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PREDICTIVE MAINTENANCE OF FIBERGLASS REINFORCED PLASTIC EQUIPMENT

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For steel, stainless steel and titanium process equipment, reliable and valid methods are used to monitor the effects of corrosion and damage in order to determine maintenance and replacement needs. This paper describes a non-destructive technology for evaluating fiberglass reinforced plastic (FRP) equipment to achieve the same results, usually while the facility is operating and without confined space entry. The results can allow the maintenance team to predict maintenance needs and the remaining service life of equipment. The method has been shown to be reliable and valid. Case studies are presented to show how the technology has been used on FRP in sulphur dioxide gas cleaning and weak sulphuric acid service.

INTRODUCTION

Fiberglass Reinforced Plastic (FRP) is widely used for tanks, scrubbers, pipelines and other equipment in many industrial applications for corrosion resistance, particularly for acidic solutions, at moderate temperatures. Common applications include containment of solutions and vapours including sulphur dioxide, sulphur trioxide and weak sulfuric acid, among many others.

FRP is commonly used at various stages in the production and use of sulphuric acid. In acid production it is used in the gas cleaning train at metallurgical plants and for weak acid handing.

In many industrial applications, especially involving corrosion, non-destructive testing is used as part of a maintenance reliability program to evaluate the condition of equipment and identify repair needs and priorities for execution in a planned and deliberate manner. Often, non-destructive condition monitoring allows repair and replacement needs and scopes to be predicted within the budget cycles of large corporations.

Traditional evaluation and condition monitoring of FRP almost always involves assessment of the surface and near-surface that is exposed to the corrosive conditions. The focus is generally limited to the corrosion barrier. This assessment 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. There are limitations of this visual inspection process: confined space entry is almost always required, equipment must usually be evaluated during outages, most pipelines cannot be inspected, limited evaluation can be made of the structural condition of FRP and skilled inspectors are relatively rare.

This paper describes a non-destructive technology that is used successfully as part of several maintenance reliability programs for FRP.

BACKGROUND

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. A direct consequence was that the corrosion rate of metallic equipment could be determined and replacement could be budgeted and planned. Figure 1 shows an example corrosion curve and illustrates how replacement can be planned. In this case, replacement should be planned by 2015 as shown by the arrow.

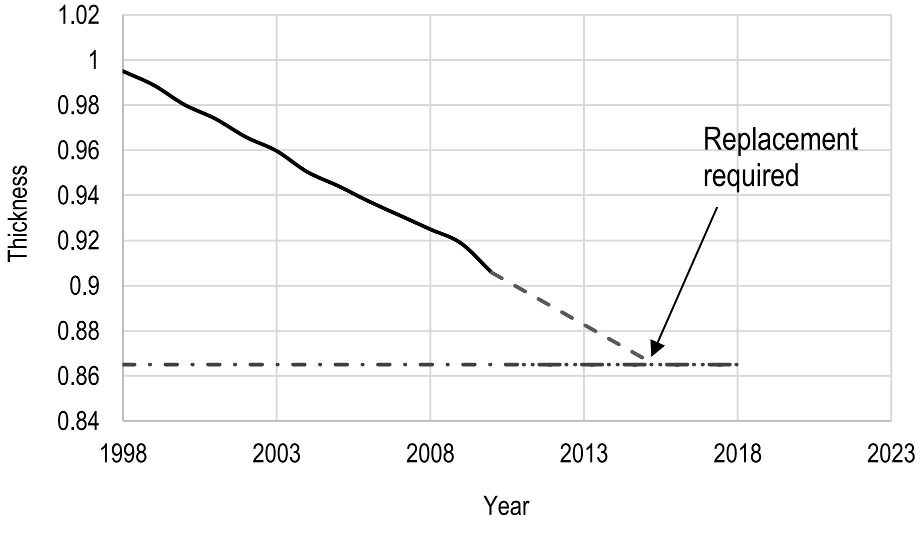

Fig 1: Typical Suitability for Service Curve

At the same time, use of composite materials such as FRP 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 (US) with these fiber-reinforced composite materials. Consistent with the experience with metals, most work focused on finding features such as foreign objects, separation of layers, gaps and gas bubbles, thickness and damage assessment.

Also in the 1960`s, FRP and other composites were being investigated for aerospace uses. Much of the investigation of US for FRP was started by NASA. Results of these investigations developed traditional inspection procedures for finding defects and features, generally limited to high cost, high strength aerospace composites. Additional findings from these investigations showed that composites, including

FRP, that are stressed will also see a reduction in strength as a result of irreversible changes that have occurred. Further, investigators found that these changes can be detected through changes in acousto-ultrasonic responses of the composite[1].

Technology development has been completed with the following objectives:

Develop procedures to allow the use of commercially available US equipment;

Verify the results of calculations for FRP.

The results of the work are summarized below.

Commercially Available Ultrasonic Equipment

Part of the process for evaluating the changes that have occurred to the US signals as they travel through the FRP requires that calculations be done on the data received by the flaw detector equipment. Data files are stored in the equipment at the time that readings are taken and are processed after data collection.

Readings are taken with specific ultrasonic equipment, following a written procedure. US equipment selection is partly based on the ability to extract the data files from the equipment for processing. There is currently a small list of equipment that meets the data-handling requirements for this evaluation.

Data files including the readings are extracted from the equipment after the readings are completed and further information is added about the FRP. The resulting data file is then analyzed and calculations are completed to provide the existing properties of the FRP.

The calculation output of interest for this paper is the percentage of design strength (PDS) for the FRP. The PDS multiplied by the design modulus of the FRP will give the current modulus.

Verification of Results

To verify the US results, samples of FRP have been removed from various structures and tested, both by collecting ultrasonic data and by using a destructive test to determine the strength of the FRP. Most of the specimens were from cylindrical tanks and pipes where the material properties in the hoop direction were of most interest. The designation of the destructive test used is ASTM D790[3].

For each of the samples tested, the following procedure was followed:

1. Ultrasonic data and thickness measurements were collected from the sample.
2. The sample was cut into test specimens in accordance with ASTM D790.
3. Where the lamination sequence of the sample was unknown, a specimen was also cut for ignition loss analysis in accordance with ASTM D2584[5] and reinforcement analysis.
4. A third-party test laboratory completed the ASTM D790 and ASTM D2584 (as applicable) testing and reported the results.
5. The 3rd party laboratory returned the reinforcement from the ASTM D2584 specimen as it was removed from the furnace.
6. The ASTM D2584 residue was used to determine the lamination sequence.
7. The original properties of the FRP were modeled using lamination analysis as described in ASME RTP-1[6].
8. The flexural modulus result obtained from the ASTM D790 test was normalized by dividing it by the design values from lamination analysis modeling. This is termed "Normalized Strength Fraction"
9. The Normalized Strength Fraction is compared to the PDS from the ultrasonic analysis.

An example of the calculation process is shown in Table 1 below:

Table 1
Example Calculation Process

Column A	Column B	Column C	Column D	Column E
-	-	-	A/C x 100%	-
Design Flexural Modulus (GPa)	Thickness (mm)	ASTM D790 Modulus (GPa)	Normalized Strength Fraction	Ultrasonic PDS
15.36	48.03	9.25	60.2 %	60.4 %

In a laboratory situation, it is normal for thickness of FRP to be measured and used as part of the analysis. It is also normal for the thickness of the FRP in installed equipment to be unknown, especially if it was provided some time ago. For this reason, two (2) sets of results from the US testing are reported here. One set is for the results with the thickness known and one set is for data collected as if the thickness is unknown.

The specimens were provided from a number of sources and included FRP that ranged from newly made to having 30 years in corrosion service.

RESULTS

Destructive Test Results

The results of the Normalized Strength Percentage calculations are presented in Figure 2. The data have been ordered from highest to lowest. Note that the values range from 43 % to 132 % of the calculated design value.

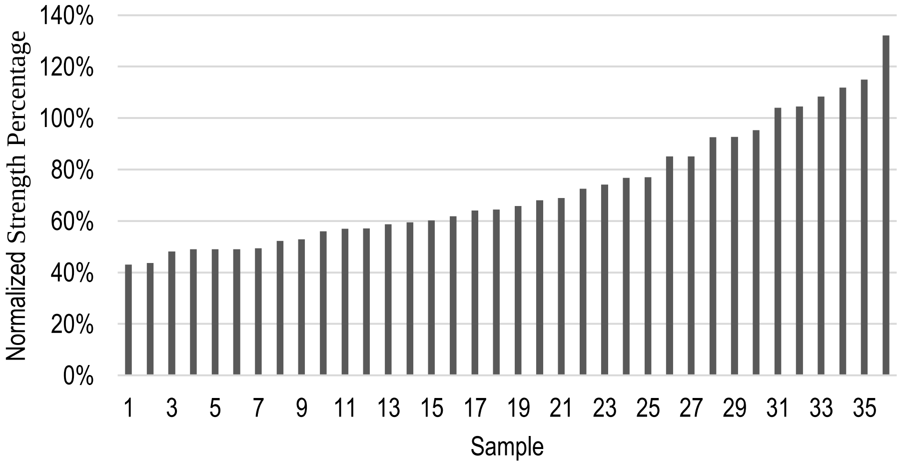

Fig 2: Normalized Strength Percentage of Desxtructive Tests

Ultrasonic Test Results

US Procedure Outline

The procedure for taking US readings from the samples is outlined below:

1. The transducer was a Panametrics M2008 with DL25 delay line
2. Conventional US Flaw Detectors were used. Panametrics Epoch 4 or Olympus Epoch 1000.
3. Complete A-Scans were saved for each reading taken. The readings were:
    a. Only the transducer with delay line.
    b. Readings with the transducer delay line coupled to the surface of the FRP, generally spaced in a grid pattern.
    c. Only the transducer with delay line.
4. All readings saved were exported from the Flaw Detector into a computer.

5. The exported data was post-processed in a computer program, where every reading was analysed. The two transducer-only readings were used to determine the effect of any temperature changes that may have occurred while the readings were taken.
6. The results of the processed readings were then saved in a computer file.

Note that this procedure does not use reference standards to calibrate the US readings.

Thickness is Known

When the thickness of the FRP is known from some other source, such as a drawing, quality assurance records, or physical measurements, this is then considered. When the thickness is considered, the parameter calculated is a function of attenuation and sonic velocity and is known as LV. Mathematically this is shown in Equation 1. The parameter values determined for each specimen are plotted in Figure 3 against the destructive results for the specimen.

$$LV = f(attenuation, thickness, transit\ time) \quad (1)$$

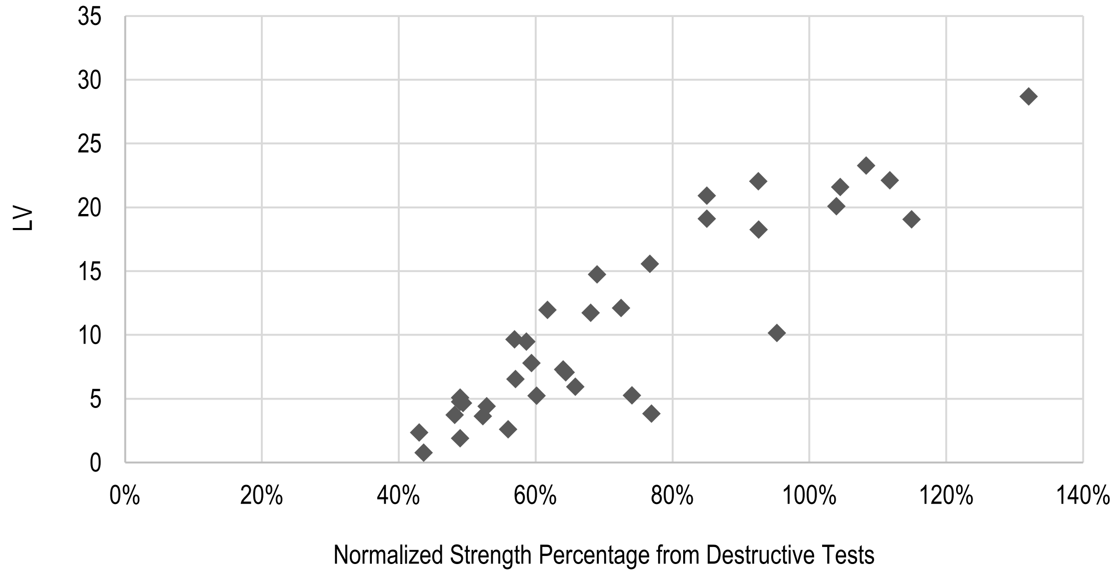

Fig 3: US Results, Thickness Known

The correlation coefficient for the parameter vs the destructive results is 0.898, which is considered to be a strong correlation. When a linear regression line is fitted to the data, the R-squared value is 0.806.

Using a linear regression curve, the value of LV for Normalized Strength Percentage of 100 % is 19.085.

Thickness Unknown

When the thickness is unknown, the analyst has only the data that is available from the US flaw detection equipment. For this portion of the investigation, thickness was ignored and a new parameter, L_{tt}, was calculated as shown in equation 2.

$$L_{tt} = f(attenuation, transit\ time) \quad (2)$$

The parameter values were plotted against the destructive results as shown in Figure 4.

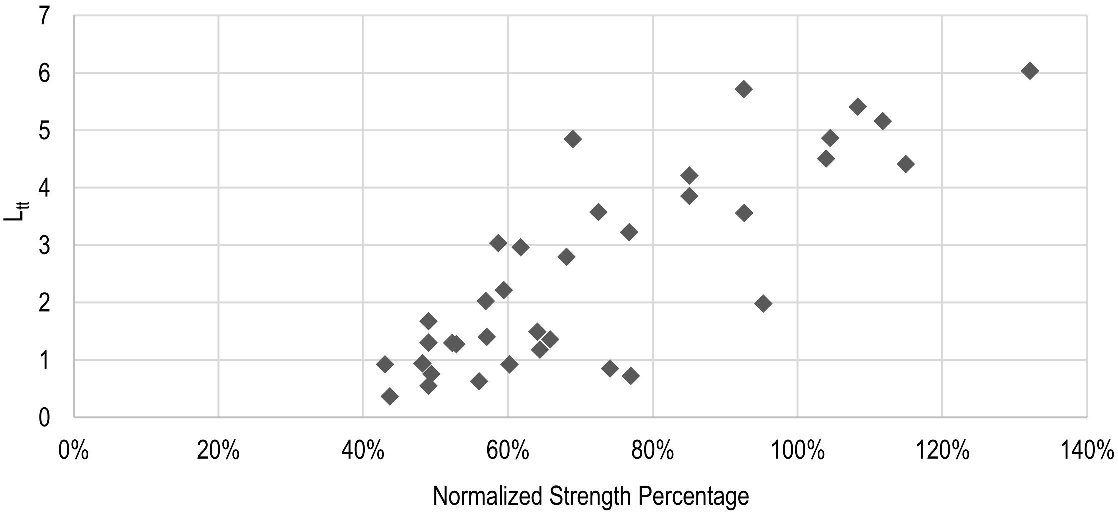

Fig 4: US Results, Thickness Treated as Unknown

In this case, the correlation coefficient is 0.827, still considered strong. The R-squared value for a linear regression curve fitted to the data is 0.6833. Note that linear regression is weaker than when thickness is known.

Using linear regression, the L_{tt} value for Normalized Strength Percentage of 100 % is 4.261.

Calculating Design Strength from US Parameters

The values of *LV* and L_{tt} were normalized by dividing by the respective values at Normalized Strength Percentage of 100 %. This has produced a set of values that can be expressed as percentages. The data points were plotted again and linear regression curves generated. It is expected that a zero (0) value for either *LV* or L_{tt} corresponds to a zero value for strength, therefore adjustment has been made to bring the conversion curves to zero. The curves are shown in Figure 5 for *LV* and Figure 6 for L_{tt}.

In the charts, the value returned on the ordinate, or y-axis of the chart, is the Percentage of Design Strength (PDS). This is equivalent to the Normalized Strength Percentage.

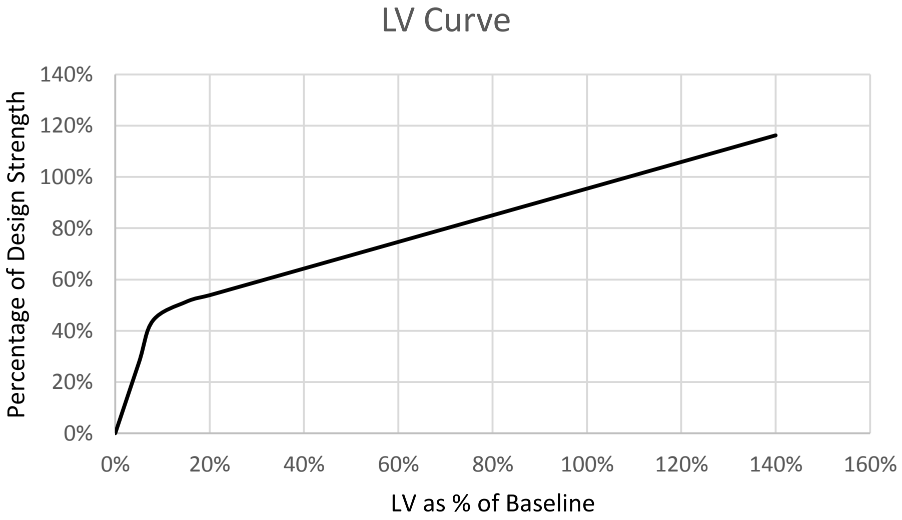

Fig 4: Curve to Convert LV to PDS

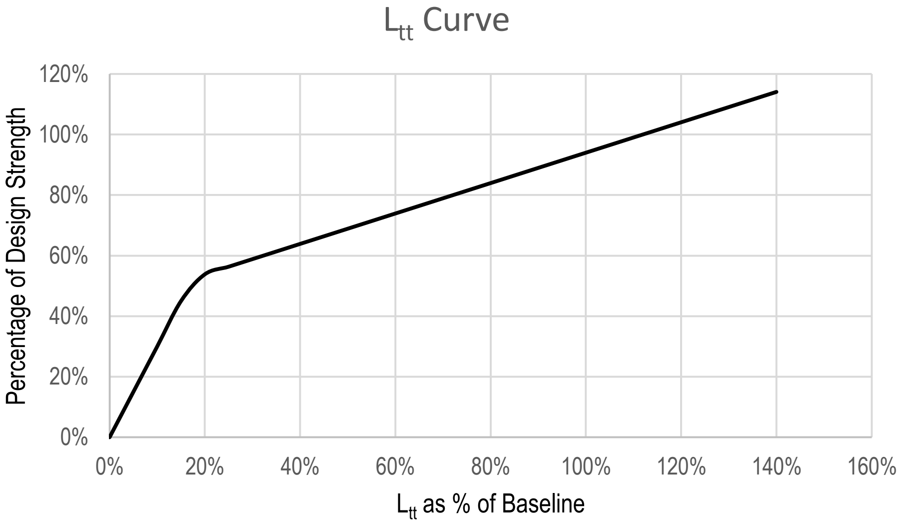

Fig 5: Curve to Convert L_{tt} to PDS

These curves can be used to convert the parameters calculated from US readings to PDS. To convert PDS to actual bulk modulus values, it is necessary to know, at minimum, the reinforcement orientations in the composite.

Comparison

Figure 6 shows a re-ordering of the data. In the figure, the age of the samples is shown along the horizontal and the destructive results are compared to the calculated results.

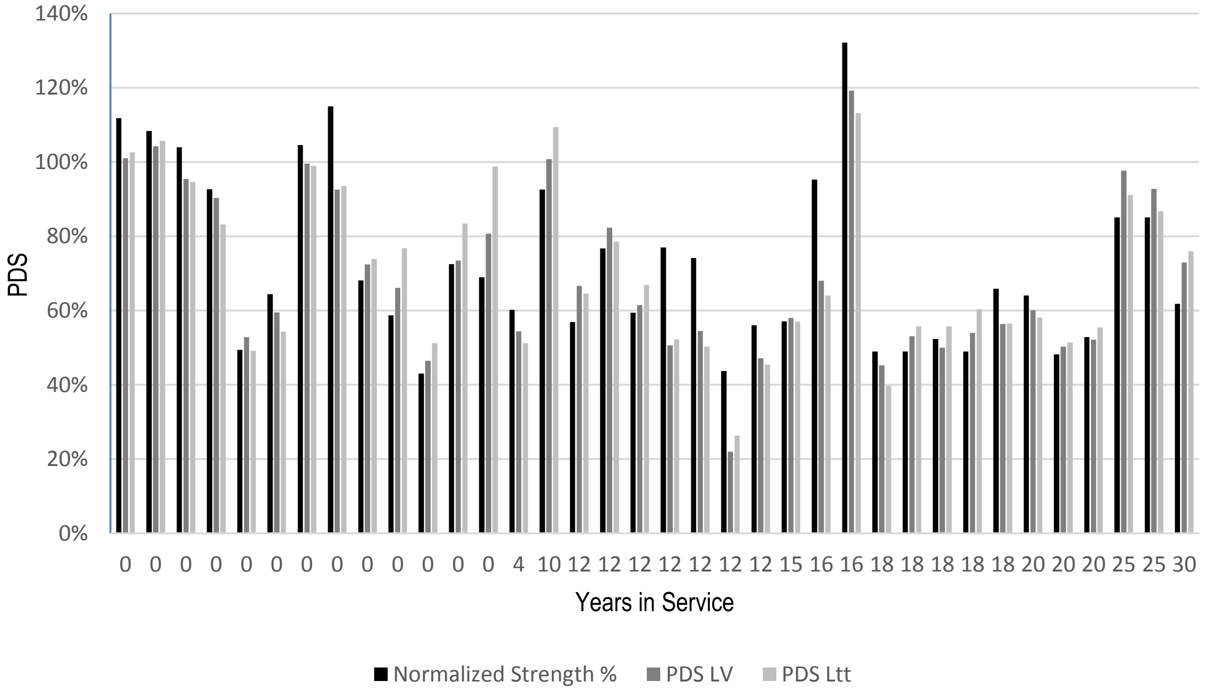

Fig 6: Comparison by Age

The same correlation coefficients apply to this chart as have been reported above. On average, the calculated US results are within 3 % of the values from destructive testing.

Other Results

While completing the validation work, several other features of the UT analysis process surfaced. These are summarized below:

1. Readings taken from the outer surface can show the condition of the inner surface, or corrosion barrier.
2. Readings can be taken from FRP equipment in operation, with or without liquid on the opposite surface.

APPLICATIONS

Returning now to figure 1, where the lifetime of a metal vessel is modeled based on thickness; it is proposed that parallel results can be produced for FRP.

First consider the case where the thickness of FRP does not change appreciably over time and exposure to contents. This would apply generally for many applications. In this case, the PDS value can be determined periodically, often while the FRP equipment is in operation. The analysis can be used to produce an ongoing history of PDS values (and corrosion barrier condition) for sections of the equipment.

The recommended way to monitor changes is to have a baseline for the FRP in the equipment when it is new, as some variability exists among all new FRP. If this is not available, the value for Normalized Strength of 100 % has been used successfully. Using this "standard baseline" always assumes that the new FRP was at 100% of its design strength.

It is important to note that each set of readings is independent and the value of the starting point will not affect any data collected for the FRP. At the time of this writing, original baseline data for most FRP in use is not available. The standard baseline value has been found to generally yield conservative predictions for corrective action. As history for particular FRP develops, it is possible for the starting point to be adjusted or modified to match the data.

Remaining Service Life

The remaining service life is the time until corrective action is recommended. It is reported as the date when corrective action should be expected. In most cases remaining service life is calculated using a straight line model, similar to methods used for metal structures.

Reliable calculation of the remaining service life requires criteria for its calculation. The method used is;

1. Obtain some information about the equipment from nameplates or drawings to determine design safety factors, age and operating conditions. This can usually be done during the first field evaluation,
2. Determine the PDS where the Safety Factor is expected to be 2, and identify that as the Critical PDS where Corrective Action is recommended.
3. Determine the PDS where the equipment is expected to be at ¾ (75%) of its life. At this PDS, Engineering Review is recommended to verify the Critical PDS and identify potential reliability and lifespan improvements.

If very limited information is available, it is still generally possible to develop the required parameters based on experience and knowledge of FRP.

Condition Monitoring

The condition monitoring process starts with some planning for the equipment to be monitored. The plans determine what sections of the FRP are to be tested by considering information available and safe working environment.

Readings are taken from the FRP according to written procedures from equipment that is empty or full and pressurized or evacuated.

After the readings are taken, the data from the UT equipment is exported to a computer program that prepares a data file. For most equipment, several data files are usually produced at an inspection. These data files are combined for the asset into an inspection file.

The inspection file is then sent to an experienced engineer who completes the analysis using specialized computer software. Every reading is reviewed and calculations are performed. From each inspection file, a report is generated showing the results from all data files combined to present the FRP asset as a whole.

This will include history and calculation of remaining service life for the equipment as a whole, while recommending corrective actions.

CASE STUDIES

This process has been applied to several sulphur dioxide gas cleaning systems. Two cases are presented here.

Duct Scheduled for Replacement

The subject duct serves as a collector for 2 smaller ducts at the inlet to a drying tower. This duct is normally inspected internally during normal maintenance outages at 18 month intervals. On several occasions, the inspector identified need for immediate internal repairs. Before this US examination, the other inspector recommended replacement of the duct section soon as it was in “poor condition”.

The duct has inside diameter of 2m. and operates at internal pressure below atmospheric. Figure 7 shows a typical external view of the duct including an FRP expansion joint. Couplant is visible from US readings taken from the expansion joint.

The inspection in this case was conducted to determine the urgency of duct replacement.

Data was collected from the outer surface of the duct and expansion joints. Using the methodology and calculations described above, the following was concluded:

1. The PDS of duct sections averaged 83 %.
2. The PDS of expansion joints averaged 56 %.
3. The remaining service life of the duct was determined to be limited by the structural condition of the expansion joints.

Fig 7: Duct View

The difference in PDS values of the expansion joints compared to the duct can be explained by the varying bending moments that are continuously carried by expansion joints. This will normally cause more rapid bulk modulus reduction than the relatively static external pressure load. Remaining service life projection of the duct is shown in Figure 8.

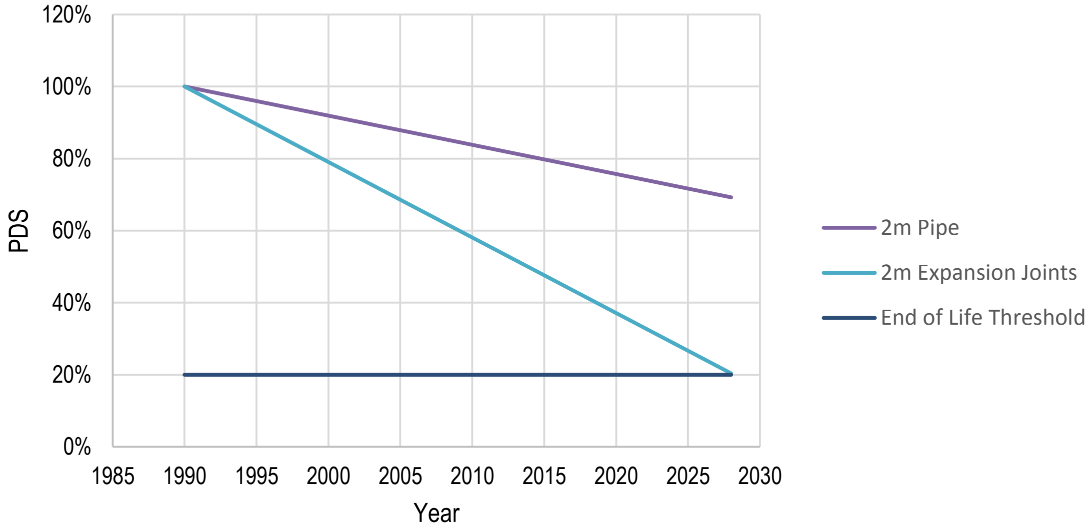

Fig 8: Remaining Service Life Projection

It was concluded that immediate duct replacement was not required for the foreseeable future. Periodic evaluations have been recommended to verify the rate of strength change.

In this example, there are two (2) important items to note. First, this evaluation was conducted while the smelter and acid plant were operating, with no interruption of production. Second, personnel were exposed to minimal safety risk.

Precipitator Outlet Duct

This duct was installed at a smelter in 1978. The Owner established an ongoing evaluation of the duct starting in 2011. The chart in Figure 9 shows the history and remaining service life projections developed to date. Based on the data, no significant action is recommended for some time.

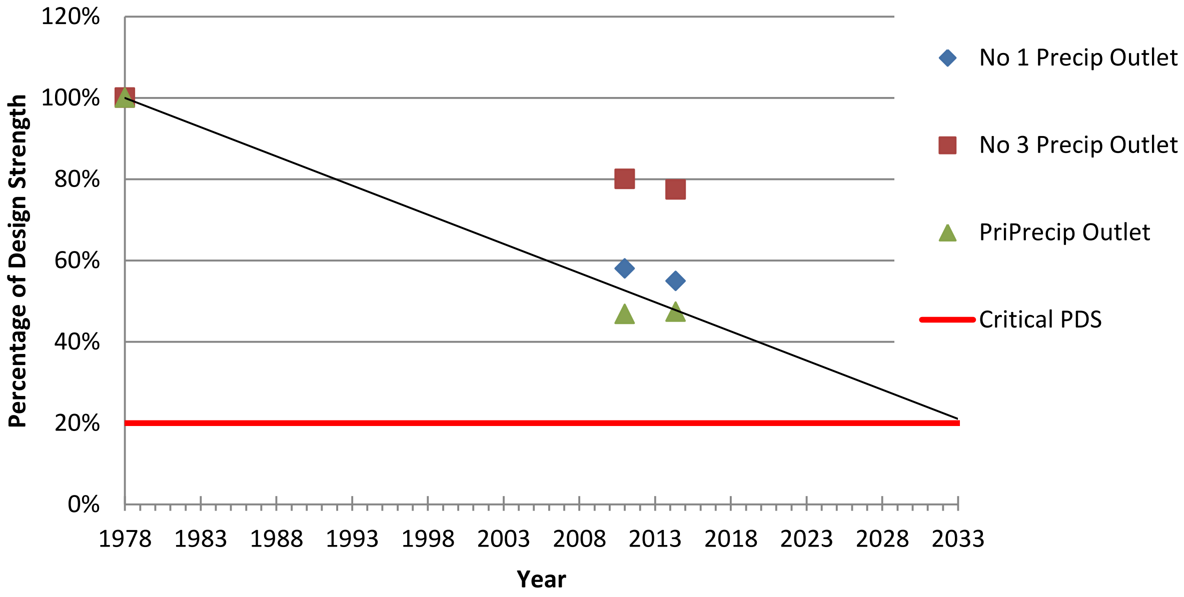

Fig 9: Precipitator Duct History

References:

1. Vary, Alex, Lark, R.F., “Correlation of Fiber Composite Tensile Strength with the Ultrasonic Stress Wave Factor”, Journal of testing and evaluation, 185-191, 1979.

2. ASTM International, "Standard Guide for Acousto-Ultrasonic Assessment of Composites, Laminates and Bonded Joints", Designation E-1495, 2007.
3. ASTM International, "Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials", Designation D-790, 2003.
4. ASTM International, "Standard Test Method for Ignition Loss of Cured Reinforced Resins", Designation D-2584, 1994.
5. American Society of Mechanical Engineers, "Reinforced Thermoset Plastic Corrosion-Resistant Equipment", Designation RTP-1.
6. Clarkson, Geoffrey E., "Suitability for Service Using the UTComp System R4", UTComp White Paper, 2014.