Analysis for Corrosion Monitoring and Prediction of Life of Mild Steel Plate by NDT Technique

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Abstract— Mild Steel is one of the major construction materials used in the industries. Corrosion is one of the serious problem affecting ship, pipe line and aviation industries. It affects the body of ship and thickness of pipe and an Aeroplane wings, surface, between joints and fasteners with the increased utilization of this metal in the manufacturing and construction firms, one of the major problems encountered is the control of corrosion rate when exposed to different corrosive environments. Corrosion is a natural process that reduces the binding energy in metals with the end result involving a metal being oxidized as the bulk metal losses one or more electrons. During the thickness measurement of any corrode plate, Any material whose thickness is lower than the low limit of the probe due to corrosion of metal piece will cause Measurement errors. Sometimes the displayed reading is twice as big as the actual thickness. To prevent these errors, the critical thin Materials should be measured repeatedly for verification. This paper looks at the root causes of poor performance with ultrasonic. This paper summarizes some of the major aspects of precision ultrasonic thickness gauging. Ultrasonic nondestructive testing (NDT) characterizing material thickness, integrity, or other physical properties by means of high-frequency sound waves has become a widely used technique for quality control. In thickness gauging, ultrasonic techniques permit quick and reliable measurement of thickness without requiring access to both sides of a part. The presences of corrosion underneath the paints of surface and between joints are not easy to be detected. The unnoticed presence of corrosion may cause the many accident leading to human and money loses. To detect the thickness of the metal surface, various methods and tests are used. These tests conducted should be such that it does not destroy or disassemble the equipment to parts or damage its surface Hence for the further use of the equipment, Non-destructive tests (NDT) are carried out. In the field of NDT industry one of the most important method to detect the thickness of component is the ultrasonic thickness measurement. The change in the thickness of any plate with respect to the time is also helpful for determining the corrosion rate and prediction of remaining life of corrode plate as well as prediction for the measurement error due to corrosion of any steel plate.

Key words: NDT, UT, Corrosion, Measurement Errors

I. INTRODUCTION

Mild Steel is one of the major construction materials used in the industries. This paper focuses on the experimental study of the corrosion behavior and mechanism for mild steel in three different media namely: 0.1M of Hydrochloric acid, Atmosphere, Salt water (Nacl). Mild steel of length 108 mm and 65 mm width and 10 mm thick was used for this experiment and studied for a period of one year interval of each three month weighing and re-immersing. The weight losses were tabulated and analyzed graphically. Any suitable NDE technique, such as ultrasonic may be used as long as it will provide minimum thickness determinations. To detect the thickness of the metal surface, various methods and tests are used. These tests conducted should be such that it does not destroy or disassemble the equipment to parts or damage its surface. Hence for the further use of the equipment, Non-destructive tests (NDT) are carried out.

The another and The simplest, and longest-established, method of estimating corrosion losses in plant and equipment is weight loss analysis. A weighed sample (coupon) of the metal or alloy under consideration is introduced into the process, and later removed after a reasonable time interval. The coupon is then cleaned of all corrosion product and is reweighed. The weight loss for each three month was obtained using the weighing balance and the difference in weigh for each of the week was then calculated that is the difference between the weight of each plate before and after each week of the immersion of the sample in the different environments.

A. Non-Destructive Tests

Non-destructive testing as the name suggests is testing procedure without any damage to the part being tested. The various non-destructive testing methods used are:

1) Visual inspection
2) X-ray inspection
3) Die (liquid) penetration inspection
4) Magnetic particle inspection
5) Eddy current inspection
6) Ultrasonic inspection

II. EXPERIMENTAL WORK

A. Experimental Set Up used in Thickness Measurement Operation

Equipments used to perform ultrasonic thickness measurement is shown

S. No	Equipment/ Material used
1	Power hacksaw
2	Ultrasonic thickness Gauge
3	Single Element Transducer/ 2.25MHz Probe
4	Calibration Block
5	Micrometer/Vernier caliper
6	Couplent/Gel
7	Corroded plate(specimen)

Table 1: List of Equipment and material used for thickness Measurement Operation

For the measurement of plate thickness of corroded plate using point to point reading of each surface of plate like A1, A2 as show in the figure

Fig. 1: Division of specimen for different observation point to point

III. EXPERIMENTAL PROCEDURE

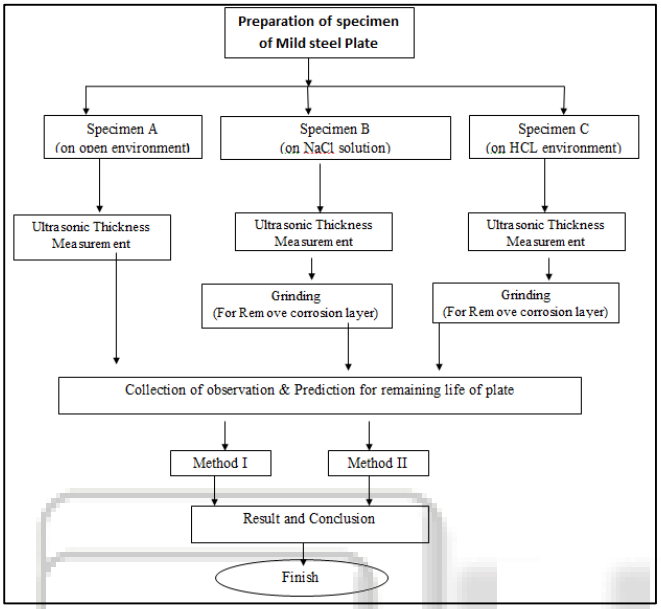

Fig. 1: Experimental Procedure

A. Error Detection

Measurement Error of the thickness gauge will continuously increases with respect to period of corrosion. Therefor it is advice to consider probability of detection first. The highest degree of measurement accuracy on detected pits is of little consolation if the deepest pit has not been detected. I consider that the probability of detection depends on the Scanning technique.

Two quite different approaches are common use, spot readings on a defined grid pattern and area scanning on an overlapping raster pattern. Clearly the grid pattern Technique is suitable for erosion monitoring if suitable grid spacing is chosen. From the Reflectivity of erosion author can suppose that both Digital Thickness Meters (DTM's) would be suitable for this application. The DTM is simpler to use and may have some advantages in the hands of less experienced Operators. However the grid pattern technique is just as clearly not suitable for isolated Pitting of either lake or cone type, So if author want to detect pitting type corrosion, author must use an area scanning technique. Nevertheless, i still see operators taking 12 random readings on plate 10 metres by 2 metres.

	Specimen A			Specimen B			Specimen C		
	Before	After	% Error	Before	After	% Error	Before	After	% Error
3 Month	10.11	10.09	0.198	10.09	10.06	0.298	10.18	10.01	1.698
6 Month	10.08	10.06	0.199	10.01	9.91	1.009	9.64	9.51	1.367
9 Month	10.04	10.02	0.200	9.64	9.42	2.335	9.04	8.93	1.232
12 Month	10	9.95	0.503	9.26	9.14	1.313	8.33	8.24	1.092

Table 2: Thickness of Specimen a before & after grinding with different time period

B. Analysis of Error Propagation with Least Square Method

Suppose in the present study work, a physical system involving two quantities: x and y were used. Also suppose that author expect a linear relationship between these two quantities, that is expect y = ax+b ,for some constants a and b. Author wish to conduct an experiment to determine the value of the constants a and b. Author collect some data (x_1; y_1); (x_2; y_2)……(x_n; y_n), which author plot in a rectangular coordinate system.

Since author expects linear relationships, all these points should lie on a single straight line.

The slope of this line will be a, and the intercept is b. In other words, author should have that the following system of linear equations has exactly one solution.

$$ax_1 + b = y_1$$
$$ax_2 + b = y_2...$$
$$ax_n + b = y_n....$$

That is, author should expect the system of linear equations above to be consistent.

Unfortunately, when author plot our data, author discover that our points do not lie on a single line. This is only to be expected, since our Measurements are subject to experimental error. On the other hand, it appears that the points are approximately \collinear." It is our aim to find a straight line with equation

$$y = a\,x + b$$

Which fit the data\best." Of course, optimality could be defined in many different ways.

By the method of least squares. It is customary to proceed as follows.

Consider the deviations (differences),

$$\Delta h_1 = (ax1 + b) - y_1$$
$$\Delta h_2 = (ax2 + b) - y_2$$
$$\Delta h_n = (ax_n + b) - y_n$$

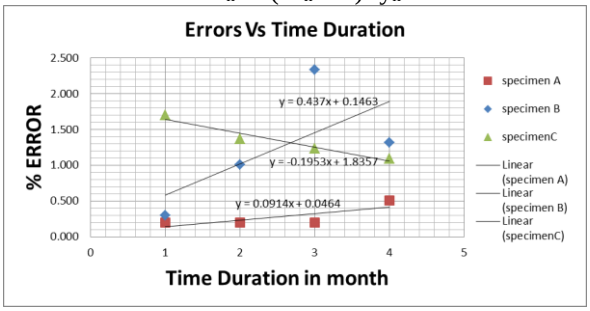

Fig. 3: Least square analysis of specimen A, B & specimen C with time duration

If all the data points were to be lying on a straight line then there would be a unique choice for a and b such

that all the deviations are zero. In general they aren't. Which of the deviations are positive, negative or exactly zero depends on the choice of the parameter a and b. As a condition of optimality author minimize the square root of the sum of the squares of the deviations (\least squares"), that is, author choose a and b in such a way that $\sqrt{\Delta h1 + \Delta h2 \dots \dots \dots + \Delta h^2 n}$ is as small as possible.

IV. ANALYSIS OF CORRODE PLATE FOR REMAINING LIFE

A. Corrosion Rate Determination of Existing plate (Method I)

Corrosion rate for thinning damage mechanisms is determined by the difference between two thickness readings divided by the time interval between the readings. The determination of corrosion rate may include thickness data collected at more than two different times. Suitable use of short-term versus long-term corrosion rates is determined by the inspector. Short-term corrosion rates are typically determined by the two most recent thickness readings whereas long-term rates use the most recent reading and one taken earlier in the life of the equipment. These different rates help identify recent corrosion mechanisms from those acting over the long-term.

Condition monitoring locations (CMLs) are designated areas on plates where periodic examinations are conducted to monitor the presence and rate of damage. The type of CML selected and placement of CMLs includes the potential for localized corrosion and service-specific damage. Some of the CMLs include locations for thickness measurement, locations for stress cracking examinations, and locations for high temperature hydrogen attack examinations.

The short-term (ST) corrosion rate was evaluated within one year and was calculated from the following formula:

$$\text{Corrosion Rate} = \frac{\text{t (initial)} - \text{t (actual)}}{\text{time betweenintial and actual (in year)}}$$

Where

$t_{(initial)}$ = The initial thickness at the same Condition Monitoring Location as . It's either the first thickness measurement at this or thickness at the start of a new corrosion rate environment, in mm.

$t_{(actual)}$ = The actual thickness of a plate, in (mm), measured during the most recent inspection

$t_{(Required)}$ = The required thickness at the same CML or component, in mm as the $t_{(Actual)}$ measurement. It is computed by the design formula (e.g., pressure and structural) and does not include corrosion allowance or manufacturer's tolerances. Construction code for pressure, Part 1.Construction Code for First Class Pressure Plates Section 2.Shells Article 10,other pressure parts of the pressure plate shall be as specified below for each type of the plates: (1) Not less than 2.5 mm for carbon and low alloy steel plates.

1) Remaining Life Calculation of plate

The remaining life of the plate (in years) was evaluated from the following formula:

$$\text{Remaining Life} = \frac{\text{t (actual)} - \text{t (required)}}{\text{corrosion rate}}$$

Plate	Maximum Thickness (mm)	Minimum Thickness (mm)
Sample A	9.93	9.95
Sample B	9.23	9.14
Sample C	8.36	8.24

Table 3: Thickness of Specimen A, B & C

Sample calculations of parameters done on specimen A

$$\text{Corrosion Rate } C_R = \frac{10.11 - 9.95}{\text{Year 2015} - \text{Year 2016}} = 0.16 \text{ mm/year}$$

$$\text{Reaming Life} = \frac{10.11 - 6.00}{0.16} = 25.68 \text{ year}$$

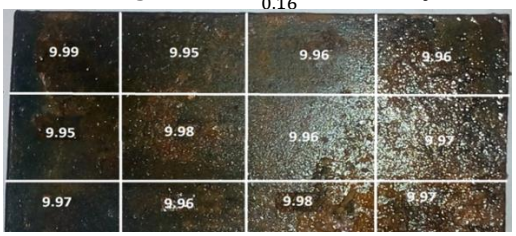

Fig. 4: Thickness marking on corrode plate after measurement of specimen A

Specimen A			
Month	**Thickness (mm)**	**Corrosion Rate CR (mm/Yr)**	**Remaining Life (Year)**
3 Month	10.09	0.16	25.68
6 Month	10.06		
9 Month	10.02		
12 Month	9.95		

Table 4: Corrosion Rate and remaining life of Specimen A

Specimen B			
Month	**Thickness (mm)**	**Corrosion Rate CR (mm/Yr)**	**Remaining Life (Year)**
3 Month	10.06	0.95	4.305
6 Month	9.91		
9 Month	9.42		
12 Month	9.14		

Table 5: Corrosion Rate and remaining life of Specimen B

Specimen C			
Month	**Thickness (mm)**	**Corrosion Rate CR (mm/Yr)**	**Remaining Life (Year)**
3 Month	9.95	1.77	2.26
6 Month	9.51		
9 Month	8.93		
12 Month	8.24		

Table 6: Corrosion Rate and remaining life of Specimen C

2) Discussion

The designated areas on the plates where periodic examinations were conducted to monitor the presence and rate of damage were the plate A, B and C. These CMLs become the critical areas on the plates where failure (localized corrosion and service-specific damage) becomes probable. The corrosion mechanisms of all the inspected plates with exception of sample A are lesser than sample B

and C. This implies that, the short term corrosion rate may be relied on in predicting accurately the remaining life of the plates (A, B and C). Plate three had its year on year corrosion rate uniform (the closeness of short-term) hence one can use the short-term corrosion rate of such plate to predict its remaining life.

The most common method that is used to address corrosion in plates is to specify the corrosion allowance. This allowance is supplemental metal thickness that is added to the minimum thickness that is required to resist the applied loads. This added thickness compensates for thinning (corrosion) that will take place during service. It is of this allowance (added thickness) that helps in predicting the service life of a plate in a particular working or environmental conditions had its minimum wall thickness at CML.

The estimated annual corrosion rates of the inspected plates (1, 3 and 4) are in excess of what is prescribed by the code. These high corrosion rates can be attributed to the aggressive working conditions (situated close to the coastal regions) of the plates.

B. Corrosion Rate Determination of Existing plate by Measurement of weight Loss (Method II)

1) Introduction

The simplest, and longest-established, method of estimating corrosion losses in plant and equipment is weight loss analysis. A weighed sample (coupon) of the metal or alloy under consideration is introduced into the process, and later removed after a reasonable time interval. The coupon is then cleaned of all corrosion product and is reweighed. The weight loss for each three month was obtained using the weighing balance and the difference in weigh for each of the week was then calculated that is the difference between the weight of each plate before and after each week of the immersion of the sample in the different environments. The weight loss is converted to a corrosion rate (CR) or a metal loss (ML), as follows:

$$\text{Corrosion Rate (CR)} = \frac{\text{Weight loss (g) x K}}{\text{Alloy Density (g/cm3) x Exposed Area (A) x Exposure Time (hr)}}$$

2) Determination of Corrosion Rate

The most common method for estimating a corrosion rate from mass loss is to we igh the corroding sample before and after exposure and divide by the total exposed area and the total exposure time making sure that appropriate conversion constants are used to get the rate in the required units. The method in mm/yr can be represented by the following equation

$$CR = \frac{k \times \Delta w}{A \times T \times \rho}$$

Surface area for plate: 2 x (108x65) + 4x(65x10) = 16640 mm^2

Approximate weight = 0.5560 kg

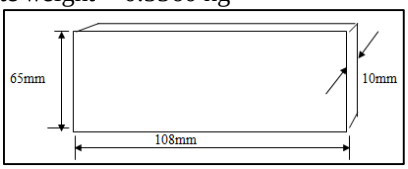

Fig. 5: dimension of specimen

CR = Penetration (corrosion) rate (mm/yr), Δw = Weight loss in gram, A = Exposed surface area of plate= 16640 mm^2, ρ = Density of mild steel ($gcm3$) = 7.86$g/cm3$, T = Time of exposure in hours, k = Constant for unit conversion = 8.76×10^4.

3) Experimental Results and Data Analysis

The weight loss and corrosion rate of metal depend to a large extent on a number of factors. The weight loss and the corrosion rate of the different mild steel samples were calculated and shown in tables 4.5 and 4.6

Medium	Initial weight of specimen (in gram)	Remaining Weight (in gram)			
		3 Month (2160 hr)	6 month (4320 hr)	9 month (6480 hr)	12 month (8640 hr)
Atmosphere	553.5	549.5	545.8	538.3	526.5
Nacl	557.9	544.3	510.8	489.5	422.2
0.1MHCL	555.6	522.4	464.3	416.9	369.04

Table 7: Remaining weight of plate after each quarter year

Medium	Initial weight (in gram)	Remaining Weight (in gram)			
		3 Month(2160 hr)	6 month(4320 hr)	9 month(6480 hr)	12 month(8640 hr)
Atmosphere	553.5	4	7.7	15.2	27
Nacl	557.9	13.6	47.1	68.4	135.5
0.1MHCL	555.6	33.2	91.3	138.7	186.56

Table 8: Remaining cumulative weight of plate after each quarter year

The laboratory corrosion test revolves around the actualization of facts for the perfect selection of materials for specific environments, determination of environments in which materials are especially suitable, corrosion control methods that can be applied and the study of corrosion mechanisms. In this project, three different environments were used; hydrochloric acid, Nacl (salt solution) and atmosphere. Mild steel plate of the same dimensions were exposed to the corrosive properties of these environments and monitored on quarterly of year basis. The results obtained were then used for this analysis on the rate of corrosion and its effects on mild steel.

Medium	Initial weight (in gram)	Metal Loss (in gram)	CR (in mm/Yr)
Atmosphere	553.5	27.1	0.2093
Nacl	557.9	138.7	1.0565
0.1 MHCL	555.6	184.46	1.429

Table 9: Corrosion rate of plates in different condition

4) Physical Changes Observed on the Coupons during the Experiment

The specimens exhibited different features in terms of colour, texture, surface appearance, type and size of the

corrosion products on the metal. The physical features observed in the different media are discussed.

a) NaCL (Salt Solution)

By the end of the first week the mild steel rod showed patches of grey and black on its surface. Between the third (3rd) to fourth (4th) week about 50 - 80% of the surface became rough, with a hard brownish corrosion product, which when washed off left the surface with more black patches than the grey patches. Towards the end of the experiment circular bumps were formed on the surface which when washed off exposed circular pits inside. The base of the pits was grey in colour. The remaining surface was black. Generally at the fourth (4th), the water appeared dark yellowish brown with brown particles at the bottom.

b) Atmosphere

This also appears to have formed oxide films in the middle of the first month, which reduces the rate of corrosion. The corrosion rate and weight lost were very low, hence decreases as the time increases.

c) Hydrochloric Acid

The mild steel plate coupon showed severe uniform corrosion. At the end of the first (1st) month the mild steel plate had shinny smooth grey surfaces and the 0.1M hydrochloric acid turned to light green, up to the second (2nd) month with grey patches underneath the media. At the end of the third (3rd) month the colour of the 0.1M hydrochloric acid turned to brown yellow up to the end of the fifth (5th) month with heavy brown corrosion patches which settles underneath the media.

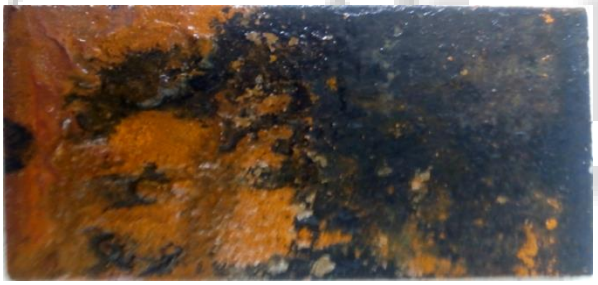

Fig. 6: actual view of specimen after corrosion

C. Result Analysis

The results of the experiment obviously show that corrosion occurred, because weight losses were evident. But interestingly the rate of corrosion for the various specimens varied increasingly in the following trend: 0.1M hydrochloric acid, salt water and atmosphere. The specimen in hydrochloric acid experienced what is considered in engineering literature as chloride aggressiveness. The presence of halide ions breakdown any passive films available and can sometimes prevent passive films from forming on the mild steel plate. The corrosion rate observed for the specimen in the atmosphere was low; this was as a result of the components of the atmosphere, Constant processing of chemicals do not take place in the place where the mild steel plate was kept and so the emissions of various corrosion stimulating gases was reduced from the first three months, the corrosion rate was really slow then became rapid between the third and fourth month, this occurred when the passive films that were formed between the first and third month broke down and thus corrosion commenced, but the weight loss in general was small when compared to the specimens in the rest of the environments. The types of salts present in salt water (salt solution) media were critically not accounted for and the corrosion rate was not too intense. For the fresh water the corrosion was slightly high at the start of the experiment then continued at an approximate constant rate with a small increase at the last month of the experiment, the low amount of ions in the water was responsible for this behaviour since the available oxygen and the medium will form a corrosion cell and initiate the corrosion process until passive films were formed when the rate became constant.

D. Comparison of result between two methods

Specimen	Corrosion Rate (CR)	
	Method I	Method II
Atmosphere (Specimen A)	0.16	0.2093
Nacl (Specimen B)	0.95	1.0565
0.1MHCL (Specimen C)	1.77	1.429

Table 10: Comparatively study of corrosion rate

Weight loss determination has a number of attractive features that account for its sustained popularity:

- Simple - No sophisticated instrumentation is required to obtain a result.
- Direct - A direct measurement is obtained, with no theoretical assumptions or Approximations.

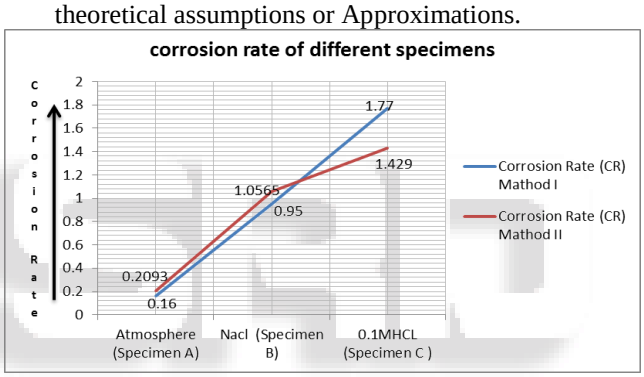

Fig. 4.5: comparatively study of corrosion rate

At the end of the experiment the following observations were made

- Method II is more efficient as compare than method I and also easiest.
- Weight loss method is easy to perform and no need to precious equipment.
- Corrosion will proceed at a faster rate in the presence of ions.
- In the absence of potential pollutants in the atmosphere, corrosion will proceed at a controllable rate.
- Micro-organisms by their metabolic activities tend to provide corrosion stimulating ions especially in swampy areas and hence increase corrosion rate.
- In the presence of an acid, corrosion can prove detrimental in a short period of time.
- Corrosion rate in the acidic medium is faster than in salt water, atmospheric, fresh water and salt soil medium.
- The rate of corrosion is proportional to the time of exposure.

The rate of corrosion of mild steel in the various media decreases in the following manner: 0.1M Hydrochloric acid, salt Solution and open environment.

REFERENCES

[1] Investigation Of The Effect Of Corrosion On Mild Steel In Five Different Environments by international journal of scientific & technology research volume 3, issue 7, july 2014
[2] Root cause analysis for the thickness measurement of corrode metal sheet by ultrasonic thickness gauge Sheetal kumar dewangan & k Ganpati Rao,Department of Mechanical Engineering, CCET Bhilai, Chattisgarh, India.
[3] Role of Oxide Scale Thickness Measurementsin Boiler Conditions Assessment" M. Alardhi, A. Almazrouee, S. Alsaleh, World Academy of Science, Engineering and Technology,Vol:5 2011-09-26.
[4] Alexander nana kwesi, Determination of corrosion rate and remaining life of pressure Vessel using ultrasonic thickness testing technique, G.J. E.D.T.,Vol.3(2):43-50 (March-April, 2014)
[5] Chinwko Emmanuel Chuka, Investigation of the effect of corrosion on mild steel in five different environments, International Journal Of Scientific & Technology Research volume 3, issue 7, July 2014
[6] J. C. Drury, Ultrasonic Flaw Detection for Technicians and Corrosion Monitoring and Thickness Measurement - international journal of ndt
[7] Theory and application of precision ultrasonic thickness gaging by By Kenneth A. Fowler, Gerry M. Elfbaum, Karen A. Smith and Thomas J. Nelligan,- The Journal of the British Institute of Non-Destructive Testing.
[8] Feasibility of thickness mapping using ultrasonic guided waves by Pierre Belanger A thesis submitted to Imperial College London for the degree of Doctor of Philosophy Department of Mechanical Engineering, Imperial College London December 2009.
[9] Kang llLEE, Department of Physics, Kangwon National University, Chuncheon 200-701 (Received 24 November 2009, in final form January 2010)
[10] Assessment of deteriorated corrugated steel culverts" Van Thien Mai,Queen's University Kingston, Ontario, Canada (January, 2013).
[11] Measuring oxide scale thickness on the inner surface of a boiler tube using advanced ultrasonic method Ahmed YAMANI Electrical Engineering Department, King Fahd University of Petroleum and Minerals.
[12] Investigation Of The Effect Of Corrosion On Mild Steel In Five Different Environments by international journal of scientific & technology research volume 3, issue 7, july 2014
[13] Root cause analysis for the thickness measurement of corrode metal sheet by ultrasonic thickness gauge Sheetal kumar dewangan & k Ganpati Rao,Department of Mechanical Engineering, CCET Bhilai, Chattisgarh, India.
[14] Role of Oxide Scale Thickness Measurementsin Boiler Conditions Assessment" M. Alardhi, A. Almazrouee, S. Alsaleh, World Academy of Science, Engineering and Technology,Vol:5 2011-09-26.
[15] IACS Unified Requirements Z10.1 (Rev.12), Z10.3 (Rev.7) and Z10.4

