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# Using Ultrasonic Technique to Determine Fitness for Service of FRP Equipment for Chemical Handling Applications

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## ABSTRACT

Fiberglass reinforced plastic materials are well suited to a wide variety of chemical handling equipment where resistance to corrosion is required. A significant impediment to adoption of these materials for many suitable applications lies with the inability to do a fitness for service determination after the equipment and piping have been in service. This is largely due to the lack of effective non-destructive and non-intrusive techniques for plastic materials. This paper presents a case study of a fiberglass reinforced plastic scrubber which was evaluated with a novel ultrasonic technique followed by a destructive evaluation for retained mechanical properties and corrosion barrier condition. When compared, the results showed good correlation. Although the FRP unit was already discarded this study indicated that significant life had still remained.

*Keywords: Non-destructive testing, FRP, corrosion barrier, fitness for service*

## INTRODUCTION

Many chemical processing facilities use fiberglass reinforced plastic (FRP) to contain corrosive liquids and gases. Current practice in the chemical industry is to base the useful life of FRP on the condition of the surface and the near-surface that is exposed to the corrosive conditions. This part of the FRP structure is known as the corrosion barrier, and is constructed to act as a barrier that reduces corrosion and chemical attack of the FRP that supports the structural and pressure loads required.

Current practice in the chemical processing industry is to base the useful life of FRP equipment on the condition of the corrosion barrier. Once the corrosion barrier is compromised, the FRP carrying the structural loads can degrade rapidly, sometimes leading to catastrophic failure. Traditional assessment of the corrosion barrier allows some measurements and calculations of corrosion and oxidation rates and prediction of maintenance needs for the corrosion barrier. With the use of best practices and skilled inspectors, reliability gains can result. However, there are limitations of this visual inspection process: confined space entry is almost always required, equipment must usually be evaluated during outages, most piping cannot be inspected, limited evaluation can be made of the structural condition of FRP and skilled inspectors are relatively rare. While these conventional inspections are normally non-destructive, they are not non-intrusive. Because of the many limitations, it is not always possible to determine corrosion barrier damage in a timely and efficient manner. In some cases, corrosion barrier damage is discovered only at a late stage, resulting in damage to the structural thickness and leading to emergency responses to find solutions and maintain facility operations. These responses normally involve additional intrusive and destructive testing and sometimes total replacement.

This case investigates whether a novel non-destructive and non-intrusive ultrasonic technique can be used to provide timely information about the condition of FRP equipment in corrosion service.

## EQUIPMENT CONFIGURATION AND DESCRIPTION

The FRP equipment used for this investigation was a vent scrubber at a facility of a large chemical company. The scrubber was used to neutralize hazardous gas with sodium hydroxide solution in a countercurrent flow. The configuration is shown in Figure 1.

The original scrubber had been built and installed in 1985. In 1995, all sections were replaced. In 2002, the lower section was replaced. In 2015, all sections of the scrubber were replaced because the structural integrity was suspected to be compromised based on visual inspection of the corrosion barrier. The scrubber that was removed in 2015 is the subject of this investigation, since it was no longer in service and could be made available for comparison of non-destructive and destructive evaluation.

All sections of the scrubber from 1985 to 2002 were manufactured by the same manufacturer. The lay-up method was contact molded, known as hand lay-up. The corrosion barrier thickness was about 5.4mm. The resin was a Bisphenol-A epoxy vinyl ester. The corrosion barrier was cured using benzoil peroxide (BPO) as the curing agent and dimethylaniline (DMA) to accelerate the cure. The curing agent used for the resin in the structural layers was methyl ethyl ketone peroxide (MEKP). Heated post cure at temperature of 66°C (150°F) was completed to ensure that the resin in the corrosion barrier was cured.

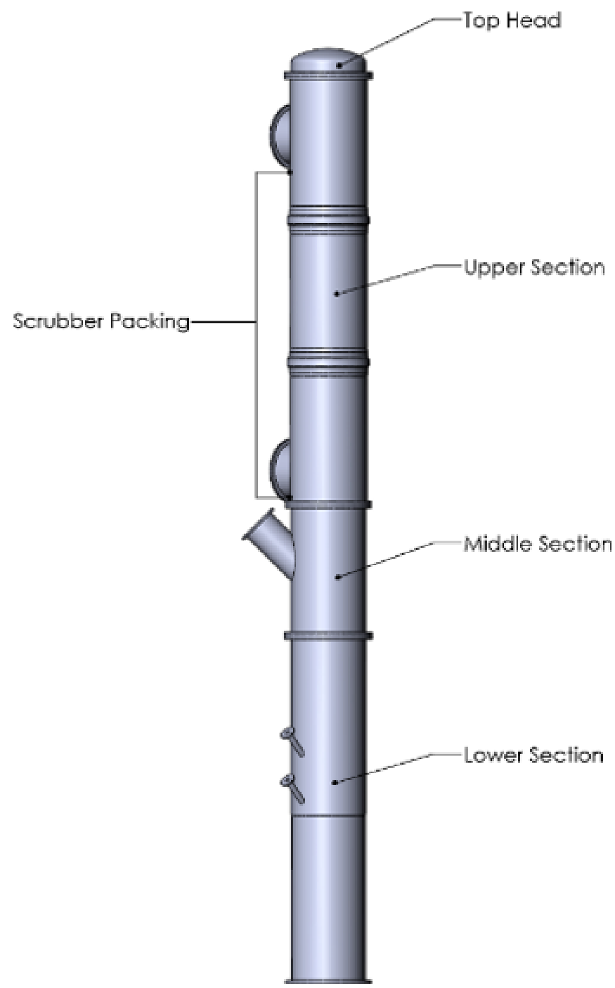



**Figure 1 – Equipment Configuration**

## HISTORY OF ULTRASONIC TESTING OF FRP

In the early 1960's, use of ultrasonic testing (UT) was already showing reliable results for finding flaws in metallic structures. One of the desirable attributes of this technique is that reliable data could be generated if only one side of the material under investigation was accessible. This meant that in addition to finding flaws or defects, the same techniques could be used to produce thickness records of reasonable accuracy. At the same time, use of composite materials such as glass reinforced thermoset plastics was being explored for a number of structural and corrosion-resistant applications. Starting in the mid 1960's, researchers started to examine uses of ultrasound with these fiber-reinforced composite materials.

Vary[1] applied ultrasonic pulses to composites and received the responses using acousto-ultrasonic devices, thus mixing the principles of ultrasound with acoustic emission testing. This process is known as "acousto-ultrasonic" because the forces applied to the specimen are from ultrasonic pulses, whereas for acoustic emission, the forces applied to the composite are from mechanical loads applied, such as pressures and weights. This technique is the subject of two American Society for Testing and Materials (ASTM) standards[2,3].

Several researchers[1,4,5] have reported experimental results showing good correlation between the elastic modulus of FRP and acousto-ultrasonic results. This includes correlation of changes in strength that has occurred from applied stresses and chemical permeation with changes in ultrasonic response of the FRP.

# EXPERIMENTAL PROCEDURE

## NON-DESTRUCTIVE ULTRASONIC ASSESSMENT

The scrubber was provided in a location where it could be inspected using contact of an ultrasonic transducer on the outside surface. All openings were covered, thus allowing a non-intrusive inspection to be simulated. During the ultrasonic inspection, the inspector had no access to the inside of the scrubber. This ensured that reports from the ultrasonic inspection did not contain any fore-knowledge about the condition of the corrosion barrier.

The Ultrasonic Assessment of the fiberglass reinforced plastic (FRP) in the scrubber used the equipment and procedure outlined below:

1. Ultrasonic inspection used the contact pulse-echo method, where a single transducer was applied to the outer surface of the vessel.
2. The transducer operates at a pulser frequency of 0.5 Megahertz (MHz). Square pulses were applied at a repetition frequency of 30 pulses per second (30 Hz).
3. Conventional Ultrasonic Flaw Detector was used.
4. Complete A-Scan images and data were saved for each reading taken. Example of the A-scans saved are in Figure 2.
5. All readings saved were exported from the Flaw Detector into a computer.
6. The exported data was post-processed in a proprietary computer program to determine attenuations and changes in wave shape.

Description of ultrasonic inspections and the locations of cutouts removed for verification is shown in Figure 3 along with details of inspection locations.

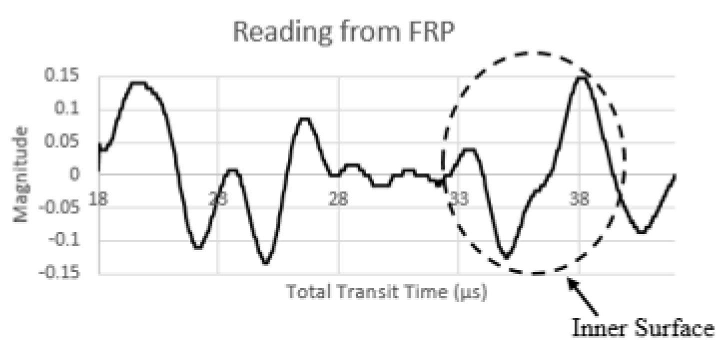



**Figure 2 – Examples of Ultrasonic Reading Taken from Shell A above Ring 1**

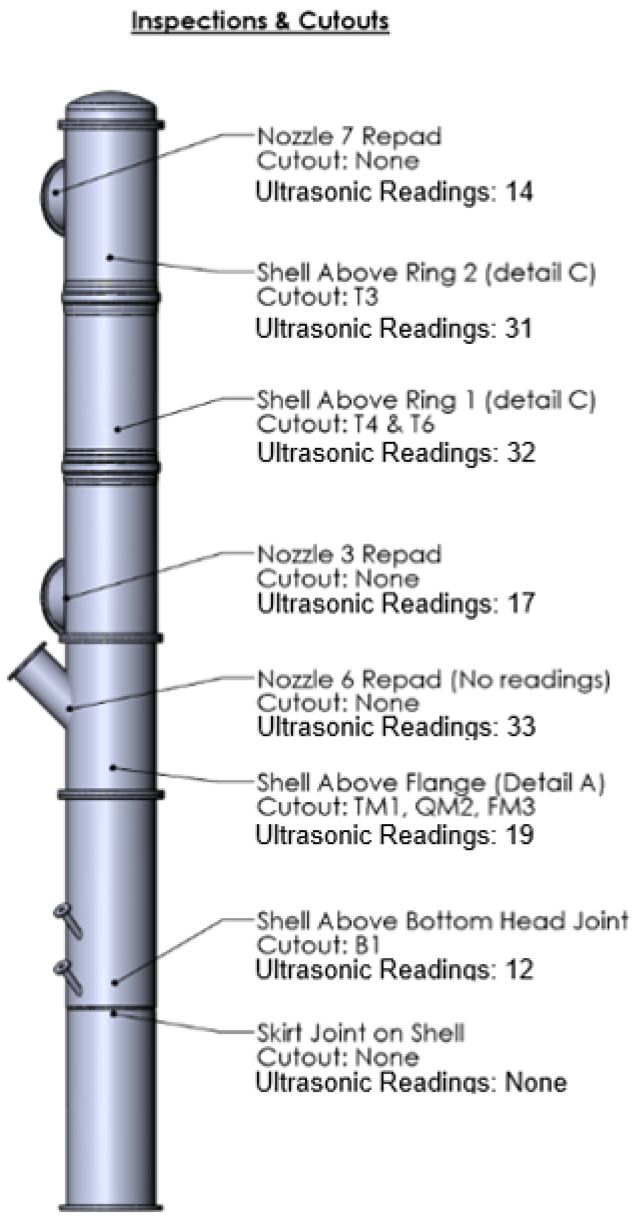



**Figure 3 - Inspections**

Structural capacity is expressed as Percentage of Design Stiffness (PDS) as shown in equation 1.

$$PDS = \frac{Current\ Flexural\ Modulus}{Theoretical\ Flexural\ Modulus} \qquad (1)$$

## COMPARATIVE VISUAL AND DESTRUCTIVE ASSESSMENT

After the non-destructive readings were taken, portions of the FRP shell were removed for comparative evaluation. Figure 4 shows all of the cutouts removed from the vessel along with their locations. Cutouts FM3 and QM2 were not used for quantitative property verification because they were too small or did not have uniform thickness. The cross-section of some of these samples were examined for verification of the condition of the corrosion barrier as reported from the ultrasonic analysis. This was the first time that the inspector witnessed the internal condition of the FRP.

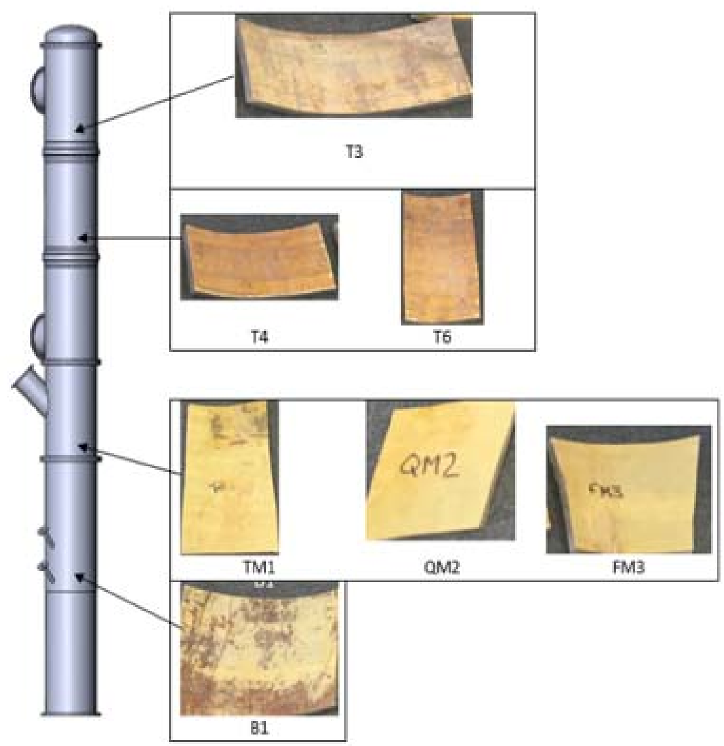



**Figure 4 – Cut-outs from Scrubber**

## RESULTS

### STRUCTURAL

Before the ultrasonic readings can be used to calculate quantitative values such as PDS and the depth of corrosion barrier damage, the readings are processed using a proprietary computer algorithm to compensate for coupling variations with the FRP, accommodate instrument variations and employ statistical tools to determine 95% confidence intervals. An example of the end result of this processing is shown in Figure 5. The reading shown is the same as in Figure 2.

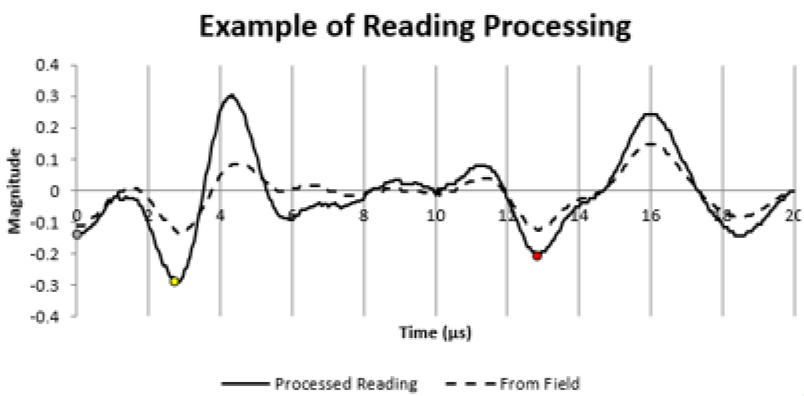



**Figure 5: Reading Processing**

From the ultrasonic readings, results were obtained regarding both damage to the inner surface of the FRP from chemical reactions in the scrubber and the current structural condition of the FRP. The results of the non-intrusive ultrasonic tests are given in Table 2 along with predicted results from calculated laminate physical properties and the destructive results. The destructive testing[7] was completed by a third party, a reputable fabricator with no connection to the scrubber.

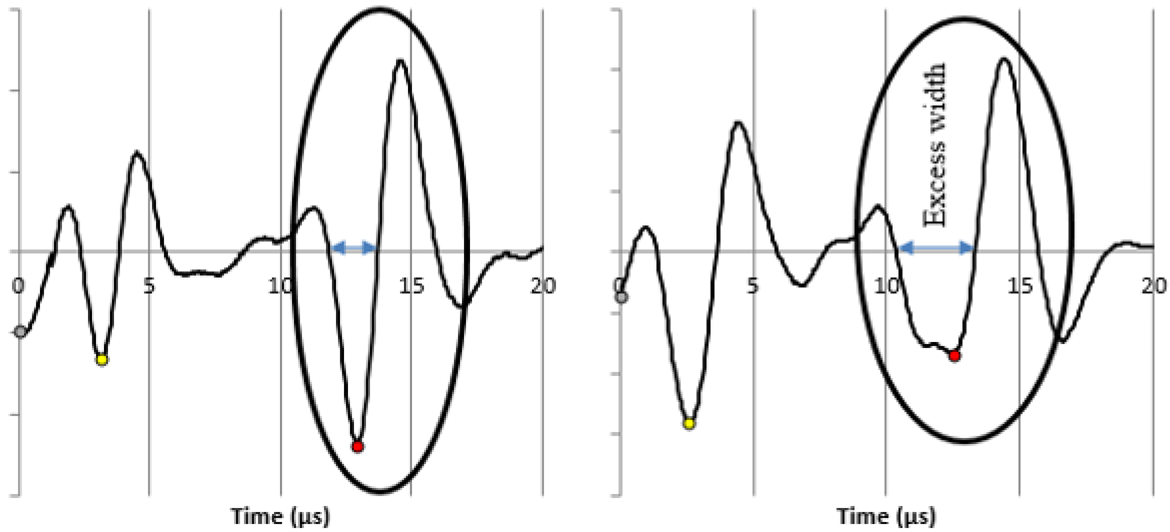
**Table 2. Structural Results**

| Section | Cutout | Average Thickness (mm) | Section Average PDS | Predicted Hoop Flexural Modulus (ksi/GPa) | Destructive Hoop Flexural Test Results (ksi/GPa) |
|---|---|---|---|---|---|
| Shell Above Ring 2 (Detail C) | T3 | 19.8 | 72% | 990 (6.82) | 948 (6.53) |
| Shell Above Ring 1 (Detail C) | T4 | 19.8 | 69% | 949 (6.54) | 855 (5.89) |
| Shell Above Flange (Detail A) | TM1 | 19.8 | 87% | 1,196 (8.24) | 1,368 (9.43) |
| Shell above bottom head joint | B1 | 16.0 | 72% | 990 (6.82) | 1,019 (7.02) |

The predicted values are all within 12% of the destructive test values.

### CORROSION BARRIER

Corrosion barrier assessment was completed by evaluating features within the opposite surface reflection of the ultrasonic reading. Figure 6 shows a typical comparison taken from different locations in the Shell above Ring 1 (Detail C, Cutout T4). Common features used to determine if damage had occurred are the width of the main reflection lobe (circled area) and the presence of undulations in the reflection.




a) Undamaged Corrosion Barrier

b) Damaged Corrosion Barrier – Damage depth 1.75mm

**Figure 6. Typical Corrosion Barrier Analysis**

The results of the ultrasonic assessment of the corrosion barrier are listed in Table 3.

**Table 3. Ultrasonic Corrosion Barrier Assessment**

| Section | Corrosion Barrier Assessment |
|---|---|
| Nozzle 7 Repad | Damage to 1.25mm deep detected in 50% of readings |
| Shell Above Ring 2 (Detail C) | Damage to 1.25mm deep detected in 16% of readings |
| Shell Above Ring 1 (Detail C) | Minor damage detected in 23% of readings |
| Nozzle 3 Repad | No damage detected |
| Shell Above Flange (Detail D) | No damage detected |
| Shell Above Flange (Detail A) | No damage detected |
| Shell above bottom head joint | No damage detected |
| Bottom head joint | No damage detected |

In Table 3, the average depth of corrosion barrier damage detected for the shell sections above rings 1 and 2 was 1.25mm. Based on the shape of the reflected ultrasonic signal, the type of damage was assessed to be caused by oxidation of the resin. Several of the cutouts were examined to quantify the damage to the corrosion barrier.

Evaluation of the cutouts confirmed the ultrasonic results where the damage depth to the corrosion barrier was measured in the lab to corresponded to the results in Table 3.


a) Inner Surface of T4 b) Edge of T4 Cutout

**Figure 8 – Corrosion Barrier**

## REMAINING SERVICE LIFE PREDICTION

The principal output of this novel ultrasonic analysis is PDS. PDS can be used to provide a prediction of the remaining time when the FRP will have sufficient structural capacity. Graphical illustration of remaining service life prediction where the minimum allowable PDS is set to 20% is shown in Figure 9.

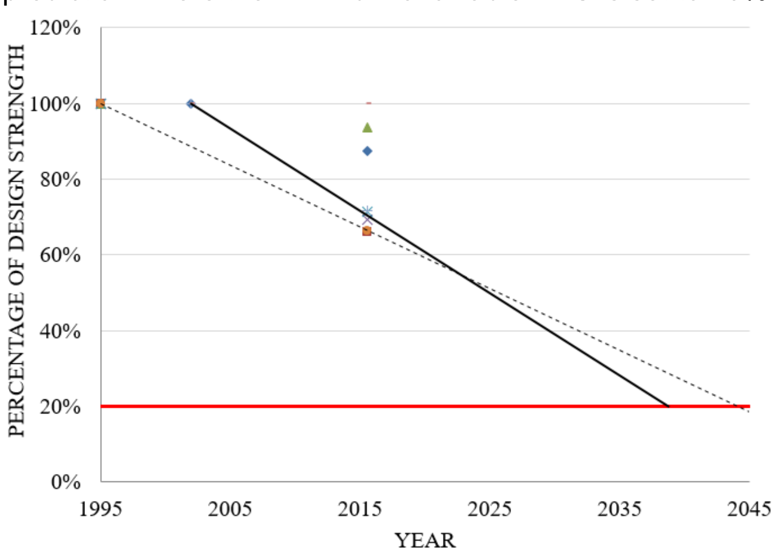



**Figure 9 – Chart Showing Remaining Service Life**

For this scrubber, this was the first evaluation using this method and no previous data was available. When this occurs, it is conservative to assume that the new FRP had 100% of its theoretical strength when new. Also, note from above that the upper sections and lower section were different ages.

Remaining service life could also be determined on the basis of the corrosion barrier damage detected in this case using the damage depth and criteria for end of corrosion barrier service life.

## CONCLUSIONS

The results provided a good match between information provided by the UT readings and the actual retained mechanical properties of the cutouts. The examination of the cutouts also indicated minimal damage to the corrosion barrier thereby suggesting a significant remaining life which this study also predicted. Fitness for service of FRP equipment in chemical handling applications is usually done by the condition of the corrosion barrier. However, plant operations are often confronted by situations where the structural integrity of the equipment is in question due to or regardless of the condition of the corrosion barrier. In such situations this UT technique could be helpful as evidenced by this study. More such studies are required to verify and fine-tune the predictability of this technique.

## ACKNOWLEDGEMENTS

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