchased in liquid form and are reacted to a solid with chemical additives.

The most commonly used thermosetting resin systems for corrosive industrial applications are:
- Vinyl ester
- Bisphenol-A fumarate
- Terephthalic polyester
- Isophthalic polyester
- Chlorendic polyester

These resin families have unique usefulness depending upon the specific corrosive, temperature, and engineering requirements of the application. For more information regarding selecting the proper resin for a specific application, please consult a Reichhold materials selection guide, or call the Reichhold Corrosion Hotline at 1-800-752-0060.

Additives

Industrial thermosetting resins require incorporation of additives before use. With pre-promoted resins, only an initiator (often called a catalyst) is required to initiate the curing reaction. However, resins are often purchased in non-promoted form, requiring addition of carefully measured quantities of promoter(s), and thoroughly blending them into the resin before initiator is added to effect curing.

Resin additives are typically highly reactive and must be stored and handled according to manufacturers' recommendations. **NEVER MIX PROMOTERS WITH INITIATORS, SINCE VIOLENT DECOMPOSITION AND POSSIBLY EXPLOSION MAY RESULT.**

Peroxide Initiators

Initiators are typically the final additive required to initiate the curing reaction. Promoters and/or inhibitors may be added to prepare the resin hours, days, or weeks before it will be used. The initiator is added immediately prior to use, and the amount employed is one factor that determines the working life of the resin.

The most commonly used initiator systems for the resins listed previously include:

Methyl Ethyl Ketone Peroxide (MEKP)
Methyl ethyl ketone peroxide is the workhorse initiator system. It is generally the easiest to use, especially in adverse conditions. It provides excellent curing performance, and responds well to post-curing.

Cumene Hydroperoxide (CHP)
Cumene hydroperoxide is used when a more controlled reaction rate is required. When used in conjunction with MEKP, it can reduce or eliminate foaming in vinyl ester resins, and lower the laminate exotherm temperature of bisphenol fumarate resins.

Benzoyl Peroxide (BPO)
Typically used in paste form, benzoyl peroxide may be more difficult to evenly disperse in resin than MEKP. It also requires special care to ensure that the correct ratio of BPO to dimethylaniline accelerator is maintained throughout the resin. This initiator is sometimes specified in the mistaken belief that it enhances the corrosion resistance of FRP. Given the mixing issues, the need for more precise measurements, and its post-cure insensitivity, use of BPO for enhanced corrosion resistance is questionable in all applications.

Promoters, Inhibitors, and Other Additives

These materials are used to prepare the resin for reaction with the initiator and to alter rheology, flame-retardance and other specialized resin or laminate properties. They are often added by the resin manufacturer.

Promoters
Cobalt naphthenate or octoate are used to adjust the gel time of the curing reaction.

Inhibitors
Hydroquinone (HQ) and tertiary-butyl catechol (TBC) are used to stabilize polyester and vinyl ester resins after manufacture. They are seldom added in the field but may be useful in conditions where the reaction time and rate cannot be controlled by adjusting other additives. In vinyl ester resins, 2,4-pentanedione (PDO) is sometimes used to achieve very long gel times. This effect is not consistently observed with other types of resin.

Accelerators
Dimethylaniline (DMA) has a significant effect on the hardness development and peak exotherm temperature of the curing reaction, and can be used to reduce gel time.

Additives for Flame-Retardance
Antimony trioxide and antimony pentoxide are added to halogenated resins at 1.5% to 5% by weight. In a fire, these materials exert a synergistic effect with chlorine and bromine by forming antimony

oxychlorides or oxybromides, which are highly effective flame retardants. Antimony is only effective in the presence of chlorine or bromine. Addition of antimony compounds to resins that do not contain chlorine or bromine will not provide any additional fire protection.

Thixotropic Additives

Fumed silica is added to resin to prevent it from flowing out of the reinforcement before cure. It can also be used to formulate resin putties. Fillers, pigments and thixotropes are typically not used in the corrosion barrier due to their adverse effect on corrosion resistance.

Fillers and Pigments

Common fillers include silica flour, glass microspheres, milled fiber, graphite, carbon, metallized fibers, silicon carbide, and ceramic beads. These materials may be added to extend resin or to add other properties, such as electrical conductivity or abrasion resistance. Pigments are used to modify the color and opacity of the resin. Fillers and pigments are not commonly used in the corrosion barrier.

Wax Solutions and Topcoats

Wax solutions, typically 10% wax dissolved in styrene monomer, are sometimes added to resins in order to provide enhanced surface curing. When resin cures, wax exudes to the surface and forms a barrier between atmospheric oxygen and the curing laminate. This prevents the oxygen from inhibiting resin cure at the laminate surface. Typically 1.0% to a 5.0% wax solution is used. Call the Reichhold corrosion Hotline at 1-800-752-0060 for recommendations.

Wax-containing resins are used whenever it is necessary to create a laminate with a fully-cured surface, for instance when performing repairs to an existing corrosion barrier, or applying an FRP lining.

Care must be taken when using wax solutions for two reasons. Wax can separate out of the resin, or out of the original solution, upon exposure to low temperatures. Also, use of waxed resin typically produces a cured laminate that may not bond to subsequently applied layers of FRP. Should it be necessary to apply a secondary laminate to FRP prepared with wax-containing resin, surface preparation will be required.

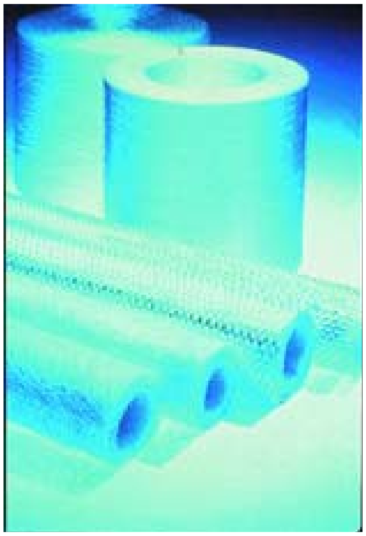
Wax topcoats are often formulated by blending wax, thixotrope, a UV stabilizer and possibly a pigment into resin. This topcoat is then applied to the outer surface of corrosion resistant equipment, where it protects the equipment from sunlight and the effects of the external environment.

Reinforcements

Fiber reinforcements that are used in the corrosion fiberglass industry include various forms of glass fiber, such as E-glass and a newer, more corrosion resistant version, called ECR-glass. Synthetic fibers such as polyester surfacing veil, or carbon veil (for abrasion resistance and conductivity) are also available. Occasionally, aramid or carbon fibers may be used in the structural laminates to improve the strength-to-weight ratio. The most common forms of glass reinforcement are:

Fiberglass Roving

Spooled fiberglass roving is commonly used in the corrosion industry for filament winding and as feed stock for chopper guns (fiberglass and resin spray guns).



Fiberglass Cloth and Woven Roving

When fiberglass strand is woven into a fabric, it is called cloth or woven roving depending upon its weight.

Woven roving is a heavy fabric that is the primary structural component of most hand lay-up laminates. Both 18 and 24 oz/sq. yd woven rovings are commonly used. Six and 8 oz/sq. yd fiberglass cloths or directional fiberglass reinforcements may be used where strong, thin laminates are needed.

Chopped Strand Glass Mat

Roving strand is cut into approximately 2” lengths and formed into a sheet using a resin binder.

Chopped-strand mat is available in thicknesses ranging from 3/4 to 3 oz/sq. ft. The most commonly used mats are 1.5 oz/sq. ft.

Surfacing Veil

Surfacing veil is a very thin sheet material formed from either synthetic polyester fiber of random lengths or very fine C-glass fibers. Exotic veils, such as carbon fiber veil, are sometimes used where specialized properties are needed. Veil is used to place a thin (10mils per ply), even, highly resin-rich surface onto FRP equipment in areas that will be in contact with a corrosive environment.

In most applications, use of 1 ply of C-veil is sufficient, and can be easily and effectively applied. Polyester surfacing veil is more difficult to work with, but it may improve corrosion resistance in services such as chlorine dioxide and hydrofluoric acid. Use of multiple veils will result in a thicker resin-rich layer that may be beneficial, but also increases the risk of cracking in thick, highly resin-rich areas.

Laminate Construction

FRP laminates for corrosion service are constructed using a variety of processes and materials as noted below. Different as they appear to be, these processes have many similarities. Most corrosion-grade laminates have a corrosion barrier and a structural wall.

The corrosion barrier is dedicated to resisting surface corrosion and to preventing the process environment from permeating into the structural wall. The structural wall is that portion of the laminate dedicated to mechanical support. In some cases, such as ducting or hoods intended for mildly corrosive service conditions, the laminate may be manufactured using only random chopped glass and therefore have no separately defined corrosion barrier and structural wall.

Construction Methods

FRP materials are products of both the raw materials and the construction process used. The most commonly used processes for producing corrosion-grade FRP parts are filament winding, contact molding, centrifugal molding, matched die compression molding, and pultrusion.

Filament-wound parts are relatively inexpensive to make and are characterized by a high strength-to-weight ratio. Strength and stiffness are gained by winding tapes, random chopped glass, or glass roving in a spiral pattern, commonly referred to by its helix angle (the angle between the longitudinal axis and the spiral pattern).

For helically wound laminates, the primary strength and stiffness can be varied between the hoop and axial direction by altering the helix angle of the wind. A good corrosion barrier is necessary to protect the continuous filament wound structural laminate from the effects of permeation or “wicking” by process fluids should the corrosion liner be breached.

Contact Molding

Contact molding refers to a process by which layers of dry glass saturated with resin are applied against a form or mold.

The laminate produced by contact molding is often referred to as “hand lay-up.” Hand lay-up may also refer to any laminate that is composed of plies of fiber reinforcement in sheet form where the resin and reinforcement are applied using a spray gun, a bucket and brush, or a special spray system called a chopper gun, which simultaneously applies chopped glass and resin.

Contact molding is used to produce ancillary parts for tank shells, such as nozzles, elbows, and flat, conical, or dished heads and bottoms. It is also used for complete tanks and pipe. Normally, hand lay-up parts are very tough and resistant to permeation and wicking. While not as strong as filament-wound FRP for a given thickness, contact molding is unquestionably the best way to manufacture the most highly corrosion-resistant equipment intended for the most challenging corrosive services. ASTM C 582 gives typical construction and properties of corrosion-resistant hand lay-up laminates.

Laminate Types

FRP is referred to as a composite material because it combines the widely divergent properties of its constituents – reinforcing fibers and resin – into a unique material. Reinforcing fibers contribute virtually all of the material’s strength; resin channels stress into the fibers and provides corrosion resistance. Because of this, corrosion-resistant FRP uses two basic laminate types: a corrosion barrier and a structural laminate.

Corrosion Barrier

Corrosion barrier laminates are usually made starting with one or more plies of resin saturated C-glass or synthetic veil against the process surface. The resin-rich veil plies in the corrosion barrier contain approximately 90% resin by weight, making them effective barriers to permeation and corrosion. Veil is followed by two or more plies of 1.5 oz chopped strand mat, or an equivalent thickness of resin and chopped roving. This second layer contains about 70% -75% resin by weight, and also functions as a permeation and corrosion barrier. The high resin content of the corrosion barrier effectively shields the structural laminate from chemical attack.

Structural Wall

The structural wall gains its strength from glass fiber, and therefore maximum glass content of the structural wall is sought. The fiberglass may be filament-wound or hand lay-up, or may use another arrangement wherein plies of continuous, directional fiber are placed to provide specific strength and stiffness as required by the equipment specification. The fiber content of structural wall laminates may range from 25% by weight for hand lay-up to 70% or more for filament winding. This high fiber content permits FRP structures to combine high strength, light weight and low cost.

Codes and Standards

A quality assurance inspection program is intended to verify that the level of quality inherent in the specifications is, in fact, delivered to the purchaser. In order to make this happen, that level of quality must be detailed clearly and quantitatively in the specifications,

A poorly written specification with conflicts, errors, and omissions is one of the most frequent cause of disputes during inspection or elsewhere in the purchase documents.

The specification writer must be aware that existing standards for FRP may not always be sufficiently rigorous to assure a given level of quality. It is sometimes necessary for the specification writer to add further descriptive language.

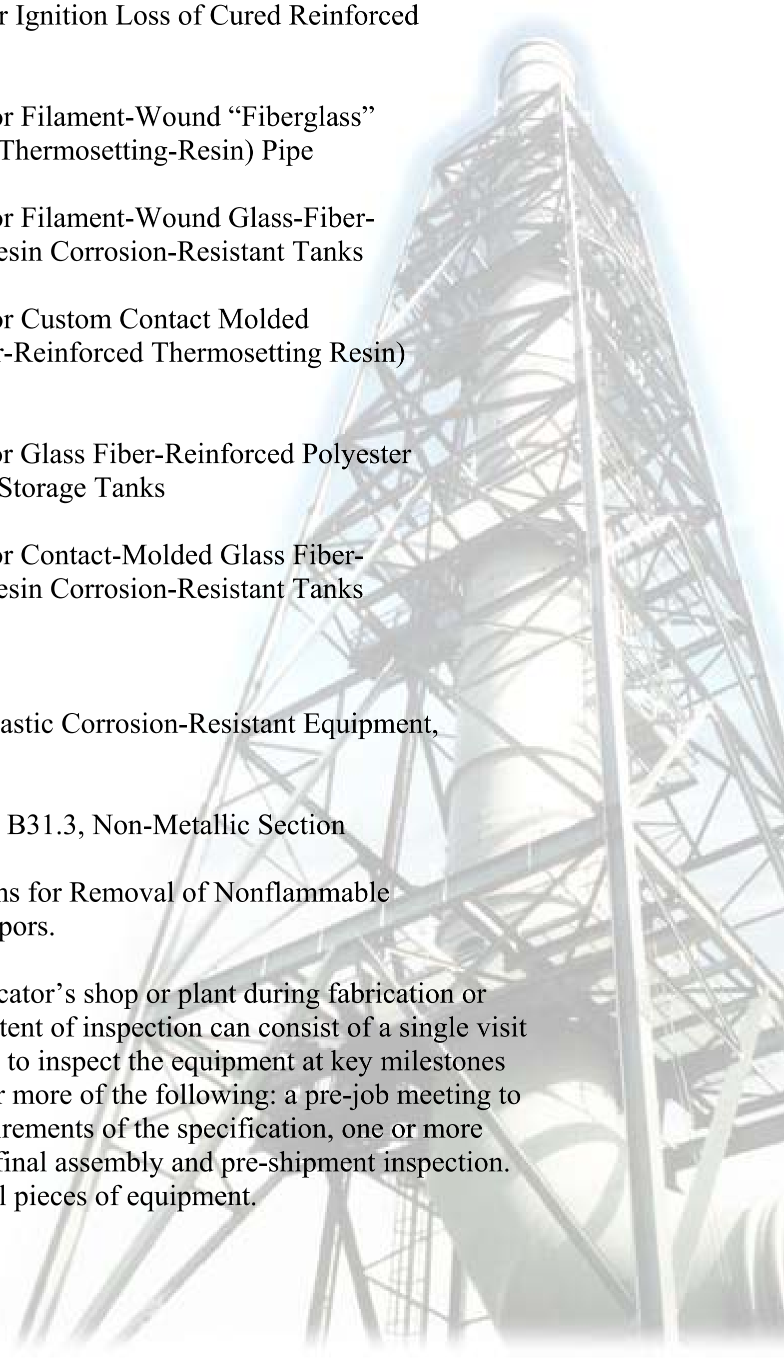
It is the specification writer's responsibility to ensure that the language of the specification is sufficiently rigorous to establish the desired level of quality.

The following commonly used codes and standards have related content:

ASTM C 582	Standard Specification for Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion-Resistant Equipment
ASTM D 2310	Standard Classification for Machine-Made "Fiberglass" (Glass-Reinforced Thermosetting-Resin) Pipe
ASTM D 2471-71	Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins

ASTM D 2517	Standard Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings
ASTM D 2563	Standard Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts
ASTM D 2583	Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
ASTM D 2584	Standard Test Method for Ignition Loss of Cured Reinforced Resins (Burn Test)
ASTM D 2996	Standard Specification for Filament-Wound “Fiberglass” (Glass Fiber-Reinforced Thermosetting-Resin) Pipe
ASTM D 3299	Standard Specification for Filament-Wound Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks
ASTM D 3982	Standard Specification for Custom Contact Molded “Fiberglass” (Glass Fiber-Reinforced Thermosetting Resin) Duct and Hoods
ASTM D 4021	Standard Specification for Glass Fiber-Reinforced Polyester Underground Petroleum Storage Tanks
ASTM D 4097	Standard Specification for Contact-Molded Glass Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks
ASME Section X	Vessel Code
ASME/ANSI RTP-1-1995 1995 Edition	Reinforced Thermoset Plastic Corrosion-Resistant Equipment,
ASME	Code for Pressure Piping B31.3, Non-Metallic Section
ICBO Report ER-4055	Class 5 FRP Duct Systems for Removal of Nonflammable Corrosive Fumes and Vapors.

Quality assurance inspection is typically done in the fabricator’s shop or plant during fabrication or immediately after fabrication and before shipping. The extent of inspection can consist of a single visit to inspect the final product, or it can include several visits to inspect the equipment at key milestones during fabrication. The latter will generally include one or more of the following: a pre-job meeting to inspect the shop and tooling and discuss the specific requirements of the specification, one or more inspection visits during winding or lay-up of parts, and a final assembly and pre-shipment inspection. On large orders, these milestones often overlap for several pieces of equipment.



Quality Assurance (QA) Inspection Technology

Inspection Tools

Following is a list of tools and equipment used to verify the conformance of fabricated parts to the requirements of the specifications.

Common Hand Tools

Tools commonly used include flashlights, a sounding wand (e.g. putty knife with a solid handle to tap for voids), a protractor, and dial or digital calipers. A 35 mm camera or a high resolution digital camera with strobe for normal range and macro images is ideal for documenting appearances. Use of dimensioning tape is suggested to provide scale in photographs.

Dimensional Verification

A tape measure and/or calipers are used for linear measurement. A Pi (π) tape is used for measuring diameters of molds and finished products.

Thickness Verification

Most equipment will have cutouts for nozzles and access ways that can be checked for accurate thickness with calipers. For equipment where access is not available, ultrasonic or magnetic meters are available.

Low frequency ultrasonic meters that are specifically designed for FRP use provide accurate and rapid one-sided measurements, assuming that a representative laminate of known thickness is available for calibration[1]. The Polygauge® modified magnetic intensity (gauss) meter* provides another method of measuring laminate thickness[2]. This instrument employs a calibrated permanent magnet and provides very accurate thickness reading, assuming that both sides of the laminate are accessible.

Cure Verification

Barcol** hardness is the industry standard for measuring laminate surface hardness[3], which is directly related to the degree of resin cure. An acetone sensitivity test for surface solubility of uncured resin can provide a rough indication of surface cure.

Sounding Wand

An approximately 3-ft-long slender wand with a metallic bead on the end is useful for sounding large surface areas for voids. This method, which involves wiping the bead over the surface in a smooth continuous motion, is much more efficient than tapping with a heavy object. However, it may be necessary to tap as well, particularly to detect deeply embedded defects.

** Polyguage® is a registered trademark of Brampton Nameplate Inc., Brampton, Ontario, Canada*
*** Barcol hardness is a value derived using the Impressor® hardness tester from Barber-Colman Company, Loves Park, IL, USA*

Inspection Methods

Dimensional Inspection

It is assumed that any experienced inspector will be familiar with the methods of layout inspection. This discussion will deal only with inspection issues that are unique to FRP equipment.

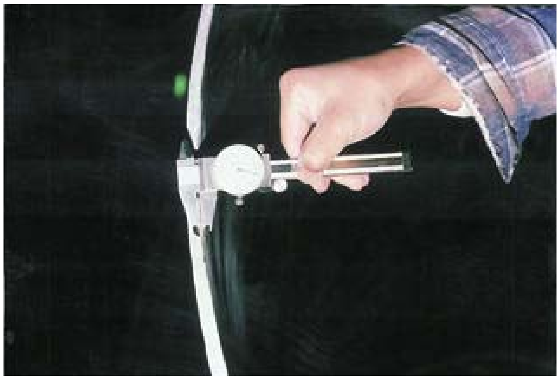
Flange Flatness

Shrinkage can cause FRP flange faces to draw back during cure. Standard specifications require flatness to 1/32" on piping and 1/16" on duct. It is commonly checked by placing a straight edge on the flange face and measuring the gap between the straight edge and the FRP surface.

Bottom Flatness

The bottom of fiberglass vessels and the support surface must be flat so that the weight of the contents will not cause damage. A straight edge is used to assure that overlays, which connect the bottom of the vessel with the side shell or are used at the mandrel shaft penetration, do not create a discontinuity greater that 1/4" in one foot.

Laminate and Ply Thicknesses



It is essential that the full specified thickness of the corrosion barrier and structural wall laminates, and the thickness and number of component plies, are maintained. Inspectors must verify ply thickness wherever possible. This may be done by asking the fabricator to save and label the location and orientation of all shell cut-outs and by carefully measuring ply thickness with calipers at all exposed cut edges during construction. When ply consistency is in doubt, conduct ignition testing of cut-outs. Responsibility for the cost of taking core samples and testing should be addressed in the specification.

Helix Wind Angle

The helical wind angle of a filament-wound structure is important because it affects the strength and stiffness of a laminate. To measure the wind angle, a protractor is used to measure the angle formed by the intersection of the winding bands. The angle should open in the direction perpendicular to the axial centerline of the equipment. The wind angle (in degrees) is then determined by the formula:

Wind Angle = 90^{o} – (the measured angle/2)

If it is difficult to measure the wind angle directly from the part, it may be measured from a paper "rubbing" of the surface. Hold a piece of blank paper on the surface and rub it with a lead pencil until an image of the helix angle appears.

Cure Verification

Barcol Hardness Measurements

The hardness of resins is an indication of the level of cure. Hardness increases as cure progresses until a maximum for the resin type is reached.

ASTM D 2563 requires a minimum of 10 Barcol hardness readings to determine the hardness of a specimen of plastic. This is accomplished by taking 12 separate readings, discarding the highest and lowest readings, and averaging the remainder. Minimum Barcol hardness readings are specific to a given resin type, but are usually about 30 at 25° C.

Synthetic veils typically reduce the Barcol harness of laminates by approximately 5-10 units. High temperature (caused, for example, by direct sunlight) can also dramatically reduce Barcol test results. It may be necessary to cool equipment before testing. It is also advisable to scratch away any wax surface coat that may be present before taking a Barcol reading. Because resin is often mixed in batches and dispensing equipment can fail, separate measurements are needed in areas of distinct resin batches or at least every 100 sq. ft on large equipment.

Acetone Sensitivity

Resins cured next to a mold are protected from oxygen as fabrication continues. However, in completing secondary overlays, such as joining or patching, the finished laminate is exposed to air. Oxygen inhibits resin cure. To prevent inhibition of the cure, the final layer is flooded with a resin that contains paraffinated wax. These surfaces can be checked for cure using an acetone wipe test. Solubility is determined by applying clean acetone to a surface and feeling the surface for tackiness after 30 seconds. Do not use reclaimed or contaminated acetone, or test results may not be accurate.

Visual Inspection

Visual inspection can be categorized in two ways, either by overall visual appearance or by inspection for localized visual defects. It is the specification writer's responsibility to ensure that the requirements of specifications are realistic. Specifications that establish a level of visual defects that are unnecessary for the process conditions may cause the equipment to become unnecessarily expensive[4].

Global Appearance

Inspectors must look at the entire vessel for general appearance, noting the presence of discoloration that may be the result of improper wetout of the reinforcement or overheating. In some instances, cure difficulties and even accidental resin substitutions have been detected by large-scale changes in color. Large-scale disbonding of a subsurface ply may be visible as light and dark areas.

Local Defects

The Standard Practice for Classifying Visual Defects in Glass Reinforced Plastic Laminate Parts (ASTM D 2563), provides the specifier with an important resource for managing the quality of corrosion-resistant FRP. ASTM D 2563 provides the option of specifying three different levels of quality. It is the specifier's responsibility to assure that the requirements of the specifications are realistic – from both the technical and the economic points of view. Specifications that establish a level of visual defects that is unnecessary for mild process conditions may increase the cost of the equipment without providing any significant benefit.

Thickness Verification

Laminate thickness may be tested using a variety of methods. Multiple thickness readings are required because of the potential for localized under-thickness resulting from missing plies and/or malfunctioning application equipment. Separate readings may be appropriate at specified thickness change, on separately molded parts, on major overlays, and for every 100 sq. ft on large hand lay-up parts.

Core sampling is the most common method for determining overall thickness of a laminate, ply thickness, and the resin-to-glass ratio. Core samples are destructive and therefore are a last resort option.

Magnetic Thickness Testing

The Polygauge® modified magnetic intensity (gauss) meter allows non-destructive measurement of laminates up to 1.25" thick, although the current (circa 1998) model does not measure against steel. A separate model is available for linings on steel. Unlike ultrasonic instruments, the Polygauge is not sensitive to laminate ply density. It is based on a Hall crystal and is therefore very sensitive to ambient temperature. Properly calibrated, the magnetic thickness meter is the most accurate method for non-destructive testing of FRP thickness.

Digital Ultrasonic (UT) Instruments

Digital ultrasonic thickness measurement instruments are available to quickly and accurately measure the thickness of FRP parts without access to both sides of the laminate. UT instruments are best used when large numbers of similar parts are being evaluated, because they must be calibrated from a representative laminate type before each test.

Pi (Diameter) Tapes

In addition to measuring diameter, Pi (diameter) tapes may be used to verify the thickness of smaller diameter cylindrical objects by measuring the diameter of the mandrel and then measuring the diameter of the completed part. This check is commonly used on large pipe assemblies and works especially well when verifying joint thickness.

Material Verification

Depending on the specification, an inspector may be required to verify the quality of the raw materials used. The inspector will need to verify that the fabricator's quality control tests have been conducted and that the data has been recorded and is found to conform to the governing specifications using accepted methods.

Fabricators may be required to maintain a list of all material batches received and to link them with exact part numbers for traceability. Because resin is partially formulated by the fabricator, a record of the type and amount of additives used should be maintained with the resin batch records. The performance of resins can be monitored by several field test procedures including gel time, peak exotherm, and viscosity. ASME RTP-1 NM-6 is an excellent source of example checklists for QC inspection, including material verification[4,5].

Gel Time and Peak Exotherm

The performance of the final laminate depends on the laminate reaching a full state of cure. Gel time and peak exotherm are two important quality control tests used to monitor the cure. ASTM D 2471 governs gel time and peak exotherm testing.

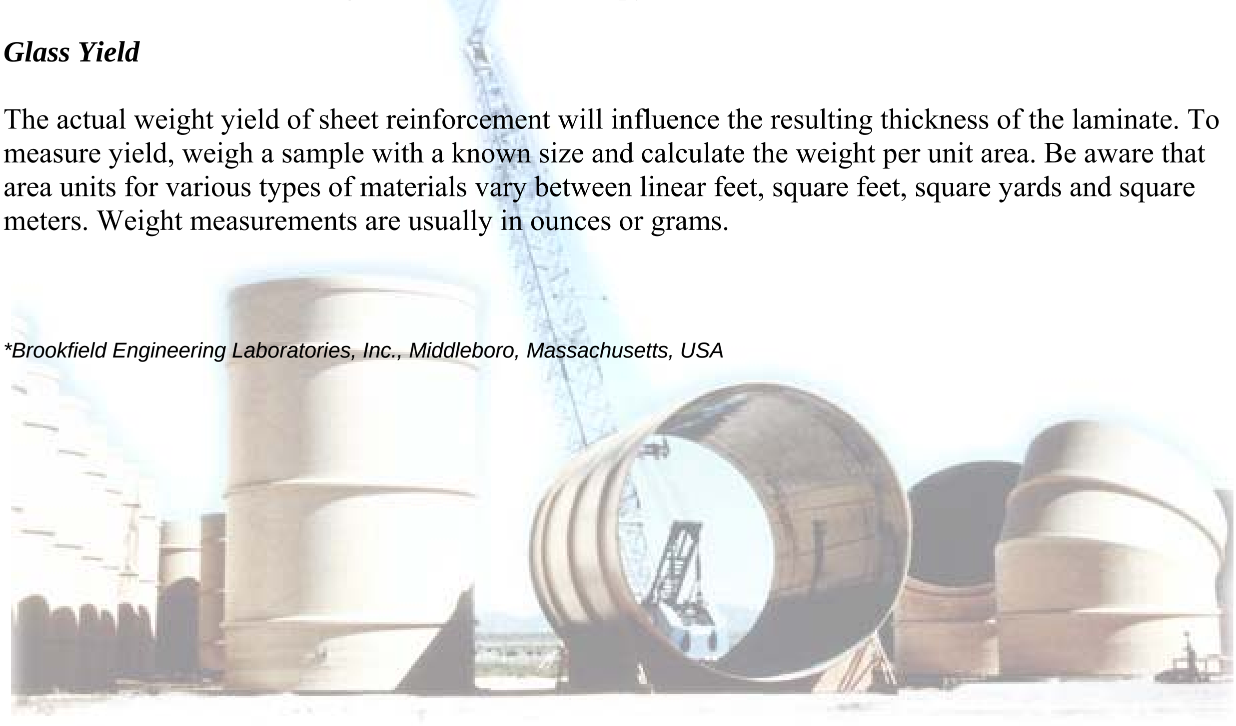
Viscosity

Viscosity that is out of specification may indicate a problem with the resin, including excessive or deficient diluent levels, settling of thixotrope, and possibly partial gelation. Temperature has a significant effect on viscosity, so all tests should be conducted at 77° F/25° C.

Brookfield* viscometers measure the resistance of a liquid to a rotating spindle and are a simple, accurate method of measuring viscosity and thixotropy.

Glass Yield

The actual weight yield of sheet reinforcement will influence the resulting thickness of the laminate. To measure yield, weigh a sample with a known size and calculate the weight per unit area. Be aware that area units for various types of materials vary between linear feet, square feet, square yards and square meters. Weight measurements are usually in ounces or grams.



**Brookfield Engineering Laboratories, Inc., Middleboro, Massachusetts, USA*

Testing

The following procedures often are not within the capabilities of an inspector and, with the possible exception of AE, are not generally used during routine shop inspections. However, they can be valuable assets and have been found to be useful in special cases.

Acoustic Emission (AE) Testing

Acoustic emission tests on used equipment are most effective when there is baseline information available. It is therefore recommended that all critical FRP equipment be baseline AE tested soon after start-up. Once in service, the amount of AE testing that is done is the owner’s prerogative. Often, equipment is tested at a point in time approximately halfway through the estimated life span of the equipment. Ongoing testing will depend on the results of this test. When critical equipment is nearing the end of its service life, regular AE testing can provide a meaningful structural evaluation that may prolong equipment use and prevent unexpected failure.

Acoustic emission testing identifies and locates active defects in laminates by detecting minute acoustic impulses that are generated as a defect propagates under load. A major advantage of this procedure is its ability to monitor an entire piece of equipment quickly. The instrumentation consists of a specialized mixer and amplifier that feeds sensor data to a software-driven signal analyzer. The size and complexity of systems vary, but most will monitor 20 transducers (microphones) simultaneously and analyze the input signal for arrival time, amplitude, and duration. This information can be organized and displayed graphically. Guidelines for procedures related to AE have been published under the SPI “Committee on Acoustic Emission from Reinforced Plastic” (CARP) and in ASME RTP-1, Appendix M-105.

Infrared (IR) Scan

This test can identify the resin type used for manufacture using a small sample of cured laminate (a 0.5” x 0.5” sample is enough). This procedure involves the use of large and expensive equipment. Commercial laboratories will require spectra from all potential resin families for comparison in order to make a positive identification. In most cases, identification will be limited to the resin family and not a specific brand name.

Documentation

Inspection Checklist

Shop inspection documentation must provide a concise, clear, and complete record of inspection. Using an inspection checklist for each part will assure adequate documentation. A complete checklist must provide a place to identify the fabricator, owner, identity of the project, and to record all other relevant information.

This may include:
- Fabricator shop QC documentation
- Material verification records and test results, batch records, burn tests
- Manufacturing controls, such as shop environment, use of chopper gun
- Laminate quality, cure tests, visual defects
- Layout verification and part name tag identification
- Verification tests, such as hydrostatic pressure or acoustic emission (a separate report would be required for AE, but the checklist should record that the test was done).

Use of Photography

The use of still photography is recommended to document defects. Either 35 mm or high quality digital photographs are acceptable. Inspectors should label the subject on the photograph and provide a reference to give scale. Inch labeling tape or simple 2-inch stickers will suffice in most cases. Photographs of equipment loaded on the delivery truck can prevent later misunderstandings between owner and manufacturer. Load-out photographs should be taken from all available angles before shipping. Videotaped documentation with narration can also be useful.

Preventive Maintenance Baseline Data

The inspection checklist, along with photographs or videos, provides excellent baseline data for future Preventive Maintenance inspection programs. If possible, a core sample cutout should be retained as well for future reference.

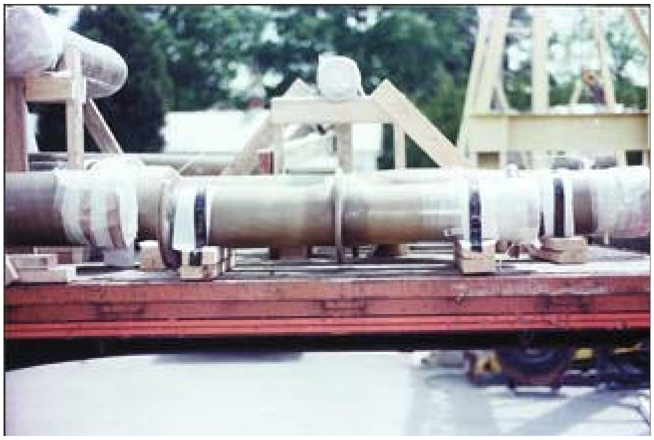
Special considerations for Field QA Inspection

Shop inspection is performed in the fabricator’s shop. Field inspection, on the other hand, is performed during installation. While many issues are the same in the shop and the field, some field requirements are more stringent. This section will discuss those quality issues that require additional attention in the field.

Shipping and Installation

Damage found in FRP equipment in service can often be attributed to shipping and handling or improper installation. For this reason, the equipment specification should include handling and installation practices. For additional information on shipping practices, refer to ASME RTP-1 NM-8.

The equipment manufacturer should provide a set of guidelines for shipment of the equipment. The guidelines should include the location and a generic description of saddle types and a plan to provide protection for sensitive areas, including flange faces, mating joint surfaces, and cut edges. The tie-down methods should assure that rubbing and points loading are prevented.



Handling and storage instructions should be provided for unloading and setting the equipment. It is recommended that the inspector examine and photograph each load before leaving the site and, if possible, after arrival at its final destination.

Tanks should be placed on full support bases without sharp discontinuities. A thin foam pad may be used, but long-term support must be assured. Tanks may be set in wet grout, but only by an experienced, qualified contractor.

Environmental Monitoring

When field lamination is required, environmental conditions must be monitored to assure reliability. Resin manufacturers typically limit working temperature to between 60° F and 90° F. Most resins are capable of reacting significantly outside these limits, but consistency is more difficult to control. Colder temperatures make attainment of a high degree of cure challenging; at warmer temperatures fast gel times and high laminate exotherms can be problematic. High humidity can result in bond failures when moisture is allowed to condense on the work surface. Painting specifications require that the working surface temperature be at least 5° F greater than the ambient dew point. Environmental conditions should be monitored and logged with the option to take readings whenever there is an apparent change in ambient conditions.

When it becomes necessary to alter the ambient temperature in the work area, use a non-contaminating heat source, such as an electric, propane, or oil-fired heat exchanger. Avoid direct-fired oil or kerosene. Humidity problems may be exacerbated by propane heaters because propane produces water vapor when it burns. Portable air conditioners are available for humidity control.

Control of Materials

Contamination of materials by humidity, rain, or dirt and debris must be prevented. Minimum temperature and humidity in the material storage areas must be maintained, and all joint kits must be wrapped in a non-contaminating protective covering before being moved to the site (polyethylene sheet is excellent; wax or oiled papers are not recommended). Batch wrapping overlays also makes it easier for field crews to assure proper ply-count and sequence.

Surface Preparation and Bond Testing

In most cases, secondary bonds are applied to new air-inhibited laminate surfaces that are clean and chemically receptive. Applications to such surfaces are not considered at risk of failure, and, therefore, special bond testing is not required. When secondary bonds are applied to fully cured laminates, special precautions are required.

Surface Preparation

It is always recommended that the manner and degree of surface preparation be carefully inspected before a secondary overlay is applied. In most cases, the surface will have to be roughened by grinding before applying secondary overlays. As described below, it is often advisable to conduct bond tests before proceeding with field installation.

Primers

In many new equipment applications, primer is not required to achieve an excellent secondary bond. On used equipment, complete abrasion to remove all obviously wet, contaminated, or discolored materials is always required. Contamination may not be visible, so primer may be required to achieve the desired results. Reichhold's ATPRIME® 2 is a special FRP primer with excellent wettability, surface tolerance, and adhesion characteristics.

Part Fixturing

Part movement during bonding is a common cause of laminate failure during start-up or hydrotesting. This is particularly common in the field because of difficult set-up and changing conditions. For instance, if the temperature changes thermal expansion or contraction may dramatically alter the position of an unrestrained pipe run. Adequate fixturing must be assured before lamination.

Bond or Adhesion Testing

Two issues must be considered when deciding whether to repair or replace FRP equipment:
What is the physical condition of the equipment, and is it in a condition that can be effectively repaired? One key issue that must be understood before deciding to repair is how well the existing substrate will accept an adhesive bond. For this reason, bond testing may be used as a qualifying test prior to specifying repairs, and may also be conducted as part of the inspection to predict the effectiveness of proposed repairs.

Typical questions resolved by bond testing are:

- How deep must the surface removal go to achieve a bond?
- Will a primer be required?
- Will a thin bonding ply (a thin layer of mat, cured separately before starting the repair laminates) be required to reduce stresses on the bond plane?
- Will the chosen surface abrasion method be adequate?

There are portable field instruments for testing adhesion; however, they are designed for testing thin film coatings (such as paint) and do not work consistently with laminates. Therefore, most actual field testing is by a method commonly called peel testing. Peel tests are conducted by applying a patch of laminate to the subject surface and removing the patch after it has cured. The effectiveness of primers and surface preparations can be compared by judging the amount of damage done to the surface during removal. Peel testing is a qualitative test, heavily dependent on the experience of the inspector.

A 10” x 10” bond test patch is suggested, consisting of MMWRMWRM (M = 1.5 oz random chopped mat, WR = 24 oz woven roving). This assures that the patch is large enough for evaluation and stiff enough to peel at the bond plane if the bond is weak. Tape is left under one edge of the patch to start the peeling.

The sites for test patches are prepared in a matrix so that all the variables under consideration are explored. Test patches are applied, using the same methods, time, and environmental constraints that will be used during fabrication. The patches are allowed to cure until specified Barcol hardness is reached, and then removed by prying loose. The separated surface is examined for damage. An excellent bond will result in severe damage to both the sample surface and the substrate.

Optimally, the sample will shear and not be removed whole. An inadequate bond will result in wholesale failure at the bond plane with little damage to the sample or substrate. Often it is necessary to accept results that are less than optimal; however, there should always be torn fiber at the interface and some transfer of the substrate to the sample or the reverse. At least 80% of the sample surface should be severely affected. Bonding can often be dramatically improved by applying a thin layer of Reichhold’s ATPRIME® 2 according to the manufacturer’s instructions before applying a new laminate.

Preventive Maintenance (PM) Inspection Technology

While there are similarities between quality assurance inspection and preventive maintenance inspection, their purpose is quite different. Quality assurance inspection, whether in the shop or in the field, is the inspection of new fabrications. Preventive maintenance inspection is the inspection of equipment that is already in operation. As its name implies, the purpose of PM inspection is to prevent unnecessary repairs and maintenance by detecting problems before they lead to failures or to excessively costly repairs.

Inspection Tools

The same tools used for QA inspection are used for preventive maintenance inspection.

Inspection Methods

Inspection methods that are unique to preventive maintenance inspection include:

Control Area

A control area is an area where the development and progression of defects can be monitored over a period of time. This technique is used to document the extent of cracks, blisters, or other widespread visual defects.

Document the exact location of the control area and the location of all defects within the control area on the wall of the vessel along with a dimensional reference. Photograph the area in detail and include the photographs with the inspection report.

Infrared (IR) Thermography

IR imaging allows a rapid, non-contact overview of equipment and provides a global assessment of potential defects, such as large inner-surface thickness irregularities and voids in the laminate. Depending on the age and model, cameras vary widely in size, performance, and cost. A compact, planar array unit with internal cryogenic cooling is recommended. This type of unit is expensive, but it will provide optimum clarity with the least ambient interference, and will minimize blurring between warm and cold zones in the image. Use of thermography is more of an art than a science. It is recommended that a thermographer with experience with FRP equipment and technology be engaged for this purpose.

X-ray Radiography

A radiographer with specific FRP experience can use X-ray to evaluate FRP piping that is less than 30 inches in diameter while the pipe is in use. The X-ray technique used on FRP is relatively low power and produces high-resolution results that will normally allow differentiation between the corrosion barrier and structural wall. On-line radiographs must be set up so that vibration of the running pipe does not interfere with the exposure. Gauge blocks in the image plane are required for valid thickness measurements.

Types of Damage

Many types of damage may be found in FRP equipment, and the causes of this damage are likewise numerous. This section summarizes the most common types and causes.

Aging Damage

In addition to many of the types of defects found during QA inspection, e.g. delamination, cracking, etc., there is damage to in-service FRP equipment that is characteristic of the aging process. Aging damage is progressive, beginning with attack by aggressive fluids to the corrosion barrier and progressing over time into the structural wall. A laminate is considered to have failed when aggressive fluids have breached the corrosion barrier and attacked the structural wall.

Various types of aging damage are described below.

Surface Attack

Surface attack is the most obvious type of aging damage in FRP equipment. It takes many forms and may be the result of chemical reactions, heat, erosion, or a combination of influences. Surface attack is often most severe at start-up because:

- The process may not be well-controlled at start-up
- An inner film on the surface of equipment may not be fully cured
- A protective barrier film may be formed on the inner surface after start-up that limits further attack.

These factors make it important not only to understand the cause of degradation, but also to measure its ongoing rate before making maintenance decisions. Surface degradation is expected and may not be a problem unless the rate of attack is such that structurally significant plies of the laminate are, or will be, damaged before repairs can be completed.

Barrier Film Formation

In some services, a film or barrier that is a product of a reaction between the resin and process chemicals forms on the process surface of FRP equipment. In chlorine services this is often referred to as chlorine butter. As noted above, a barrier film that is firm enough to stay on the process surface will form a thermal and chemical barrier that reduces the ongoing rate of attack.

Stripping

Sometimes the surface will appear stripped of resin. In some cases, there will be loose fiber remaining, leaving a fuzzy surface. This implies that the process fluids have decomposed and carried away the resin but have not attacked the fiber. If the stripped surface is polished, it is probably caused by erosion.

Mud-Cracking

Mud-cracking is a term that refers to a surface that appears parched with random interconnected cracking. The cracking will normally be slightly open and limited to the inner veil layers and may be curled up near some of the cracks (reminiscent of a mud-puddle in the summertime). Mud-cracking is common in hot chemical environments and is the result of shrinkage caused by the loss of matrix materials to the process stream. This defect may be limited to the veil layers, not penetrating far into the inner mat layers of the corrosion barrier. Even then, it will expose the mat layers directly to the corrosive media, which may lead to more rapid deterioration of the corrosion barrier.

Erosion/Corrosion

The combination of erosion and chemical attack is particularly damaging for FRP. Without a protective surface layer, there is always fresh, reactive chemical available to continue the process of corrosive attack. When erosion/corrosion failure is expected, the short-term viability of the equipment may be in question. In these situations a detailed review by qualified engineering personnel is recommended.

Permeation

Organic polymers are semi-permeable and are penetrated by elements of the process environment. This is expected, and is not a problem unless the permeant reacts with or solubilizes components of the laminate, damaging the laminate matrix or causing the formation of pressure-filled pockets. These pockets are commonly referred to as osmotic blisters. The term semi-permeable indicates that the material will allow passage of some permeant while filtering out others. Small polar molecules are most likely to permeate into laminates made from corrosion-grade resins. In most cases, the permeant is almost entirely water; however, some process materials, such as hydrochloric acid, can permeate FRP quite effectively.

Osmotic Blistering

In most cases, only a very small percentage of an FRP laminate is soluble in permeants. When permeant in a laminate collects in a small void and finds sufficient concentrations of soluble materials, the dissolved solution can exist at pressures high enough to cause disbonding and formation of pockets (blisters). Osmotic blisters normally grow rapidly in the first years of service but gradually stop growing as the concentration of soluble material is diminished. Blisters are not considered a problem unless they result in break- up of the inner surface or contamination of the process, or if they expose the structural laminate.

Fiber/Resin Bond

Permeant, including warm water, can eventually cause disbonding between the resin and reinforcement. The separation causes the reinforcement to become more visually prominent (called jackstraw). Jackstraw by itself is seldom a cause for repair, because it is typically limited to the corrosion barrier and does not affect performance of the corrosion barrier laminates.

Stress Corrosion

While it is often difficult to identify stress corrosion as a mechanism apart from stress or chemical attack, it is valuable to understand that highly stressed areas of a laminate may be more susceptible to corrosive attack. Stress corrosion is suspected when deep cracking occurs from the process side of a laminate that is essentially free from loose fiber on the separated surfaces.

Mechanical Damage

Mechanical damage refers to cracking and deformation of the laminate. It is important to distinguish mechanical damage, caused by shrinkage or thermal shock, from defects related to physical overloading of the structure. There are several important indicators to consider.

Structural Cracking
Is the direction or location of the damage associated with a support, stiffener, or with a change in shape of the equipment? If the answer is "yes", the cause may be stress concentrated at those locations. When cracking is deep and follows the direction of the reinforcement, or when major bundles of structural reinforcement are severed, the cause of the damage may be an overloaded structure. If an overloaded condition is suspected, short-term viability of the equipment is in question and qualified engineering personnel should review the situation.

Surface Crazing
Surface crazing is often a pervasive shallow surface defect. It is a pattern of fine interconnected, closed cracks, also referred to as "spider cracking," that is usually limited to the inner veil layers. Surface crazing is most often shallow and slow growing. It should be monitored by a control area, but it typically does not warrant immediate repair.

Deformation
Severe deformation in any support related area of equipment is a structural concern that should be referred to a qualified engineer.

Heat-related Damage

Corrosion-grade thermosetting resins have upper temperature limits that vary depending on their chemistry. Several things occur when FRP is exposed to inappropriate temperatures.

Loss of Strength, Stiffness, and Hardness
Laminates soften and lose rigidity with excessive heat. Overloaded conditions will be exacerbated and erosion may increase. If the overheated condition is brief and does not cause significant chemical attack, the laminate may regain its former properties when it cools. If equipment has been severely overheated, structural concerns may warrant in-depth engineering evaluation, possibly including tests such as acoustic emission.

Thermal or Shrinkage Cracking
FRP laminates shrink during cure and have a coefficient of thermal expansion approximately six times that of steel (depending on reinforcement). Because of these factors, it is not uncommon to find cracking related to shrinkage or expansion in FRP equipment. Shrinkage cracks occur when shrinkage causes the laminate to bend, stressing the inner surface. They are often shallow, parallel patterns that follow an abrupt change in laminate thickness.

Thermal Shock-Related Cracking
Thermal shock-related cracking is often manifested in round vessels as widespread patterns of short parallel cracks running in the axial direction. The cracks are shallow, but they warrant more long-term

attention than shrinkage-related defects, because the cause is a process condition that may be ongoing, thus leading to ongoing crack growth.

Shrinkage
Shrinkage-related defects might not create an immediate maintenance concern because they are shallow and because the causal factors are not ongoing.

Oxidation
Oxidation is the final stage of heat damage and will leave a charred surface and possibly internal laminate damage. The short-term viability of charred equipment may be questionable, and qualified engineering personnel should review such situations.

Preventive Maintenance Inspection Methodology

Step One – Understanding What You Have

This means gathering as much of the original information as possible. Review files to retrieve the purchase specification and drawings and all available records of repair or inspections. It is not uncommon to find that the files do not contain specifications or drawings of the original equipment, much less information on how the equipment was originally fabricated and installed.

Fill in the blanks by discussing the equipment with the operators to gain additional historical data and information on how the equipment is currently being used. Tanks originally intended to hold one chemical might have been pressed into service involving other chemicals that the original design did not anticipate.

Document this information in condensed form in the equipment and maintenance history sections of the PM report.

Step Two – Perform an Initial Evaluation of the Equipment

Review all of the above before the equipment is taken out of service. Time is at a premium during shutdown. Every task done beforehand saves time and permits a more intensive inspection of the inside of the equipment when it is opened.

Step Three – Inspect the Equipment and Gather Data

Preventive maintenance is a long-term process. Therefore, it is imperative to know where you started from by developing a baseline. The baseline is data to which all future inspections are compared. It allows analysis of trends in equipment performance and extrapolation of future performance. If the PM program has begun well into the service life of the equipment, some deterioration of the equipment may already have occurred. Nonetheless, this becomes the starting point for future inspections.

In subsequent inspections, new deterioration should be compared to the baseline data documented in previous inspections.

Much of the preventive maintenance inspection process is subjective, but the inspector should make every effort to quantify inspection measurements. Measurements may include deformations of the equipment, wall thickness, depth of the corrosion layer, and hardness of the laminates, photographs of defects which include scale references, drawing maps of deterioration including dimensional data, using standard symbols of your own creation for each common defect and measuring the extent of each defect.

Inspection requires patience, craftsmanship, and attention to detail in an environment that may be driven by time pressures of a shutdown schedule. Inspectors must take precise measurements and document them carefully, and maintenance managers must ensure that the inspector has sufficient time inside the equipment to do a proper job.

Vessel Inspection Procedures

Inspection is not a predictable process. Every piece of equipment is different, even if it is only the orientation of the piping which, by virtue of its geometry, introduces greater or lesser thermal forces into the shell of the equipment. Damage will vary and often operates through complex interactions. Most defects will not be understood until time has been spent studying the equipment and considering the forces and dynamics that characterize its operation.

The following overview of the inspection process is intended to provide the reader with a starting point and inspection cues for in-depth evaluation of a system. It is not a complete list of procedures and is not intended to be a training guide or a substitute for professional engineering inspections. However, in some cases, advanced inspection technologies are described.

Exterior

Vessels
The purpose of exterior inspection is to find defects that may indicate structural failure, including possible cracking at hub or surrounding shell penetrations, and cracking and/or deformation in the proximity of supports or stiffeners.

Fine cracking at the hub of flanges is common; however, severe or open cracks may be evidence of failure in progress. Hoop cracking in winding bands that attach lifting and hold-down lugs is probably the result of resin shrinkage and is not a maintenance concern. Crystalline build-ups are an early sign of leak-through. Discoloration may indicate laminate damage.

Inspect the concrete base of the tank for evidence of leakage or damage to the concrete.
Check the condition of the hold-down lugs.

If a tank is insulated, the scope of external inspection will obviously be restricted. It will be possible to check the flanges, base, lugs and weep-holes at the base of the insulation jacket for signs of leaking.

Piping

Gather isometric drawings of all critical FRP runs (if available), and organize them into PM units. In the absence of a pre-established order, organize the drawings into runs that connect major pieces of process equipment (each run may involve several line numbers and multiple drawings), and that share a common process environment.

Next, organize the PM units in logical process order starting with the most critical. A single report is normally required for each PM unit. Add as-built and historical information to the piping report. It is best to use inspection isometric drawings that are drawn for that purpose in CAD, because they will be less confusing and more compact and comprehensive. If this is not possible, construction isometrics can suffice, but will require manual updating.

Conduct a complete external inspection of each pipe run. Mark all leaks, cracks or other high risk defects for repair. Look and listen for severe vibration, cavitation, or obvious design/manufacturing deficiencies. If the pipe is partially empty, use ultrasonics to test the portion of the pipe that is above the liquid level with estimated velocity settings. This will yield readings that are within 10% to 15% of actual and provide an indication of severe underthickness. Estimated velocities are obtained by testing representative samples of various laminate constructions in advance.

Identify and prepare locations for X-ray gauge points on critical pipe runs. In general, at least one gauge point every 200 feet on critical runs is suggested. They should be located at potential wear/corrosion points, such as tees, injection points, elbows, pump discharges, reducers, control valves, or at major changes in direction or stiffness.

Joints and elbows should be inspected. The thickness of a representative sample should be compared with the requirements of the design for pressure ratings. Joints should be centered on the pipe ends being joined. Discoloration on pipes and joints may indicate delamination.

Inspect the hangers for appropriate support. Look for missing or corroded parts. A high percentage of in-process piping failures are due to inadequate or incorrect support. Many FRP piping runs have steel supports that are better suited for metal systems and may cause abrasion damage to the FRP. Steel supports should always have a neoprene cushion between the support and the FRP pipe.

Inspect all flanges and document all critical cracking or leaking.

Identify locations where easy internal visual access is available during shutdowns and document on the inspection isometric drawing. These may include blinds and small valves, etc.

If the piping runs at least 30°F above ambient, scan the piping with an IR imaging camera and document all suspect irregularities.

Interior

Visually inspect the interior. Identify corrosion zones including liquid and vapor phase and other unusual chemical environments. Note all visual evidence of aging damage, including cracking, blistering, delamination, mud-cracking, and thermal shock. Particularly note any defects that may affect the short-term viability of the equipment, such as structural cracking or defects that expose the structural laminates to the process stream.

Sound all secondary overlays for delamination. Establish control areas to quantify the spread of pervasive defects, such as blistering and surface crazing.

If available, measure the thickness of the shell at all distinct shell thickness zones using magnetic or ultrasonic thickness testers. Also measure the remaining thickness where abrasion or structural overloading is suspected.

Take Barcol hardness readings on the liner.

Record the data in the ongoing Preventive Maintenance inspection report.

Piping Inspection Procedures

Piping systems may be best inspected while the plant is in operation (on line). Follow-up internal inspections during shutdowns are also important.

Shut-down Follow-Up Inspections

During a subsequent shut-down; follow up on the on-line PM inspection results by opening the visual access locations and confirming the visual condition and taking actual thickness measurements.

Step Four – Perform Immediate Repairs, if Necessary

Based upon an assessment of the factors listed above, be prepared to undertake repair work as soon as the system is opened and the inspection team has had a chance to look at the interior. If serious defects are found, immediate repairs, however minor, may save an unplanned outage or stabilize the equipment enough to prevent more extensive and more expensive repairs later.

Step Five – Develop a Plan for Future Preventive Maintenance Inspections

Preventive maintenance is a complex process since causes and effects of chemical attack can be subtle, diverse and act over a long period of time. The process of finding problems and then categorizing and analyzing them can be tedious and complex. As with any engineering problem-solving process, an orderly and structured process for performing and documenting the inspection is imperative to assure that all critical data is captured, especially data that is available only while the system is open. The preventive maintenance plan then becomes the “road map” for assuring that necessary maintenance is performed effectively as needed.

If this is a subsequent inspection, the existing preventive maintenance program should be updated to include the results of the current inspection.

Maintaining Control of Repairs

General

Field-applied repair laminates are far more likely to fail in service than shop laminates. A few basic steps can minimize this risk:

1. Choose a well-qualified supplier of repair services. Do not let geographic location be the major decision criterion. Repairs made by proficient and experienced contractors are usually more cost-effective in the long run.
2. Establish a specification for field repair. At minimum, it should address resin type, reinforcement type and sequence, surface preparation, laminate application, environmental conditions, bond testing, inspection, post-cure, and allowable defects.
3. Be directly involved in the project. Inspect the work while in progress and when completed.

Surface Preparation in the Field

Correctly prepared surfaces are absolutely critical to the success of any FRP repair.

In preventive maintenance repair, it is often necessary to apply new bonds to used and potentially contaminated surfaces, as in the case when “tying-in” to an existing pipe system. In these cases, the bond may be at risk, either because an in-service laminate is highly cured and not receptive to bonding, or because it is contaminated. For this reason, special precautions must be taken when applying FRP in the field.

On used equipment, complete abrasion to remove all obviously wet, contaminated or discolored materials is always required before secondary bonds are attempted. When preparing contaminated surfaces, contaminants must be removed without recontaminating the substrate with cleaning agents or other foreign materials. Clean with styrene, not with acetone. Slagblasting does not carry contamination on the media, but may recontaminate if the compressed air is not carefully filtered. Shearing has the unique quality of cutting the contaminated material away leaving the least possible residual contamination.

Abrasive Grinding

Grinding is the most commonly used method for small repairs. It is relatively slow and produces the least aggressive anchor pattern (the surface profile for adhesive bonding) of the three available methods. When using abrasive disks it is important to change disks before the final pass over the surface. Use #16 or #24 grit grinding disks.

Shearing

Shearing uses a rotary surface planer, such as the Turbo-Shear by BRER Technical, Bellingham, WA. A rotary surface shear is a specialized carbide face mill coupled to a small electric or air hand grinder. Shearing rivals sandblasting for productivity, leaves a light fiber pull on the surface that helps anchor secondary bonds, and is relatively clean, producing large chips instead of abrasive dust.

Slagblasting

Slagblasting uses a large sieve copper slag, such as Black Beauty. Slag blasters are large apparati that use slag instead of sand as the blasting medium. Slag is heavier and sharper than sand and therefore is much more effective.

Priming

Primers are often required to produce the best possible secondary bond to aged FRP and other materials such as concrete, steel and other metals, and many thermoplastics. Reichhold's ATPRIME® 2 provides excellent adhesion to a wide range of substrates. Primer must be applied over freshly prepared surfaces. No more than 24 hours should elapse between preparation and priming.

To Repair, Reline or Replace?

Two issues must be considered when deciding whether to repair or replace FRP equipment: what is the physical condition of the equipment, and is it in a condition that can be effectively and economically repaired?

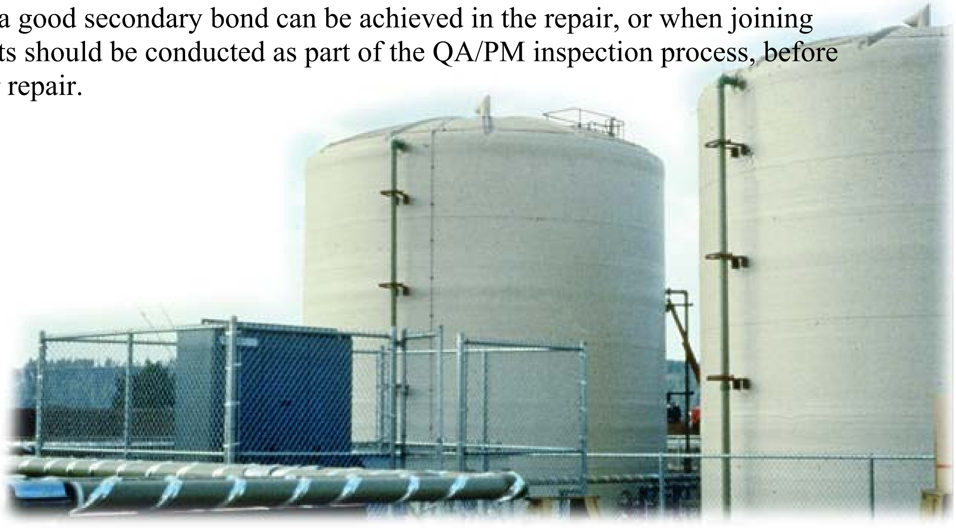
One key issue that must be understood before deciding to repair is how well the existing substrate will accept an adhesive bond. For this reason, bond testing may be used as a test prior to repairs, and may also be conducted to determine the effectiveness of completed repairs. See the preceding section titled *Bond or Adhesion Testing* on page 20 for details.

If the structure of the equipment is intact and secondary bonding is an option, it may be possible to reline the equipment with an entirely new corrosion barrier, thus economically extending its service life for many years.

The decision to repair, reline or replace is critical, and may be impacted by factors that are not immediately evident. If in doubt, a detailed review by qualified engineering personnel is recommended.

Bond Verification

A method for testing the adhesive bond of secondary overlays on laminates is described on page 20. If the inspector is not certain that a good secondary bond can be achieved in the repair, or when joining new to old equipment, bond tests should be conducted as part of the QA/PM inspection process, before committing to relining or major repair.



Documentation

Effective PM Documentation must provide an accurate record of the current condition of the equipment and a means for determining the rate of change when compared with the results of previous inspections. The report should be updated with each inspection and not replaced, providing continuity with past findings and improving its usefulness for the evaluation of trends. A PM report should contain the following information:

- A summary of conclusions and recommendations for future repair and inspection
- A complete log of all inspections to-date
- A record of equipment construction methods, materials and the operating environments to which the equipment has been exposed
- Historical information, including major upsets or overloads and repairs
- The ongoing observations and measurements of the inspectors. Inspection data is easiest to enter and interpret if recorded on a simple elevation sketch (vessels) or isometric drawing (piping).

References

1. Webster, R.M., *Safety in the Use of Fiber-Reinforced Plastic Equipment for Chemical Service*, SPI/SPE/NACE Symposium, St. Louis, MO (April 1971).

2. Bishop T.N., *Loss Prevention Through Preventive Maintenance Engineering of Fiberglass Reinforced Plastic (FRP) Equipment*, 75th Meeting of the Canadian Pulp and Paper Association.

3. Bishop T.N., *Preventive Maintenance for FRP Equipment*, Materials Performance Magazine, NACE Intl., Feb. 1994, Vol. 33, Number 2.

4. R. E. McMahon and R. J. Lewandowski, *Effect of Laminate Quality on Chemical Resistance of Reinforced FRP Structures*, 30th Anniversary Technical Conference, 1975, Reinforced Plastics/Composites Institute, The Society of the Plastics Industry, Inc.

5. American Society of Mechanical Engineers, RTP-1, 1995 Edition.

Material Safety Data Sheets

Material Safety Data Sheets are available for all of the Reichhold products listed in this brochure. Please request the appropriate data sheets from you customer account specialist before using any product.

Please Note Certain Typical Property Changes

Some of the typical properties in the publication may be slightly different from those in previous publications. The changes reflect most recent manufacturing experience and/or changes in test procedures. Due to availability of raw materials, changing government regulations, market conditions, or other reasons, typical properties may changes or a product may be discontinued.

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