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Best practice for inspecting used fiber-reinforced plastics (FRP) equipment

Scope

This document describes how to inspect fiber-reinforced plastic (FRP) equipment that is already in service (“used”) to determine its condition, knowledge of which is used to assess fitness for continued service and to plan repairs. Three complementary types of inspection are described: (1) External inspection with the equipment in service (supplemented with infrared thermography inspection); (2) External inspection with it out of service; (3) Internal inspection. In general *all three inspections should be done for a complete inspection*. Inspection methods, including infra-red thermography, Barcol hardness, acoustic emission testing, spark testing and radiography are discussed.

These inspection guidelines apply to conventional FRP equipment, including tanks, piping, stacks, ducts, etc., and to “dual laminate” FRP equipment. Inspection of resin-based linings, which can be FRP laminates or resin vehicles filled with inert materials and trowel or spray-applied, is not directly covered although the general principles and practices discussed here can be applied where such linings are protective barriers for metal and non-metal substrates.

Safety precautions

These guidelines involve internal and external inspection of vessels, tanks and other equipment in pulp and paper mills. Prior to conducting such inspections, the inspector should know the plant or mill’s safety policies and practices for working around, on top of or inside the specific equipment involved. The owner/operator of the equipment is responsible for ensuring adequate safety policies and practices are in effect and that they meet local, state and federal health and safety requirements for such work.

Basic Structure of FRP Tanks and Vessels

General construction concepts

Fiber-reinforced, thermosetting resin composite materials are called fiber-reinforced plastic (FRP), Glass-Reinforced Plastic (GRP) or Reinforced Thermosetting Resin Plastic (RTRP). “FRP” is used to represent all these terms in this document because it is widely recognized and glass is not the only fiber reinforcing material used. [ASTM or ASME standards provide guidelines on testing FRP materials and on methods of construction for FRP equipment.]

FRP equipment typically has two layered construction elements:

1. The *structural wall* provides the shape and strength of the structure.
2. The *corrosion liner* protects the process side of the structural wall against chemical attack. (In some cases, e.g. in some variants of mass-produced FRP pipe, the corrosion barrier is minimal or omitted.)

A major difference between these two composite-construction elements is their resin-to-glass ratios, which also defines many of their respective properties. Resins in composites are brittle, not very strong materials with good chemical resistance. Glass fibers have good tensile strength, but are not in a form to contain materials and can be chemically attacked by some environments. This is why the corrosion barrier/liner laminate typically has > 80%

resin content (the veil-reinforced “inner surface” layer has > 90% resin), and the structural laminate typically has between 30-60% resin, depending on the laminate design and precisely how it was constructed.

The corrosion barrier/liner and structural wall laminates usually differ in thickness, which relates to their respective design functions. The resin-rich, corrosion liner must be purposely designed for the exposure conditions. The corrosion barrier/liner typically is regarded as sacrificial and not considered as contributing to the strength of the total laminate when calculating the thickness of the structural portion. Structural laminates must have the thickness and glass reinforcement scheme to provide the design strength, which depends on the number of plies *and* the type of reinforcing in each ply. Structural wall thickness in structures like FRP bleach towers may exceed 50 mm (2 in.).

Figure 1 illustrates typical laminate designs for FRP equipment. The structural wall is either hand lay-up (HLU) (also “contact molded”) or filament wound (FW) construction. HLU laminates can be made on molds of almost any shape. The corrosion liner always is HLU construction, with the veil-reinforced inner surface constructed first, right on the mold with a release film of Mylar, wax or Polyvinyl alcohol. FW construction is amenable to pieces made by winding the glass threads on a rotating cylinder.

Tanks and vessels that are filament wound are referred to as having “hoop wound roving”, with rovings wound at angles typically between 80 - 88 degrees. Unidirectional reinforcement, axially oriented glass, is interspersed between 88-degree hoop windings to create what is called “0-90” filament wound structural laminates. These 0-90 structural laminates are used most often to meet the strength requirements of ASME RTP-1.

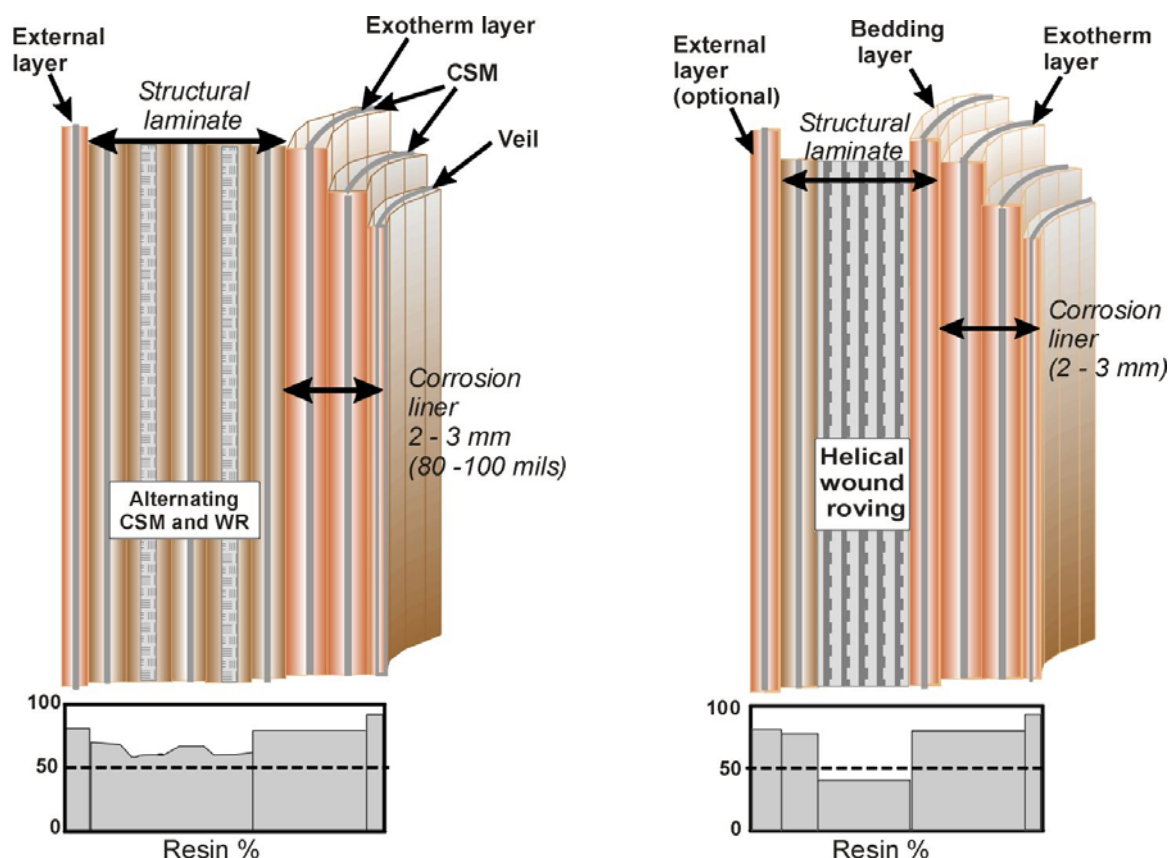


Figure 1. Cutaways of regular **hand lay-up** (HLU) (left) and **filament-wound** (FW) (right) FRP laminates. Reinforcing in HLU laminates is veil, chopped strand mat (CSM) or woven roving (WR). Reinforcing in FW laminates is WR and continuous roving (thread). Typical resin content profiles are shown.

NOTE 1: ASME RTP-1 uses Inner Surface, Interior Layers and Structural Layers (including Outer Surface), where the Inner Surface and Interior Layers are referred to as the Corrosion Barrier, rather than the Corrosion Liner, which is a term widely used in pulp and paper mills, and hence in this document.

Thickness of a regular corrosion barrier (liner) typically is about 2.5mm (0.1in). The 0.25 – 0.5mm, *inner surface* is reinforced with a veil of glass, carbon or synthetic fiber – e.g., Nexus™ polyester fabric. The multi-ply, *interior layers* typically have at least two plies reinforced with fiberglass strand mat known as “chopped strand mat” (CSM). CSM comes in both 3/4 and 1-1/2 oz/sq ft. unit weights. (Metric weight equiv. for CSM are 300 and 450 g/m²)

For especially severe service (e.g., D-stage bleaching) the corrosion liner thickness should be increased, often up to 6 mm (0.24 in), by adding more veil and/or mat reinforced layers. A “double thick” liner can have 2 veil layers and 4 CSM layers – in V/2CSM -V/2CSM or 2V/4CSM sequence, at the designer’s discretion. An *outer surface*, i.e., 2-5 mil resin coat; one veil, and/or one or two CSM, applies for internal FRP components such as baffles, dip pipes, structural members, trays in scrubbers, etc.

Final thickness and glass content of each layer depend significantly on the type of reinforcement. As stated above, reinforcement types include veils; CSM of various “weights”; fabric or “woven roving”, and continuous threads or “filaments.” Chopped strand or chopper gun layers are produced by feeding glass threads through a “chopper gun”, which propels a controlled combination of chopped glass and catalyzed resin to the laminate surface. (Deposited material usually is rolled to eliminate entrained air.)

High glass content, aligned fiber orientation and continuous threads make filament-wound laminates generally stronger than hand lay-up laminates of the same thickness. The angle of helical winding determines axial and hoop strengths of the component – a 55° winding angle (wrt. the axis) gives an optimal combination of axial and hoop strength in structural cylinders and in pipe.

While this document mostly discusses glass-fiber reinforcing, other fibrous materials also are used. Polyester fabric is one example, mostly used as veil fabric in the inner surface and also as fiber mat to reinforce cured-in-place pipe liners. Carbon fibers have excellent chemical resistance, high strength-to-weight ratio and are conductive.

Dual laminate construction

Dual laminate equipment, which uses extruded, thermoplastic sheet for the corrosion liner, may be an economic alternative for severe service. PVC, CPVC, PP and fluoro-polymers including PTFE, PVDF, ECTFE and FEP, are used. The liner is formed and constructed (joints are welded) on the mold before the FRP structural laminate is fabricated around it. The plastic liner is either chemically bonded or physically “locked” to the structural FRP laminate by virtue of an integral, glass-cloth backing that is fused into the plastic sheet. Specialized joining methods are used to assemble dual-laminate component pieces into a completed structure.

Resins

Resins used to form the matrix for reinforcing fibers in the FRP composite structure are organic thermosetting compounds that cure hard by catalyzed chemical reaction, and do not soften when heated. Epoxy and epoxy vinyl-ester resins, including novolac-containing versions, are most widely used; furans and polyester resins also are used. Polyesters and epoxy vinyl esters are common in FRP process equipment in pulp and paper mills. Epoxy resins are used in mass-produced components like pipe, valves, etc. Furan resins have excellent resistance to many organic solvents. Resin selection typically is based both on the resin properties and on published chemical resistance tables.

Epoxy vinyl ester resins generally are more chemical-resistant than polyesters, especially to oxidizing, acidic bleaching environments. The curing system usually is chosen by the fabricator and affects the resin performance. These easy-to-fabricate resins are available in fire-retardant versions, which may have lower chemical resistance than the same resin without fire-retardant additives.

Joints

An important aspect of FRP equipment reliability is how well the joints are made, e.g., head or shell joints, nozzle joints, baffles, etc. Joints are mostly made by fitting up the pieces; filling resulting gaps – which must have strict size limits – with a resin-rich paste; then wrapping the joint with an appropriate, “secondary” laminate/lay-up. Dual-laminate equipment has welded seams in the plastic liner and secondary lay-ups on the non-process side only.

Thickness, width and design of secondary laminates are prescribed by the designer, as are details for protecting cut edges of joined pieces and for optimizing the durability of the joints and lay-ups. Note: Because they are made in reverse order and the veil layer is exposed to the air, secondary lay-ups are less chemically resistant than similar primary laminates (those made on the mold).

Inspection philosophy

The key to durability of FRP components is ensuring the integrity of the structural wall. The primary risk of failure is from chemical attack of the structural wall laminate by process environment, which clearly must diffuse through or otherwise penetrate the corrosion liner. This is why inspection and repair of FRP must focus on monitoring the condition and maintaining the serviceability of the corrosion liner.

The corrosion liner is sacrificial and does not have to remain completely unaffected over time, provided it adequately protects the structural laminate for the expected service life.

In addition to potential chemical attack, the integrity of the structural wall can also be compromised by:

1. Excessive service temperatures, which can cause general laminate degradation or thermal shock
2. Cracking from mechanical or service abuse (e.g. over-pressurization, impact, poor support, water hammer, etc.)
3. Stress cracking from acids (particularly hydrochloric and sulfuric acids) affecting some types of glass fiber. (This damage mechanism *has* been found in chlorine dioxide service.)
4. Ultra-violet (UV) degradation of the resin if preventive measures are omitted.
5. Micro-or macro delaminations resulting from diffusion through the corrosion liner of highly mobile molecules like water, hydrochloric acid and some organic solvents.

If the process environment, even when not aggressive, reaches the structural laminate, careful evaluation of the equipment's fitness-for-service establishes the urgency, scope and type of repairs. From a practical perspective, its higher resin content and the clean separation between the reinforcing materials in each ply makes a HLU structural wall less susceptible to chemical attack than a wall made by filament-winding. Continuous and contiguous strands of glass in FW construction also allow faster wicking than the HLU construction.

In FRP piping, in addition to the above considerations, the corrosion liner may experience accelerated attack at flow-impinged surfaces and in turbulence zones; mechanically-induced cracks or leaks at flanges, elbows, fittings, supports, etc., as well as external damage from rubbing or vibration. As discussed further below, infrared thermography (IRT) and systematic thickness monitoring (e.g., with removable coupons, RT or UT) are practical condition monitoring procedures.

Inspection frequencies

Per good engineering practice, the frequency of inspection of FRP equipment should be related to risks associated with failure/loss of containment of the component. Higher risks naturally are associated with FRP equipment that:

1. Is located close to personnel or critical equipment.
2. Is essential to production, so that failure would cause substantial economic loss.
3. Contains hazardous or combustible materials that if released would threaten personnel or plant safety.
3. Contains chemicals known to degrade the FRP laminate at a significant rate.

FRP equipment containing solutions that are particularly corrosive or otherwise harmful enough (e.g., hot strong acids, organic chemicals or oxidizing chemicals) to warrant detailed inspection of the corrosion liner and the secondary laminates at joints and nozzles should be *internally inspected no less than every two years*. Inspection frequency may be stipulated by jurisdictional regulations, such as for Process Safety Management (PSM) processes.

In addition to considering chemical aggressiveness of the contents, FRP equipment with any of the following operating conditions or characteristics *initially should be inspected at least annually* to reliably trend its condition:

- The equipment is internally pressurized