

Toward Objective Evaluation of FRP Corrosion Barrier Condition

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ABSTRACT

Fiber reinforced polymer (FRP), polymeric composites and other polymeric materials are used in many ways to reduce corrosion damage for industrial, infrastructure and municipal applications. Applications include storage tanks, scrubbers, reactors, piping and linings of steel and concrete. For new constructions, a variety of standards and codes have been developed by consensus that stipulate resin and reinforcement material selection, design, manufacturing and quality control details. One of the standards used at this stage assists with the selection of the polymer, or resin, which makes the major contribution to corrosion protection. Since the 1950's when the use of FRP started for corrosion service, inspectors have assessed the condition of the polymer that has been exposed to chemical corrosion to determine if the corrosion barrier is fit for service. There is no consensus standard or code for determining fitness for service of FRP corrosion barriers or equipment. This paper will provide an overview of existing standards and codes used in design and construction, describe damage mechanisms and provide a pathway that allows existing standards to be adapted to determine Fitness for Service of FRP using thermoset polymers.

Key words: FRP, composites, damage, Fitness for Service, polymers, standards, corrosion,

INTRODUCTION

Fiber reinforced polymer (FRP) and other polymeric materials are used in many ways to reduce and manage corrosion damage for industrial, infrastructure and municipal applications. It is common practice to use the term "resin" for polymers in these materials. This paper uses polymer interchangeably with resin.

This paper will also only consider glass fiber reinforcements.

Applications of FRP include storage tanks, scrubbers, reactors, piping and linings of steel and concrete. For new constructions, a variety of standards and codes are used that stipulate selection of resin and reinforcement material, design, manufacture and quality control details. One of the standards that can

be used at this stage assists in the selection of the polymer, or resin, which provides the major contribution to corrosion protection. Some of these standards are listed in the References of this paper. When equipment is in service and subjected to the service environment, periodic evaluations of the installed equipment are often used to determine if the equipment can meet the requirements of its use and design. When equipment will meet these requirements, it is considered to be “Fit for Service” (FFS).

Since the 1950’s when the use of FRP started in corrosion service, it was noted that the earliest effects from service conditions are shown in the surfaces exposed directly to service conditions, such as corrosion. Inspection and assessment of the condition of the polymer that has been exposed to chemical corrosion became standard practice. Inspectors use some of the same tests used by construction codes and standards to qualify the FRP for service combined with interpretations of design documents. In some cases, owners and engineers specify criteria that are taken directly from standards and codes for application to FRP before it is put into service. This practice is consistent with use of design codes commonly used for steel equipment, where direct measurements from the in-service equipment can be used to determine if the equipment meets the design criteria. Many current standards and codes used for FRP design state clearly that they do not apply after equipment has been placed in service.

Historical methods for condition assessment of FRP have identified that many of the changes observed are not addressed in the design. The result is that objective criteria for condition assessment have not been available, so conclusions from these inspections have been subjective. There is one consensus code for inspection that provides some guidance for what inspectors might observe and neither it or the related construction codes provide any guidance for FFS assessment.

In some cases, quantitative techniques for assessment have been implemented. For example, some methods use destructive tests to report the diffusion depth of chemicals into the FRP but diffusion is not considered in the design or quality control process. Furthermore, the results do not relate back to the certainty of any codes or standards.

The problem addressed by this paper is the lack of an engineering-based Fitness for Service approach for FRP equipment in corrosion service.

This paper will draw upon existing codes and standards for brief overview of the design and construction of corrosion resistant FRP equipment. From this point, data will be used to show how damage occurs to FRP from service conditions and how this relates to the parameters from the design. The next step will relate the damage data to an existing and widely used standard practice. From this point, an approach will be proposed to update existing standards to provide quantitative FFS results.

DESIGN AND CONSTRUCTION OF FRP FOR CORROSION SERVICE

FRP and composites using thermoset polymers have been used for industrial tanks and piping since the 1950’s – about 70 years to this writing. Just as for the much older steel and concrete, good engineering practices for design of this equipment were developed over time and often included analysis of failures so that better understanding of the performance of the materials could lead to improved design practices. In the early years, it became clear that design had to accommodate both the structural requirements of the equipment; translated into engineering terms of pressures, temperatures, weights, and other forces; and damage caused to the FRP by stored chemicals or service conditions that was not expressible in these engineering terms. In effect, design required consideration of two (2) worlds.

This resulted in an approach that has been widely adopted where two different structures are combined. The portion of the FRP that is exposed directly to damage is known as the “Corrosion Barrier” or the “Corrosion Resistant Layers”. This is designed to resist and absorb the damage from the

substances and conditions that are contained, thus protecting the portion that is designed for the engineering loads. In some cases, rather than using layers of reinforced thermoset polymers, thermoplastic sheets are used to provide this protection. Polymer chemists normally play the major role in specifying the polymers and construction used for these corrosion barriers. Corrosion barriers are usually applied to the mold first and the same principles are applied for tanks and piping. Polymer makes up 85% to 100% of the volume in the corrosion barrier, with reinforcement normally as the balance.

The structure that is designed for the engineering loads is normally termed the “structural FRP” and it is usually bonded to the corrosion barrier. The structural FRP comprises layers of reinforcement mixed with polymer to achieve a thickness required by the engineering design. This is usually highly engineered material where oriented reinforcements are used with the polymers to provide strength. These materials usually have higher strength in some directions than in others. Polymer makes up 50% to 85% of the volume of the structural FRP.

Figure 1 shows examples of how the corrosion barrier is combined with the structural FRP for both FRP and thermoplastic corrosion barriers..

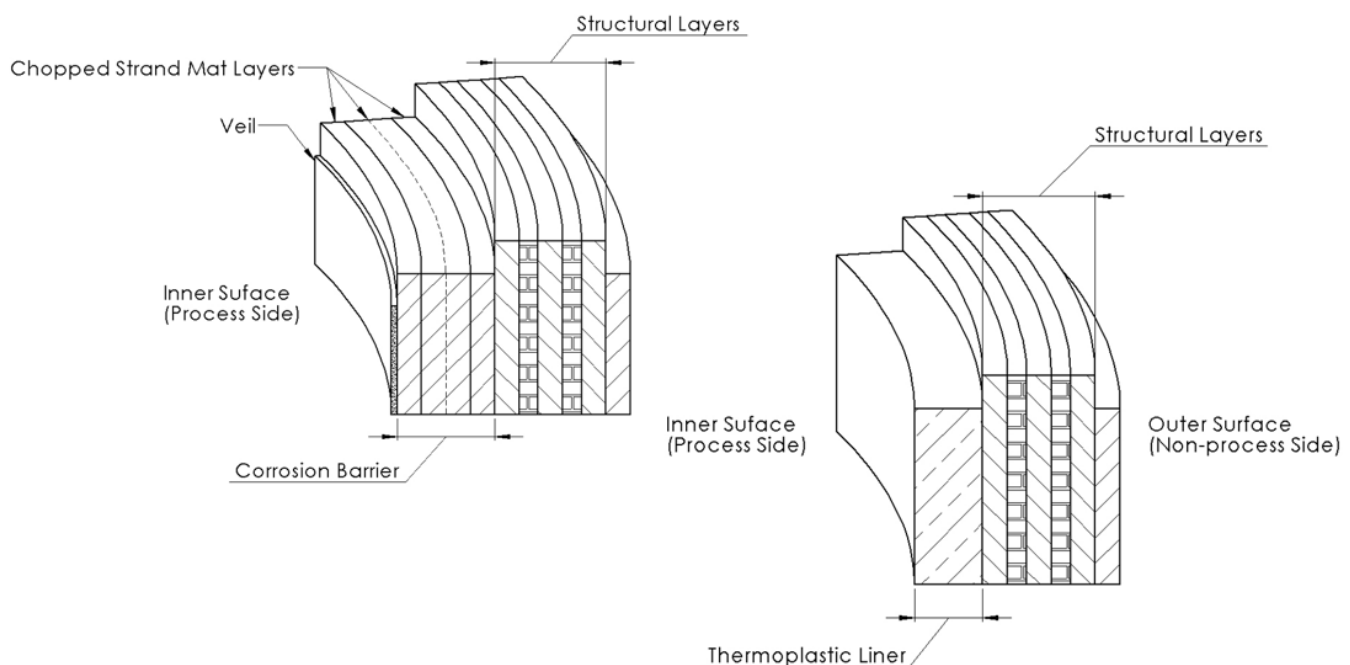


Figure 1: Assembly of Corrosion Barrier with Structural layers (Source: Author documents)

For tanks, these construction methods are embedded in construction codes and standards used globally. Examples of these include [1], [2], [3], [4], [5], [6], [7], and many others. Almost all of these standards and codes stipulate that the materials within the corrosion barrier are not to be considered or included in the engineering structural design.

In the case of piping made from structural FRP, there are some additional practices that may be used for determining the structural capability of the manufactured piping. These methods include testing samples of the piping at different stress levels using internal pressures or other loads in order to qualify the pipe design for particular service. Examples of these standards include [3], [4], [8], [9], [10], [11] [12], and others.

These approaches allow any damage that is contained only within the corrosion barrier to be considered as separate from the structural FRP.

Corrosion Barrier Materials & Parameters

The materials used in the corrosion barrier are usually specified by the chemists at polymer suppliers, upon request. These recommendations are usually based on the results of systematic testing using standardized FRP coupons that simulate corrosion barriers. The systematic testing is covered in “Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service”, [13] (ASTM C 581). The intent of the practice is to determine the chemical resistance of a specific thermosetting resin. At this writing there is no equivalent standard practice for thermoplastic polymers.

FRP coupons that are standardized to simulate corrosion barriers are evaluated using a specific set of tests after submerged exposure to chemicals for up to 1 year. The results of the tests can often allow specific polymer recommendations to be made for a chemical service.

The tests used in ASTM C 581 could be summarized in a table as shown below in Table 1. The quantitative values that result from the practice are listed relative to the values that existed for the new coupons at 0 months of exposure.

Table 1: Example Coupon Data from ASTM C 581

Chemical Tested	Example		Polymer Designation		Example
	Immersion Period				
Parameter	0 month	1 month	3 month	6 month	12 month
% Thickness Change					
% Weight Change					
% of New Hardness					
% of New Flexural Modulus					
% of New Flexural Strength					
Appearance of specimen					
Appearance of chemical solution					

Chemists can then evaluate the data to support recommendations of the polymer to use and may also recommend reinforcement type and thickness of the corrosion barrier. The practice in ASTM C 581 does not provide criteria for determining whether a polymer is suitable for the application.

It is important to note that the method in ASTM C 581 does not measure or report diffusion of chemicals into the polymer. The appearance of the coupons and solution is described but no quantitative data results from this.

Polymer recommendations are often supported by a significant amount of data that remains with the polymer supplier.

Structural FRP Materials & Parameters

When engineers receive the corrosion barrier recommendations, it is common for the same polymer to be used throughout the structural FRP. Standards and codes ensure that the structural FRP will be Fit for Service by providing criteria and design factors to be used for the results of engineering calculations. The parameters used are similar for design of equipment made from steel: tensile strength, tensile modulus, poisson's ratio, and flexural modulus. These properties are based on the polymer and reinforcement properties as supplied.

Note that flexural modulus is a mechanical property used in design and one of the parameters tested in ASTM C 581.

DAMAGE TO POLYMER & REINFORCEMENT IN SERVICE

Polymers and reinforcements in FRP are usually damaged from service conditions – both mechanical and chemical.

Damage to Glass Reinforcements

Long term sustained loading of glass fibers can result in failure at less than the new strength of the fiber. These failures can also be accelerated when the glass is exposed directly to some chemical environments, particularly when pH is low. FRP design intends that reinforcement is always surrounded by an “inert” polymer for the life of the structural FRP and it will not be exposed to damaging chemicals until the polymer has been damaged first. The long-term performance of glass fibers in an inert environment is shown in Figure 2. In the figure, the normal design stress values used from codes and standards is shown and it is clear that when glass reinforcement is protected by intact resin, the glass will not be a source of concern.

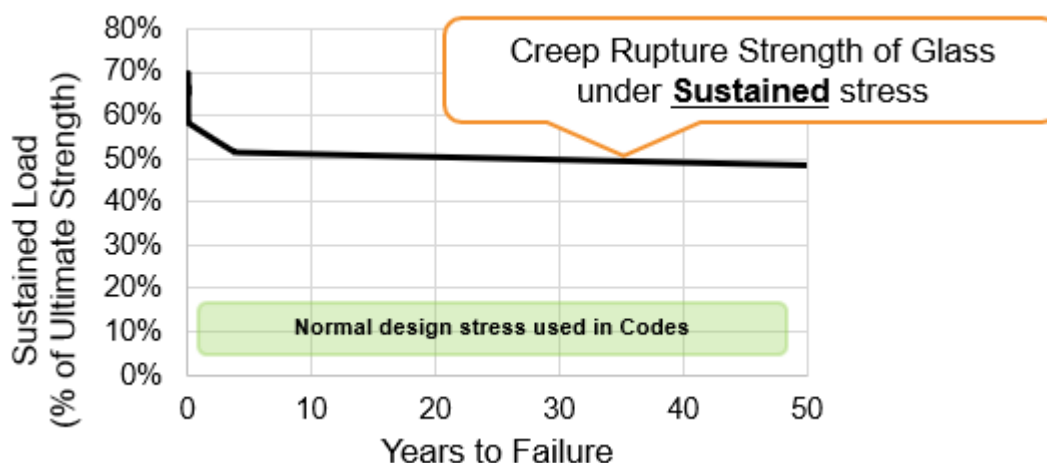


Figure 2: Long term performance of protected glass (Data courtesy of Owens Corning)

Damage to Polymers

Polymer properties are affected by both chemical and mechanical conditions.

Consider first the changes observed from chemical conditions. Data from testing of a variety of polymers was compiled for several chemicals. The chemicals used for the test were hydrochloric acid (1M), 70% sulfuric acid and 15% sodium hydroxide [14]. Data from the ASTM C 581 testing is listed in Tables 2, 3 and 4. Table 3 omits the values at 0 months, because they were all 100% and this allowed entries for 18 months of exposure which was included for this test.

Table 2: Exposure Test Data for Hydrochloric Acid at 75°C

Polymer	Parameter	Immersion Period				
		0 month	1 month	3 month	6 month	12 month
A	% of New Flexural Modulus	100%	75%	77%	69%	67%
A	% New Strain at Failure	100%	70%	78%	57%	22%
A	% of New Hardness	100%	40%	48%	45%	35%
B	% of New Flexural Modulus	100%	80%	85%	77%	73%
B	% New Strain at Failure	100%	76%	76%	67%	52%
B	% of New Hardness	100%	108%	108%	105%	100%