A Practical Guide to
Field Inspection of
FRP Equipment and Piping

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Preface

This document presents the first comprehensive field guide to the inspection of Fiberglass Reinforced Plastic Equipment (FRP). Photographs of actual failures illustrate the various degradation modes. Additional case histories and photographs will be presented in subsequent editions of this guide.

This guide will prepare an inspector to perform inspections of FRP equipment and piping even though the inspector may not be familiar with FRP technology. Understanding the basic principles of inspection methodologies is necessary, however this does not have to involve FRP equipment.

This guide is intended for inspection of in-service equipment. This guide assumes that quality assurance inspection of newly fabricated FRP equipment has been conducted, and that the requirements in the purchase specifications are met. Therefore, some defects that are only found in new FRP equipment are not included in this guide. The defects addressed in this guide refer to those that have occurred after being put in service. Inspection reports for as-received equipment and previous in-service inspection reports should reveal defects that may (or may not) have been repaired; these areas deserve special attention by the inspector.

This guide DOES NOT equip the inspector to make judgments regarding the corrective action to be taken for any defect observed. As with other inspections, the inspector should meticulously observe and report his findings. (An obvious exception is when the inspector finds a dangerous situation that requires immediate attention. This should be reported as soon as possible.) An experienced FRP specialist should recommend corrective actions.

This guide does not include complex inspection techniques such as acoustic emission testing, ultrasonic defect testing, x-ray inspection or thickness measurements (except those which can be measured using mechanical instruments such as calipers, rulers, etc.)

It is not possible to include in this guide every defect that could occur. Rare defects are not presented this guide.
CHAPTER 1

What is FRP?

This section will provide an overview of the principles of fabricating FRP equipment. Special emphasis will be given to those areas that are likely to contribute to or cause problems.

General Description

FRP is an acronym for Fiberglass Reinforced Plastic. In other countries it is known as GRP (Glassfiber Reinforced Plastic). Some years ago the term RTP (Reinforced Thermoset Plastic) was used, as it was believed to be more descriptive of the material. The common term today is FRP, but all these terms refer to the same material.

FRP is essentially a fabrication of laminates consisting of a resin matrix with reinforcement fibers optimally distributed in this matrix. The resins are Thermoset polymers that are relatively weak with strengths in the range of 2,000 to 5,000 psi (13.7 to 34.5 MPa) and they are also very brittle compared to metals. Typical elongations to failure are <1% to perhaps 5%. The laminate construction takes advantage of the very high strength and modulus of elasticity of reinforcement fibers such as glass fibers, which have tensile strengths of over 300,000 psi (2,070 MPa) and modulus of elasticity of 10x10^6 psi (6900 MPa). However, the fibers are easily mechanically damaged and the commonly used E-glass fibers are readily attacked by acids, caustics and fluoride-containing chemicals. Therefore the role of the resin is three-fold: (1) to hold the laminate together, (2) to transfer load from reinforcing fiber(s) to other reinforcing fibers, this requires excellent bonding to the fibers, and (3) to protect the fibers from mechanical and chemical degradation.

One major difference between FRP fabrication and metal fabrication is that in FRP fabrication the material (with all the inherent properties) and the shape of the equipment are fabricated and
formed at the same time. With metals, the material properties and shape are generated at the same time only when metals are cast, otherwise the metal is purchased in standard shapes, such as sheet, plate, and bar and then bent, welded, etc. to generate the final desired equipment.

Resins

There are many chemically resistant resins used in the process industries in FRP construction. Note that general-purpose resins for ordinary applications (boats, fishing rods, roof panels, etc) are not used for chemical service. The resins used for chemical service are:

*Polyester resins.* These are very popular and very versatile. There are at least two varieties: Bisphenol A fumarate polyester and Het-acid polyester (also known as chlorendic acid or chlorendic anhydride polyester). There are also a variety of modifications to increase flexibility, fire retardance, curing variations, etc. These resins are widely used, are chemically resistant, have good high temperature resistance, but are relatively brittle although some recent versions have more resiliency.

*Vinylester resins.* These resins are also very popular. They are chemically resistant and have more flexibility. Some versions (based on novolac epoxy) have higher temperature resistance and better resistance to some organic chemicals.

*Isophthalic resins.* These are less expensive resins rarely used for chemical service. One exception is underground gasoline storage tanks; however when alcohol is a fuel additive, isophthalic resins are not sufficiently resistant.

*Furan resins.* These resins are used in special cases where organic chemicals are combined with acids and/or alkalis. They are difficult to fabricate and are used only when their unique properties are required. They are very brittle and difficult to repair.

*Epoxy resins.* These resins make the strongest FRP constructions, but are not available for tank construction because of skin sensitivity of many workers to the fumes. They are used in piping fabrication where automatic construction allows hoods for venting.

*Other resins.* Rarely used are resins for special applications. Phenolic resin, originally used for electronic “bread boards”, is very resistant to many chemicals, but fabrication difficulties, cost and difficulty of repair limit its application much like furan resins.

**Reinforcing fibers.**

The reinforcing fibers must be strong to fulfill their strengthening role. Fortunately fine fibers are available with very high strengths. The most common glass composition used in FRP construction is E-glass fiber, originally made for electrical applications. This glass fiber is used
extensively for many applications including insulation, filtering, etc. and volume production makes it very economical. A summary of fibers used in FRP construction is:

*Glass fibers.* The E-glass composition fiber is the most common. However acids, alkalis and fluorine-containing chemicals, readily attack it. Therefore, it is very important to insure that the resin matrix adequately protects these fibers. Another glass composition, available recently, is E-CR glass made with less boron oxides. It is more resistant to mineral acids and is almost as available as E-glass. The most chemically resistant glass composition is C-glass. These fibers are not available in quantity but are fabricated for the “inner surface” (described below) in veil form for most applications. Other compositions of glass fibers are also available for the inner surface, but the common glass compositions are those described above.

Glass fibers are produced in a variety of forms. The veil is a web of continuous fibers but very thin so as to form a light veil with plenty of air space. Chopped strands are made by chopping strands to 1 to 2 inches (25 to 50 mm) length. The strands are multiple fiber bundles about as heavy as heavy thread. Rovings are larger bundles (less than 1/8 inch (3mm) round of continuous fibers. They are provided in spools for unwinding and applying as “filament wound” laminates or for weaving and applying as “woven roving” laminates. Other glass fiber forms are available but are rarely used in chemically resistant FRP equipment.

*Synthetic organic fibers.* These fibers are primarily polyester fibers used instead of glass in the “inner surface”. They are provided in a thin felt web of various constructions. They are used when glass veil is not appropriate, i.e. for exposure to caustic and fluorine or fluoride chemicals. A common trade name is Nexus™ veil.

*Carbon fibers.* These fibers are becoming common for the veil in the inner surface to replace synthetic veils. In the inner surface, they also are used for a static electricity discharge mat in applications where a spark could cause a fire or explosion and are replacing carbon powder filled resins. In very special cases, equipment can be made using all carbon fibers i.e. - no glass at all. This is expensive, unusual to fabricate, and therefore very rarely used.

**Laminate construction.**

FRP equipment is made up in layers or laminates either by hand or by machine - spray or winding machine. A limited thickness of laminate or combination of laminates must be allowed to (partially) cure before additional material is added in order to prevent excessive heat buildup from the curing reaction, which can cause burning, or charring of the FRP. The total wall of the vessel pipe is composed of a “corrosion barrier”, a structural wall, and (if desired) an outer corrosion barrier.

*The corrosion barrier.* The corrosion barrier is composed of an “inner surface” and an “interior layer”, see figure 1. This combination was found empirically to provide the best overall resistance to chemical attack.
**Inner surface.** This layer is composed of the veil, described above, reinforcing a resin-rich (and therefore very chemically resistant) zone. The inner surface is 10% reinforcing veil and 90% resin and is only 10 to 20 mils (0.25 to 0.50 mm) thick.

**Interior layer.** This layer is composed of chopped strand E-glass fibers often applied by hand in mat form using “chopped strand mat”. Two layers of mat are used. The total thickness is 0.1 inch (2.5 mm) and is about 25% reinforcing glass fiber and 75% resin.

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**Figure 1.** Schematic view of a laminate wall showing the corrosion barrier consisting of (a) the inner surface 0.010 to 0.020 inch thick and (b) the interior layer composed of chopped fiberglass strands 20 to 30% by weight and at least 0.1 inch thick. The structural wall is shown as (c). Note that the optional “exterior surface” is shown on the outside as (a’) and is the same composition and thickness as the inner surface (a); its purpose is to avoid chemical attack on the exterior of the equipment from, for example, spills during filling or unloading.

**The structural layer:** The structural layer is reinforced with E-glass fibers in the form of either chopped strand, filament wound, or woven roving. Filament winding is very popular as it is fast, automated, and provides a very large amount of fibers, up to 75%, which gives the highest strength for a given thickness. Pipe is almost always filament wound. However, the heads and
some other parts of tanks cannot easily be filament wound, so these are normally hand laid up using chopped strand fibers. Sometimes a whole tank is made using a spray-up technique, which builds a layers of chopped strand fibers quickly; this process can be semi-automated and is often used to fabricate a large number of standard size tanks. An example is gasoline storage tanks for underground gas storage at local gas stations.

*The exterior corrosion layer*: The exterior corrosion layer is not mandatory but is used when a protective layer is necessary to avoid chemical attack of the structural laminates in areas where spills occur or where chemicals from adjacent operations could attack the structural laminates. This exterior layer is often the same construction as the inner surface and in severe cases the same construction as the inside corrosion barrier. In most cases the external surface consists of an un-reinforced thin “gel” coat.

**Fabrication Techniques**

There are two common techniques for fabricating chemical process equipment. These are contact molding and filament winding. Both require molds to form the inside shape and both have the same “corrosion barrier”; the major difference is the kind of laminates in the structural layers.

*Contact molded laminates*. Contact molded laminates are made from chopped strand mat, from automatic spray of chopped strand, or from alternating woven roving with chopped strand lay-up. Sketches showing the structure of the glass fiber layers are shown in figure 2. The glass content varies from chopped strand at 20 to 35% by weight glass fibers to woven roving with about 50% by weight fibers. The strength and stiffness of the laminate increases with increasing glass content.

![Figure 2](image)

*Figure 2. Sketches of (a) all-mat construction composed entirely of chopped fiberglass strands, (b) woven roving ply showing woven rovings applied to form a shell, and (c) enlargement showing the construction of woven roving.*
**Filament wound laminates.** Filament winding is the lay-up of continuous bundles of rovings of glass fibers which are impregnated with resin just before automatic winding on a cylindrical mold to form the wall of a vessel. Filament winding results in a large glass fiber content, up to 70% by weight; this laminate is therefore very strong in the direction of the fibers. Of course this laminate is very weak in the direction perpendicular to the fibers. The good news is that the winding can be controlled to provide maximum strength in the directions desired; however, it is difficult to achieve the maximum strength in all the desired directions since the rovings are applied in different directions that spread out the directional properties. A schematic drawing of the winding process is shown in figure 3. Note that although pipe is almost ideal for filament winding, it is very difficult to use for the heads and bottoms of vessels and these are normally made using hand lay-up contact molding techniques.

![Figure 3.0. Sketch of a filament winding operation.](image-url)
**Winding angle.** Figure 4 shows various winding angles that can be selected for optimum strength in a specific laminate direction. Note that the view in figure 4 will result in maximum strength in the hoop (circumferential) direction, but low strength in the axial direction. If this 90° wind angle is used, additional fiberglass in the axial direction is usually applied so that the laminate has the required mechanical properties in that direction.

![Figure 4.0 Sketches of filament wound structures composed of continuous windings of fiberglass rovings. (a) Is an illustration of “hoop” winding at approximately 90° and (b) is an illustration of 54 ¾° winding that produces twice as much strength in the hoop direction compared to the axial direction.]

**Joining Equipment Parts**

It is seldom that an equipment or pipe system can be fabricated in one piece. Therefore joining of components is necessary. There are three methods commonly used to connect equipment components: butt joints, bell and spigot joints and flanged joints. Since joints are a common location for damage and failure, these regions should be areas of focus for the inspectors.

**Butt Joints.** Butt joints are made by butting the FRP components together and over-wrapping the two sides to form a “splint” as shown in figure 5. The surface of the FRP to be covered by the butt joints wraps must be abraded first so that a rough surface can aid in the strength of the bond. The bond of the resin in the joint to the original surface is not a chemical bond since the FRP of the equipment has already cured and is therefore not reactive. Next, glass reinforcing is cut to shape, wet with resin, applied to the joint and rolled to allow entrapped air to escape. The joint is built up with additional layers of glass and resin. The inside of the joint must also be overlaid as shown in figure 5. In the case of pipe, the inside wrap(s) are not applied, but the joint must be completely filled with a resin paste as shown in figure 5 a. When the joint is finished, a thin gel coat of resin is applied (like a paint) over the joint and past the abraded area on the FRP surface.

**Bell and Spigot Joints.** Bell and spigot joints are made by fitting one end of the FRP component into the expanded end of the other FRP part. See figure 6. Before the parts are placed together,
the surfaces are abraded and the joint is filled with resin paste or putty. The over wraps are then made much like those for the butt joint.

Figure 5. Sketch of a typical butt joint
Figure 6. Sketch of a typical bell-and-spigot joint.
**Flange Joints.** Flange joints are made for easy access in service. Typically all the entries and exits from a vessel are nozzles with flanges. In piping, flanges are installed where components such as valves, pumps, etc are located and where it is anticipated that sections of the pipe system will be taken apart in service. Whenever there is a flanged joint at a vessel, there must be a corresponding joint where the nozzle enters the vessel. This area is as subject to overstress similar to the flange/nozzle joint. Flanges are made up by hand and nozzles are installed by hand lay-up. Where large nozzles or manways are installed, a reinforcing pad is required on the vessel/pipe wall. In addition, for nozzle/flanges smaller than about 6” diameter, reinforcing gussets are required to prevent overstress from many sources (described below). Typical designs for flanges and nozzles are shown in figures 7 and 8.

![Figure 7. Typical Design for Flanges (Reproduced from ASME RTP-1)](image-url)
Figure 8 Typical Designs for Nozzles (a) Flush Nozzle Installation (b) Penetrating Nozzle
(Reproduced from ASME RTP-1)
Supporting FRP Equipment and Pipe

*Tanks and vessels.* There are three techniques for supporting FRP vessels: (i) a) flat bottom vessels on flat supports such as ground or concrete pad, (ii) b) vessels hung using an integral support ring, and (iii) c) horizontal vessels supported in saddles.

(i) Flat bottoms are very common for above ground vessels. The bottom itself then has very low stresses, but the bottom knuckle may be highly stressed from overpressure, high wind loads or external horizontal forces. Therefore hold down lugs are always used. Hold down lugs and vessel knuckle areas can be highly stressed in service.

(ii) Hung vessels are supported by a support ring built into the vessel. Usually these vessels are inside a structure that can minimize the influence of wind and snow loads. Damage can be caused from other stresses such as overpressure, mechanical overstress from rigid attachments, etc. Of course, to secure the bottom heads of these vessels, the wall of the vessel and the joint between the wall and the bottom must be designed and fabricated properly.

(iii) Horizontal tanks are typically supported on saddles. If the saddles are designed and installed properly, the tanks should be supported securely. Underground tanks are supported uniformly if installed properly. High stresses can develop from overpressure or from rigid attachments. Underground tanks or the attached piping may be damaged from ground shifts.

*Pipe Systems.* Pipe is supported by pipe racks or by hangers. These need to be designed so that the support is adequate. A factor often overlooked is the thermal expansion of FRP that is much greater than metals. Long runs of straight pipe can impose very large thermal expansion stresses that can cause damage. The design of the piping system can readily account for these stresses, but an inspector should be aware and look for damage at bends and rigid blocks installed to allow the expansion to be accommodated by the elasticity of the pipe material.

Protection of cut edges.

FRP is often cut to meet design requirements. Examples are the ends of pipes that enter a vessel; the sides of baffle panels, etc. These cut edges expose fiberglass reinforcement in the structural laminates directly to the contained fluid. The E-glass fiberglass is subject to corrosion by hot water, acids, alkalis, and fluorine containing fluids. Therefore the exposed cut edges must be protected by coating with a layer of resin - the same resin as used in the FRP component. This resin may contain additives such as fine silica to increase the viscosity and allow a thicker coating. Commonly a thin gel coat is brushed over the exposed edges. These coatings are usually well bonded to the cut edge, but the resin always extends over to the side of the part that is typically not abraded. This area is where de-bonding can readily occur. The coating is subject to loss due to the permeation of the thin coating, mechanical erosion or impact, and extension of de-bonding from the side.
CHAPTER 2

CAUSES OF DAMAGE TO FRP EQUIPMENT

Mechanical

Mechanical damage is the most common problem with FRP equipment. FRP has very little ability to deform without fracture; there is no yielding as in metals. Therefore overstress or impact blows often cause cracks or fracture. An inspector should pay careful attention to areas, which could see high stresses, and to areas showing mechanical impact, gouging, scratching, etc. Erosion is often seen when the flowing fluid contains abrasive particles.

Chemical Attack

Chemical attack can take many forms and have various effects.

*Permeation.* Permeation can cause blisters, de-lamination, attack of the fiberglass, swelling with resultant delamination, softening and weakening of the resin and thereby weakening of the laminate itself.

*Chemical Changes.* Chemical attack of the resin itself resulting in chemical changes in the resin which can result in weakening or softening of the resin. Some agents cause cracking or crazing of the resin at the surface of the laminate.

*Dissolution.* Solution of the resin by organic species that dissolve the resin. This results in unreinforced fiberglass sometimes hanging down from the laminate.
Environmental Exposure

_Ultraviolet Light_. Ultraviolet (UV) light can degrade the resin. This effect is seen by fiber prominence, that is, fiberglass which is white observed on the surface of outdoor sunlit areas.

_Overheating_. Overheat can cause change in color, initial softening and later hardening of the resin increasing its brittleness. Excessive temperature such as flames can cause burning, charring and finally black residue.

_Abrasion_. FRP surfaces can be abraded by misdirected blasting and rarely by storms carrying sand or other abrading particles. The interior of tanks and piping can be abraded by solid materials flowing against the surface.

**Fabrication Defects.**

Fabrication errors or omissions can often result in problems after startup. Examples are failure to remove the Mylar film used as a parting agent on the mold, inclusions of various un-desirables such as duct tape to hold joints together before making the joint, use of the wrong resin which is less chemically resistant than the specified resin, misalignment which causes high residual stresses in the FRP when components are fitted together, and high stresses in service due to section changes.
CHAPTER 3

PREPARING FOR AN INSPECTION OF FRP

History. The history of the part to be inspected is vital. A review of the original drawings and specifications is very helpful, but these are often not available. Results of the original final inspection from the fabricator and all previous in-service inspections should be carefully reviewed to identify any and all prior problem areas including repairs that deserve special attention. This review should identify problem areas that were observed and noted, but deemed not to deserve repair at that time. These areas should be carefully observed in the upcoming inspection. A discussion with operators is necessary to identify any anomalies which have been noted and which could point to specific inspection requirements. Such anomalies could include unusual noises, small leaks, changes in operating conditions that could have affected the FRP, etc.

Inspection Tools. Inspectors of FRP should have the following inspection equipment on hand:

- Adequate lighting including overall lighting AND a portable lamp for close inspection and for surface scans for irregularities
- Hand held magnifying glass
- Barcol 934-1 hardness impressor
- Small pick or pen knife
- Small amount of acetone and a cotton swab
- Camera with flash capability
- Notebook or equivalent for recording observations

Safety

Inspectors should always be aware of all the site safety requirements. Special attention should be given to vessel entry requirements and flammable restrictions (see acetone required above)
*Training.* As with all inspections, experience is the best teacher. Lacking experience, one should enlist the help of a qualified, experienced inspector.

The inspector must be trained and competent in the proper use of the inspection tools in order to obtain valid data. This includes knowledge of prescribed procedures. For instance, a knowledge of ASTM D 2583 “Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impessor” is necessary in order to obtain reliable and comparable measurements.

An inspector must have the ability to clearly record observations and to write an Inspection Report.
CHAPTER 4

Pictorial Views of Mechanical Damage

- Flange Cracks
- Gusset Cracks
- Internal Cracks in Bottom Knuckle
- Freeze Cracks in Piping
- Star Cracks
- Scratches and Gouges
- Stress Cracks in Piping
- Crazing from Thermal Stresses
MECHANICAL - CRACKS AND CRAZES

Mechanical damage is probably the most common type of FRP damage. FRP does not deform as many metals do, rather mechanical stresses cause cracking and eventually failure. Damage caused from external applied stresses or impact damage should be a primary focus for the inspectors. Careful inspection of the exterior for signs of mechanical contact should indicate locations for more detailed and thorough inspection inside the equipment.

Cracks occur because of overstress either from external applied stresses or from internal stresses. Cracks are always of significant concern as they can easily propagate and cause failure of the component with spillage of contents. At the least, a crack can allow exposure of the structural laminates to chemical attack and degradation.

Cracks are not always easy to see. When an inspection is normally conducted the stresses that result in a crack are not present resulting in the closure of the crack. Detailed inspection of areas where cracks may potentially develop is necessary. Special lighting and often a magnifying glass are recommended.

Some of the regions where stresses from external sources can cause damage are as follows:

- Nozzle connections
- Gusset connections
- Flanges
- Agitator entry nozzles
- Any secondary joint (example: body joints when the component is made up of two parts)
- Hold down lugs
- Internal knuckle radii
- Lifting lugs
- External attachments such as ladders
- Internal attachments such as baffle supports, dip pipe supports, etc.

Cracks or crazing from thermal stresses or from direct chemical attack are examples of crack damage caused by stresses generated inside the FRP.
FLANGE CRACKS

Figure 4.1

Crack was caused by a bend stress on the flange connection either from external piping forces or from improper make-up of the flange joint.
GUSSET CRACKS

Figure 4.2

Photograph showing a gusset connection almost cracked off the nozzle. This crack was the result of severe bending stress causing failure of the secondary joint between the gusset and the nozzle.
INTERNAL CRACKS IN BOTTOM KNUCKLE

**Figure 4.3**

Parallel cracks in the bottom knuckle of an FRP tank. Note that the cracks indicate a tensile stress in the inside surface of the knuckle; the resulting cracks are perpendicular to the tensile stress.

When a tank is subjected to overpressure, it will barrel out because the tank wall is constricted by the heavy cross sections at the knuckles at the ends (bottom and top) of the tank sides. This deformation causes severe tensile stresses in the inside surfaces of the knuckles and also on the hold down lugs which try to resist this deformation. The most vulnerable part of the knuckle is the inner surface that has the least reinforcement. The overstress at the knuckle causes the pattern of stress cracks shown in Figure 4.3.
FREEZE CRACKS IN PIPING

The cracks in the pipe were caused by internal overpressure from the inadvertent containment of frozen process environment.

The crack is longitudinally perpendicular to the primary stress. The failure is considered to be severe because the cracks pass completely through the corrosion barrier exposing the structural laminates to the fluid.
STAR CRACKS

Figure 4.5

Radiating cracks on the inside surface of FRP Equipment are referred to as star cracks.

They are caused by point loads on the exterior which transmit stresses to the inside surface. Often these external loads are impacts from a variety of sources such as dropped tools, hammer blows which may be misdirected, strapping loads from strapping tools, etc.
SCRATCHES AND GOUGES

Figure 4.6 (a)

Surface scratches on the interior of a vessel

The interior surface of vessels and piping may be readily scratched or gouged by: Walking over sharp objects; Ladder placement both at the bottom (floor) and where the top contacts the side of a vessel; Tools or other objects that are dropped; Spacers or braces that move and mark the surface.

Scratches that penetrate the inner surface to depths of 0.020 inch and deeper may lead to degradation of the fiberglass reinforcing of the interior laminate. Scratches less than 0.020 inch depth are usually less damaging unless the fluid is hot and contains caustic or fluorine. If shallow scratches are not heavily contaminated with corrosives, they should be reported, repaired and/or noted for review at the next inspection.
The inspector should note the location, extent, and depth of all scratches, gouges, etc. Depth is important as noted above. Depth can be measured using a depth gauge; equally important is the penetration to fiberglass, and any fiberglass observed should be noted and reported.
STRESS CRACKS IN PIPING

Figure 4.7

Sketch of a stress crack pattern on the inside surface of an over-stressed pipe.

Stress cracks take a characteristic pattern. They typically start on the inside where the inner surface is reinforced the least, and they may grow in length and depth exposing the structural laminates to the contained fluid. These fluids may attack the glass reinforcement and weaken the structure. Stress cracks are caused by a combination of overstress and alternating stresses such as those resulting from a pump or pipe hammer.
(a) Thermal crazing resulting from cold fluids flowing through the bottom nozzle onto the wall of a hot vessel. (b) Photograph taken two years later of the bottom nozzle shown in (a).

Note that there is no damage at the top nozzle where the nozzle extends somewhat into the vessel preventing the fluid from flowing directly onto the vessel wall. These cracks usually originate in the inner surface and then propagate both in length and depth. Depending on the service and the aggressiveness of the fluid, these cracks may be serious and require repair. In this case, the craze cracks were not repaired and the vessel served satisfactorily for some time as shown in photo (b
CHAPTER 5

Pictorial Views of Chemical Deterioration

• Acid Chemical Attack at Surface Porosity
• Blisters
• Color Change
• HCl Color Change
• Edge Attack
SURFACE PORES FROM BUBBLES IN THE INNER SURFACE VEIL

Figure 5.1

Acid Chemical attack at surface porosity.

The panel was exposed to concentrated hydrochloric acid, which penetrated the inner surface causing the thin resin covering of the bubbles to break. The acid then had direct access to the E-glass chopped strand mat in the corrosion barrier. The acid attacked the glass and produced reaction products that escaped through the open porosity.

The surface porosity s located at the perforations in the Nexus veil. This veil is a non-woven web that was perforated to allow air bubbles to be rolled out more ease during fabrication. However, these bubbles are difficult to remove and those remaining reside at these perforations. The exposure to hydrochloric acid caused the air bubbles to break out allowing the acid to contact the glass reinforcement. Unfortunately air bubbles are difficult to remove and some remain especially if the web is not rolled adequately to remove them. These bubbles are very small and difficult to see. Careful and detailed visual coverage of the inside surface is required. The streaks above the pores shown in figure 5.1 are caused by reaction products that escaped from the interior of the laminate and rose on the vertical surface of the test panel. These streaks may not be evident in industrial service because of movement or agitation of the fluid. The panel above was exposed in stagnant acid.
BLISTERS

A fully developed blister resulting in a large crack.

The blister in Figure 5.2 is much larger than those usually seen on the inside surface of FRP equipment. The stresses in the blister surface have increased and finally produced the crack. A second location where stresses are also very high and where cracks can occur is at the peak of the blister, the crack is then observed across the center of the blister.

Sizes of blisters vary, as expected, they start small and grow, sometimes slowly. It is common to report blisters the size of quarters.

The inspector often can easily see blisters. A flashlight may be necessary in order to see small blisters; the inspector should shine the light across the surface to highlight the surface contours caused by the blisters. Often blisters preferentially form in the roof of vessels where condensation or higher temperatures may provide favorable conditions for blister formation.

Small blisters may not be harmful, except that they will grow. The inspector should report the size, location, frequency, and any other characteristic, such as cracks.
COLOR CHANGE

Figure 5.3

Test laminates showing color change after exposure to various aggressive chemicals.

Color change may indicate significant change in the resin and should not be ignored. Any change toward white as shown in the caustic and hot water samples is more serious, indicating some attack on the glass fiber inside the laminate.
Figure 5.4

*Test laminates showing color change after exposure to boiling 20% hydrochloric acid for (a) 0 days (b) 6 days (c) 14 days (d) 28 days.*

The left panel is the control panel and had no HCl exposure. These panels were all tested for flexural strength, which explains the cracks in the middle of the panels. Note the decrease of translucency as the exposure time increased to the right test panel. Note also the blisters that are evident in the right test panel.
EDGE ATTACK

Figure 5.5

View of progressive damage to the fiberglass reinforcement in the laminate after the laminate was cut and not protected by a coating of resin. This allowed direct exposure of the reinforcing fiberglass to the corrosive fluid.

Examples of cut laminates are baffles, baffle supports, nozzle ends (the nozzle is a section of pipe), dip pipe supports, etc. All cut edges are supposed to be sealed by the fabricator with clear resin or with a thin resin paste, but this step is often omitted. The inspector should carefully inspect all cut laminates to insure that the exposed glass is still functional and is not attacked as shown above.
CHAPTER 6

Pictorial Views of Environmental Deterioration

- Ultraviolet Radiation
Sunlight contains UV radiation that deteriorates many if not most organic materials. With sunlight exposure, the resin on the exposed surface will degrade, embrittle, and will eventually be gone from the surface. The glass reinforcement will then be exposed as shown in figure 4.15. This glass is white and tends to reflect some of the UV radiation.
CHAPTER 7

Pictorial Views of Fabrication Errors

- Peeling Films
There are two possible sources of film peeling after equipment has been put into service.

- During fabrication a film, usually Mylar is used as a separating agent between the mold and the FRP lay-up. Sometimes this film sticks to the FRP and is not removed. In service this film may become loose as shown above. This loose film is not a chemical problem, but it can foul pumps, filters, valves, etc.

- A gel coat is usually applied over reinforcing wraps/lay-ups to insure that all fiberglass in the reinforcing overlays is protected from contact with any possible aggressive chemicals. The gel coat is also shiny and adds to the favorable appearance of the joint. The gel coat extends past the joint and onto both of the pieces to be joined, but past also the abraded area. Since many of these pieces are already cured, there is very little bonding between the gel coat and the cured piece. In service this thin film of gel coat often de-bonds and looks a little like the film shown in figure 4.14. This gel coat fragment is brittle, and can usually be removed by hand. Whether or not to replace this gel coat depends on many factors and a materials specialist should make this decision. The inspector should report the findings clearly in his report.
CHAPTER 8

Miscellaneous Color Plates
Metallic stud corrosion inside boss causes loss of torque and flange leak.

Inlet concentrated corrosion/erosion

Exterior corrosion due to concentrated chemical drip
A Practical Guide to Field Inspection of FRP Equipment and Piping

- Hot gas erosion
- Exterior corrosion from drip
- Poor baffle attachment
Chlorine butter and crevice corrosion

Poor gusset attachment

Buried tank internal rib failure
Uniform surface corrosion

Insufficient lug design and attachment
Exterior Drip Corrosion

Plugging and secondary bond failure
Mud Cracking in Furan

Voids in Furan due to poor wet out
Crack in packing support ledge that has propagated into the shell.