Diagnosing and Solving Corrosion Problems in Jordanian Industry (Case Study)

By

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Amman- Jordan

March 2016

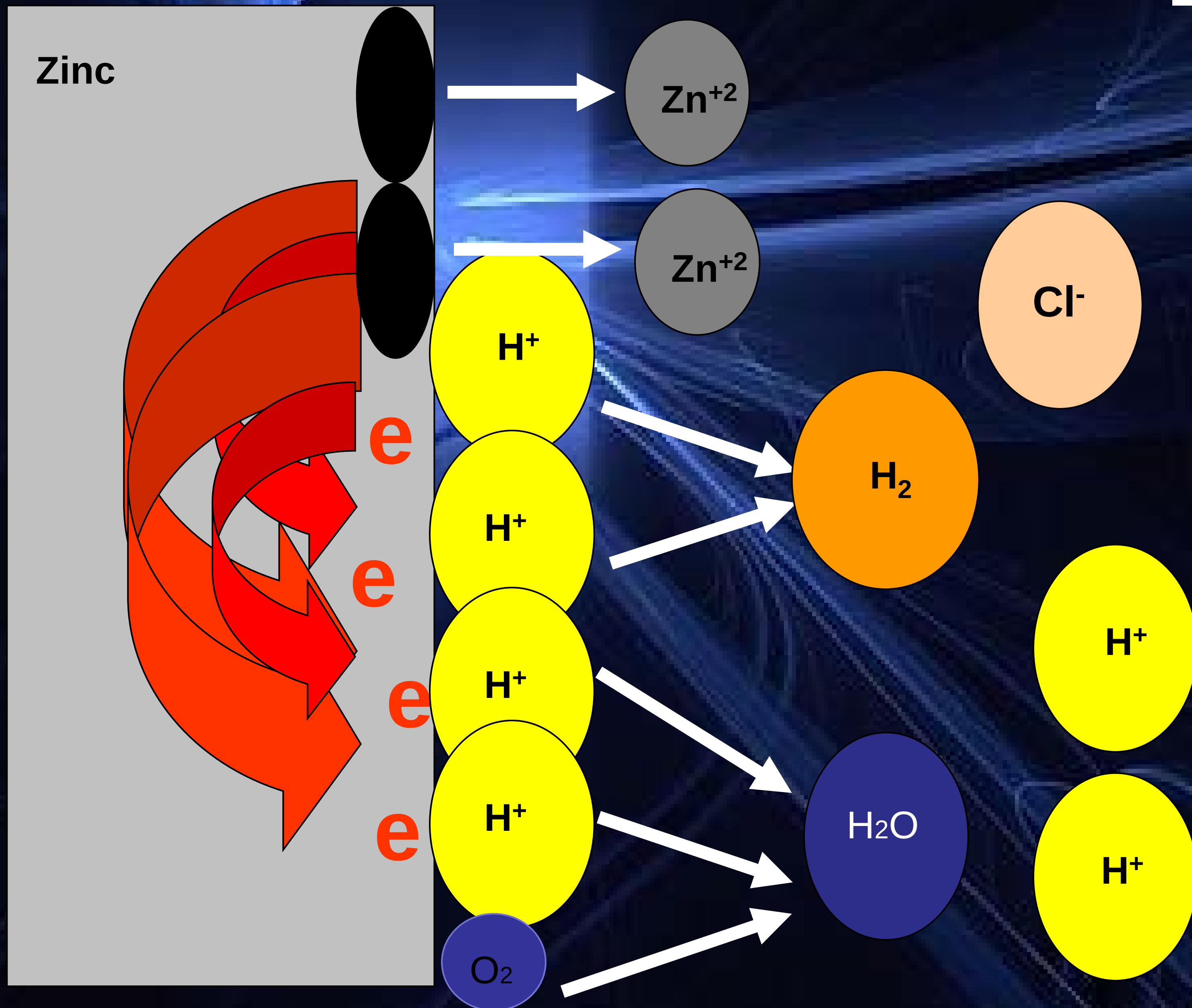
Introduction

CORROSION

is defined as
the deterioration
of a material
because
of reaction with its
environment

Introduction

HCl Solution

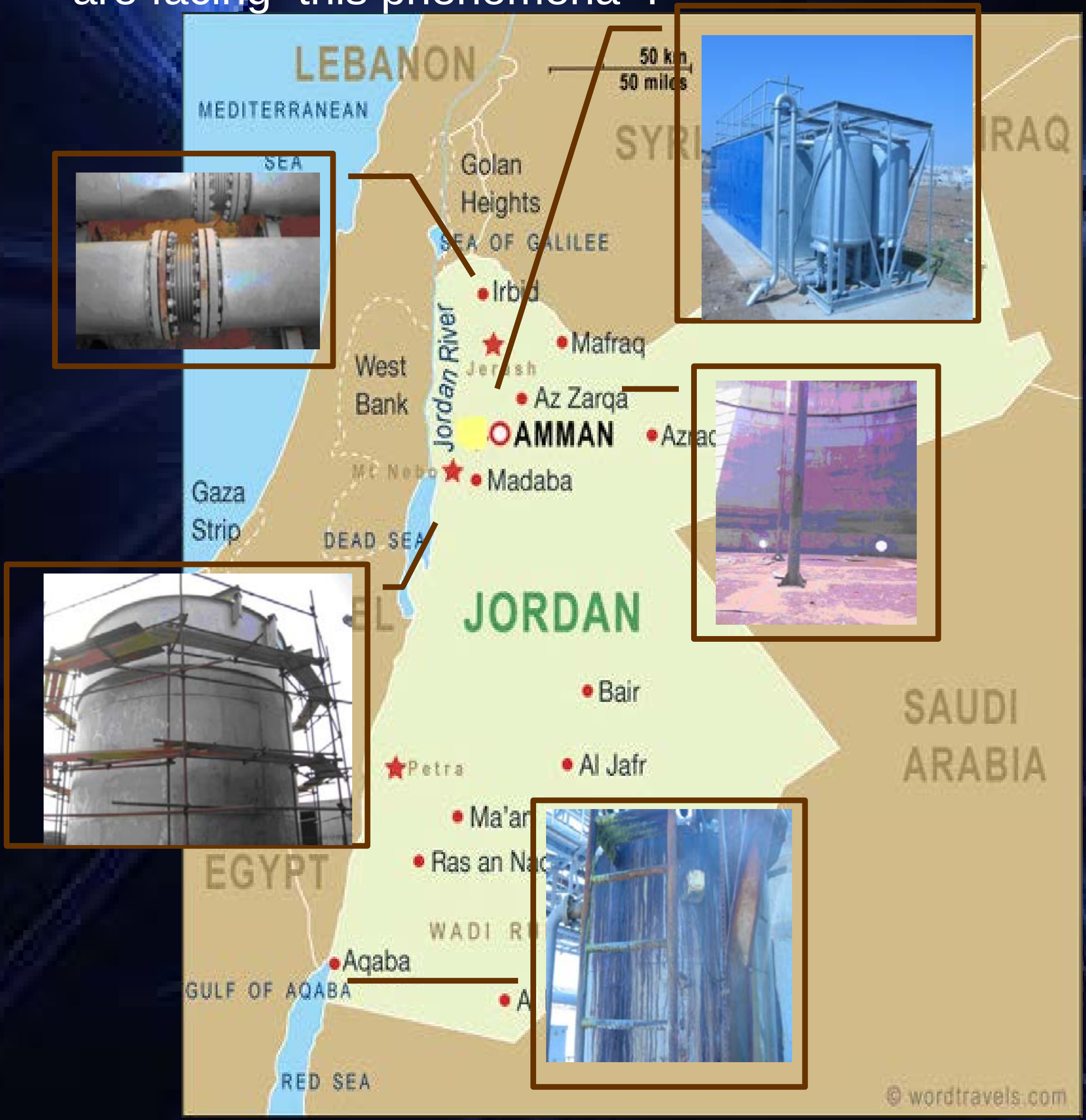


Introduction

- Loosing Mechanical Properties
- Direct Economical Losses: results from replacing corroded structures
- Indirect Economical Losses: shutdown, loss of product, loss of efficiency, over design
- Appearance
- Contamination of Products
- Loss of Safety

Introduction

After accomplishing more than 60 consultancy studies to solve corrosion problems, It is obvious that many industries in Jordan are facing this phenomena :



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Introduction

Introduction

Bhopal Disaster / Union Carbide India Limited (UCIL)

INDIA , 1984 ,
17000 Died,
558,125 permanent Injuries

water entered a side pipe that was missing its slip-blind plate and entered Tank E610, which contained 42 metric tons of MIC (methyl isocyanate). A runaway reaction started, which was accelerated by contaminants, high temperatures and other factors. The reaction was sped up by the presence of iron from corroding non-stainless steel pipelines.[The resulting exothermic reaction increased the temperature inside the tank to over 200 °C (392 °F) and raised the pressure.

This forced the emergency venting of pressure from the MIC holding tank, releasing a large volume of toxic gases. About 30 metric tons of MIC escaped from the tank into the atmosphere in 45 to 60 minutes

Introduction

- The secret of effective engineering generally lies in controlling the corrosion process through the following:
  - How to recognize the form of corrosion
  - Verifying the mechanism of corrosion failure
  - How to measure its severity
  - Inspection techniques
  - Methods of prevention

HIGH INVESTMENT IN MATERIAL = LOW MAINTENACE COST

LOW INVESTMENT IN MATERIAL = HIGH MAINTENACE COST

Types of Corrosion

- General Corrosion
- Galvanic Corrosion
- Intergranular Corrosion
- Crevice Corrosion
- Selective Leaching
- Pitting Corrosion
- Stress corrosion cracking
- Erosion Corrosion

Types of Corrosion

General Corrosion

Uniform attack occurs with equivalent intensity over the entire exposed surface.

General Corrosion

Types of Corrosion

Galvanic Corrosion

Occurs when two metals or alloys having different compositions are electrically coupled while exposed to an electrolyte.

Aluminum helicopter blade has corroded because of galvanic or bimetallic action where it was in contact with a steel counterbalance

Types of Corrosion

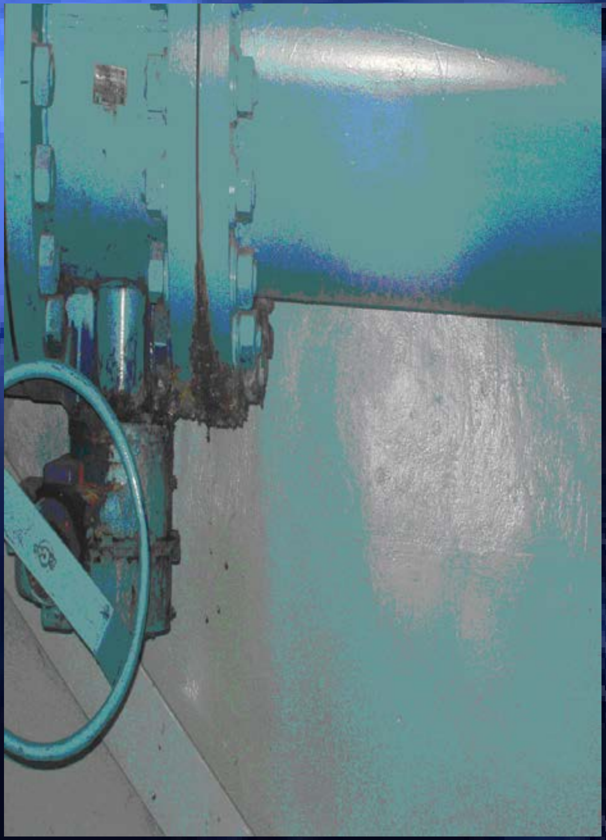
Intergrannular Corrosion

Occurs along grain boundaries for some alloys and in specific environment .Some stainless steels when heated to temperatures between 500 – 800 C for sufficiently long time periods ,these alloys become sensitized to intergrannular attack. It is believed that this heat treatment permits the formation of small precipitate particles of chromium carbide by reaction between the chromium and carbon in the stainless steel .Both the chromium and the carbon must diffuse to the grain boundaries to form the precipitates ,which leave a chromium depleted zone adjacent to the grain boundary. Consequently ,this grain boundary region is now highly susceptible to corrosion.

Types of Corrosion

Crevice Corrosion

Occurs as a consequence of concentration differences of ions in the electrolyte solution.



Crevice Corrosion

Types of Corrosion

Selective Leaching

Occurs when one element is preferentially removed as a consequence of corrosion processes.

Many brass plumbing fittings have electrochemical cells between their constituent phases. This leads to rapid corrosion cracks which have a coppery color due to dezincification where the zinc content is leached out.

Types of Corrosion

Pitting Corrosion

It is a form of localized corrosion attack in which small pits or holes form. They penetrate from the top of a horizontal surface downward in a nearly vertical direction.

Pitting Corrosion

Types of Corrosion

Stress corrosion cracking

Results from the combined action of an applied tensile stress and a corrosive environment.

The deep drawn brass cup on the right shows stress corrosion cracking under the influence of the residual manufacturing stresses and a mildly corrosive environment. The cup on the left has been annealed before putting it into service which solves the problem.

Erosion Corrosion

Arises from combined action of chemical attack and mechanical abrasion or wear as a consequence of fluid motion.

Erosion Corrosion

Miscellaneous

Case Studies

First Case Study

Corrosion
Engineering
Division

Failure Due to Corrosion Phenomenon in The Fire Tubes of The Main Boilers

Case Studies

Case Studies

Verifying the root causes of corrosion failure in the fire tubes was an ultimate goal of this study:

Fig.(1) : Fire tubes of the boilers

Case Studies

Fig.(2) : Corroded fire tube with full deterioration in the material as shown in the red arrows

Case Studies

- Therefore a thorough investigation was conducted on the following:

1. Corroded fire tubes
2. Corrosion products and ash
3. Diesel fuel
4. Water before and after treatment

Case Studies

Corroded fire tubes

Chemical analysis of the corroded fire tubes' material showed that it is Carbon Steel grade AISI 1010 with C % = 0.083 and S % = 0.0142.

Mechanical tests on the failed tube showed the following :
Yield strength = 245 MPa
Tensile Strength = 341 MPa
Elongation = 45%

Chemical analysis using EDX of the corrosion products for several metallic samples revealed the following:

Case Studies

Table (1) Sample #1 (row # 1, tube # 8), position #1 from boiler #3

Compound	Wt%
FeO	42.91
SO_3	47.23

Table (2) Sample #1(row # 1, tube # 8), position #2 from boiler #3

Compound	Wt%
FeO	49.29
SO_3	50.71

Table (3) Sample #2(row #5, tube #7), position #1 from boiler #3

Compound	Wt%
FeO	68.26
SO_3	28.21

Table (4) Sample #2(row #5, tube #7), position #2 from boiler #3

Compound	Wt%
FeO	47.72
SO_3	48.70

Case Studies

Table (5) Sample #3(row #1, tube #4), position #1 from boiler #3

Compound	Wt%
FeO	42.88
SO_3	55.98

Table (6) Sample #3(row #1, tube #4), position #2 from boiler #3

Compound	Wt%
FeO	47.56
SO_3	49.98

Case Studies

Fig.(3) : (a) Part of the failed fire tube showing the corrosion products on the internal surface as shown in the red arrow
(b) Corrosion products near the opening of the fire tube external surface located at the rear side of one of the boilers.

Case Studies

Micro-hardness analysis was conducted on random selected spots on the failed fire tube surface given in fig.(3a) and near a deep pit adjacent to seam weld line as shown in the red circles of fig.(5) and table (7) :

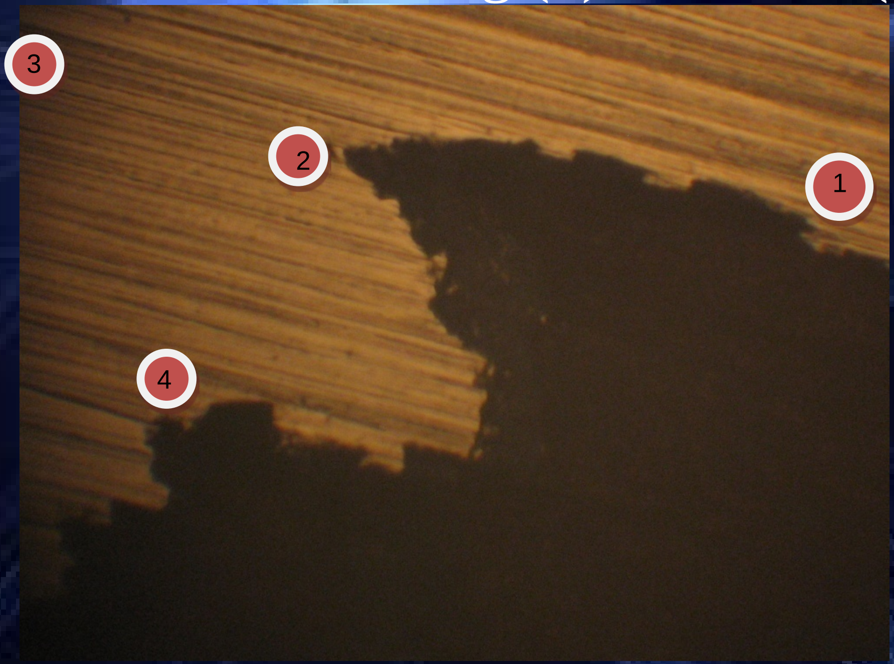


Fig.(5) : Part of the failed fire tube surface magnified using optical microscope (200 X) showing the random selected spots to measure the microhardness near a shallow and deep pit.

Case Studies

Table (7) : Measured Vickers Micro hardness on the random selected spots on the failed fire tube surface

Position No.	Measured Vickers Hardness
1	118.656
2	145.83
3	82.4
4	126.6

Case Studies

Microstructural analysis of several specimens revealed the existence of deep and large "WORM HOLES" pits.

Fig.(6) : Clear pits propagated into large " WORM HOLES" as shown in the red arrows

Case Studies

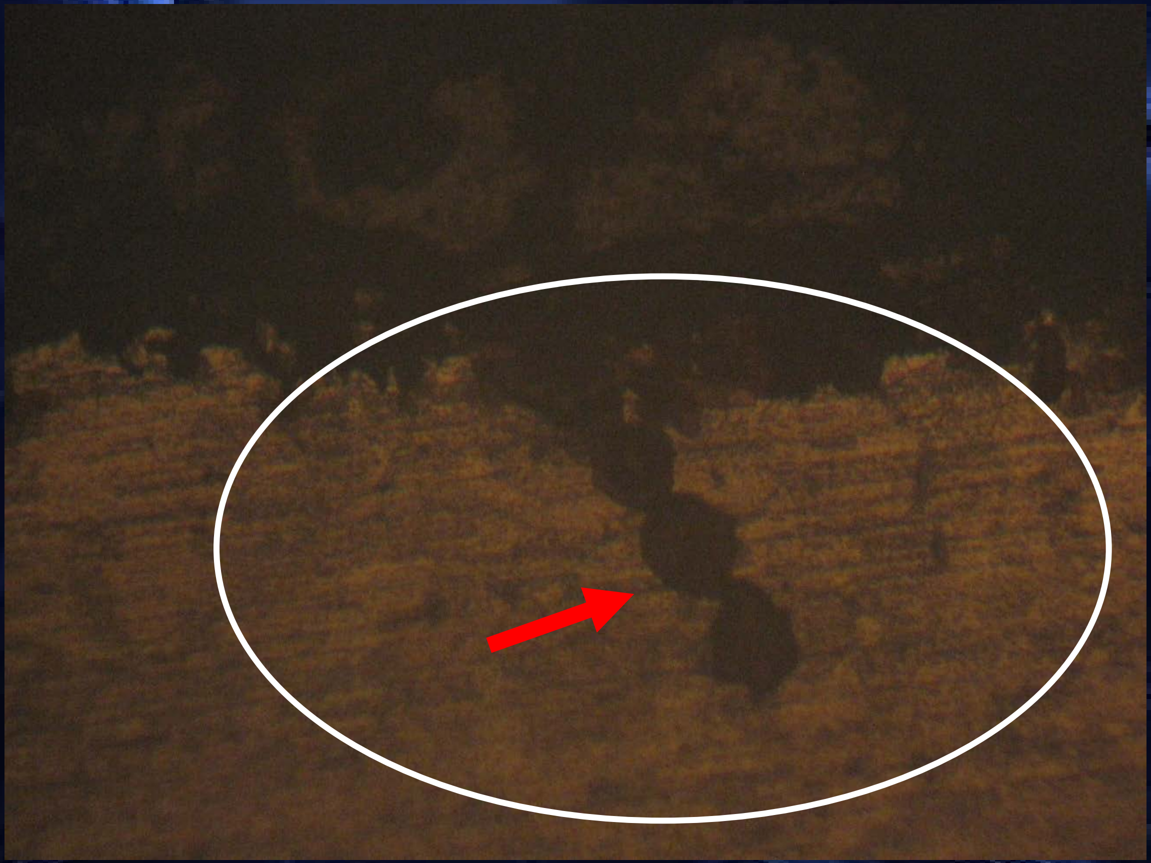


Fig.(7) : Clear pits propogated into large " WORM HOLE" as shown in the red arrow

Case Studies

Non Destructive Tests (NDT) :

Fig.(8) : Reduction in thickness in the lower part of the fire tube as shown in the red arrow

Case Studies

Fig.(9) : Reduction in thickness in the lower part of the fire tube as shown in the red arrow

Case Studies

Fig.(10) : Reduction in thickness in the lower part of the fire tube with complete deterioration in the material as shown in the red arrow.

Case Studies

X-Ray test on one of the failed tubes revealed heavy damage due to the corrosion phenomena on the internal surface of the tube with severe reduction in thickness as shown in the following figs.(11 & 12) :

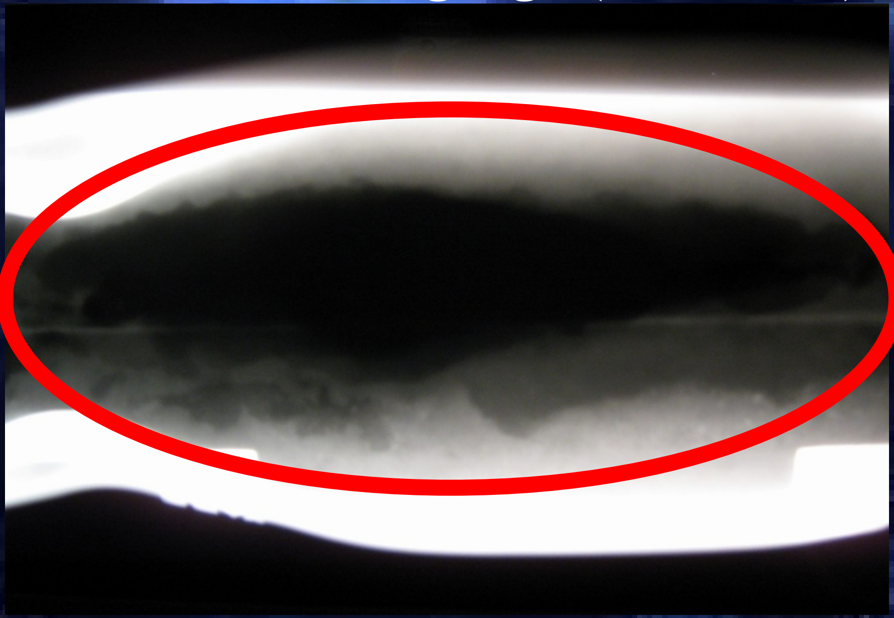


Fig.(11) : X –Ray photo of the failed tube revealed heavy damage due to the corrosion phenomena on the internal surface of the tube with severe reduction in thickness as shown in the red circle.

Case Studies

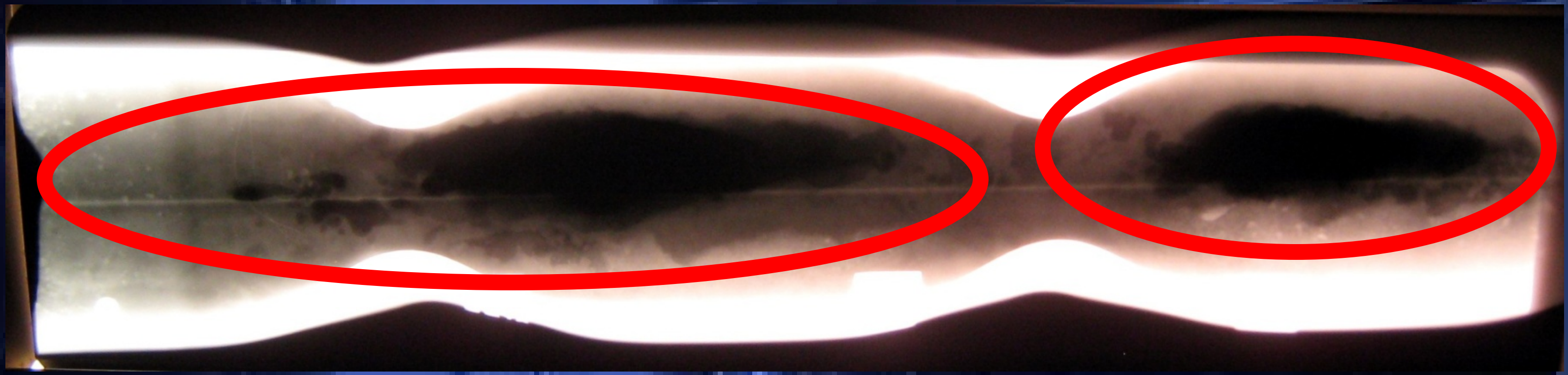


Fig.(12) : X –Ray photo of the failed tube revealed heavy damage due to the corrosion phenomena on the internal surface of the tube with severe reduction in thickness as shown in the red circle.

Case Studies

In order to measure the actual reduction in thickness of the fire tube given in figs.(11 and 12) , longitudinal cutting was implemented as shown in fig.(13) .Thickness measuments results of the fire tube given in in fig.(13) deviated between (<1 mm in the lower part of the tube and 4 mm in the upper part of the tube).

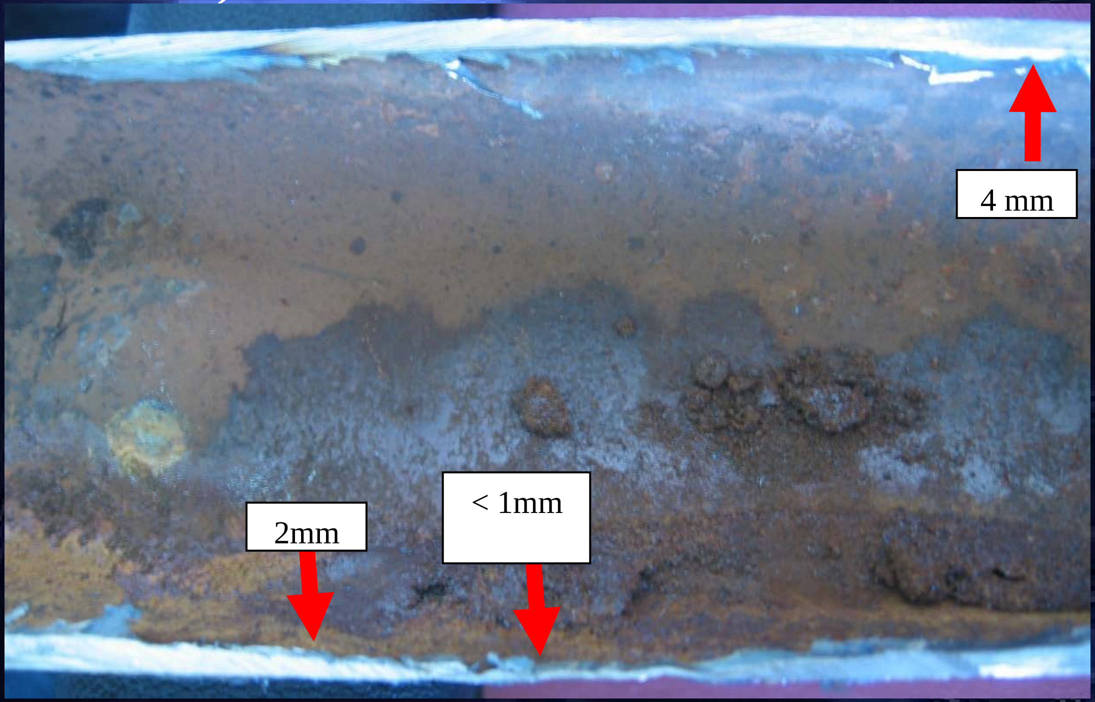


Fig.(13) : Red arrows reveals severe reduction in thickness in the lower part in comparison with the upper part.

Case Studies

Corrosion products and ash

Chemical analysis of the corrosion products and ash fetched from four random positions located in boiler # 3 revealed the following as shown in the following table:

Wt.%	S1	S2	S3	S4
Moisture Content	1.4	4.43	3.31	0.6
sulfur content	15.18	13.04	14.53	0.3
Iron content	16.5	17.5	13.9	33.3

Diesel fuel

Chemical analysis of the diesel fuel samples from main storage tank and the burner revealed higher sulfur content in ppm the following as shown in the following table:

ppm	Main Storage Tank	Burner
Total Sulfur Content	10000	9780

Case Studies

Water before and after treatment

Water analysis before and after treatment revealed the following:

Parameter	Water before treatment	Water after treatment
pH	8.28	9.28
TH (as $CaCO_3$) mg/L	132	8.83
Cl mg/L	159	129
SO_3 mg/L	<2	<2
TDS mg/L	582	476
Iron content mg/L	<0.039	<0.039

Case Studies

Conclusion:

The above results showed the following :

Mechanical tests (Yield Strength (YS) = 245MPa, Tensile Strength(TS)=341MPa and Elongation (E)= 45 % which showed a deviation from standards for carbon steel AISI 1010 (i.e.YS = 305 MPa, TS = 365MPa and E =20%) due to the corrosion phenomena.

EDX surface analysis revealed the existence of high percentages of SO_3 which deviated between (28.21 to 55.98 %) in combination with high percentages of iron oxide which deviated (42.88 to 68.26%) for various fire tube samples.

Micro hardness test results revealed an obvious increase in the hardness at the points near the pits (i.e.118.656, 145.83& 126.6 Hv) in comparison with the points far from the pits (i.e 82 Hv) .

Microstructural analysis revealed the existence of deep and large pits propagated into "WORM HOLES" .

Ultrasonic and X-ray tests revealed heavy damage due to the corrosion phenomena on the internal surface of the fire tubes with severe reduction in thickness.

Thickness measurement revealed a deviation between (<1 mm to 4 mm) due to the corrosion phenomena.

Chemical analysis of the corrosion products and ash showed percentages of sulfur deviated between (0.3 to 15.18 %) and moisture content deviated between (0.6 to 4.43 %).

Diesel fuel analysis showed extremely high percentages of sulfur content deviated between (9780 to 10000 ppm).

Case Studies

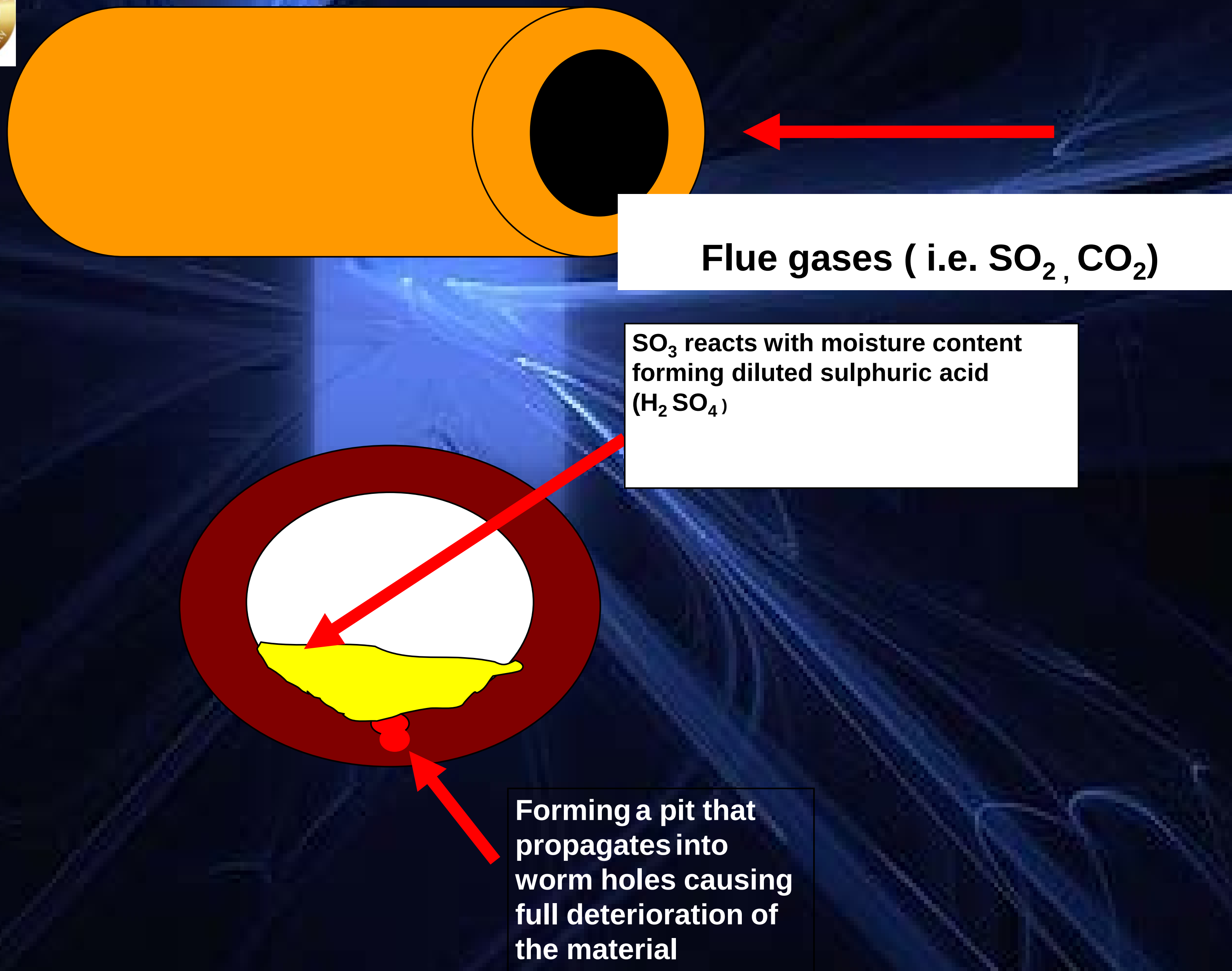
So it is obvious that the scenario of the failure in the fire tubes of the three main boilers occurred due the existence of large quantities of sulfur in the diesel forming sulfurous gases (i.e. SO_2 and SO_3), which as a result SO_3 reacts with moisture formed from the condensation of air near the outlet of the fire tubes (i.e. 20 cm before the outlet) due to deviation in temperature between (water side and fire side across the fire tube wall) causing the formation of diluted sulphuric acid (i.e. H_2SO_4) according to the following chemical reactions and the sketches :

$$S + O_2 \rightarrow SO_2$$

$$SO_2 + 1/2O_2 \rightarrow SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Case Studies



Case Studies

Because this grade of steel (AISI 1010) doesn’t resist sulphuric acid , therefore oxidation of iron occurred causing the initiation of deep and large pits which propagated into WORM HOLES and as a result thinning of the wall or full deterioration in the material of the fire tubes occurred. On the otherhand the accumulation of corrosion products and ash with high percentages of sulfur compounds will cause the initiation of what is called localized concentration cells which plays also an additional role in increasing the aggressiveness of the corrosion attack.

Case Studies

Recommendations

Replacement of the material of the existing fire tubes (i.e. AISI 1010) with new material made of iron base alloy containing Chromium (Cr) and Molybdenum (Mo) in order to resist the saturated sulfur and sulfur dioxide (SO_2) gaseous environment and other compound formed as a secondary reaction (i.e. Dilute H_2SO_4).

Monitoring the percentage of sulfur content in the diesel fuel .It should be with minimal.

The boilers should be cleaned three times a year at least in order to remove any materials that might be generated at the internal surface of the fire tubes within the corregations.Taking into consideration that improper cleaning will reduce the lifetime of the fire tubes and the boiler as a result due to corrosion phenomenon as well as increasing the consumption of fuel.

Regulating and monitoring the fuel- to- air mixture ratios in the burner by an expert because it has a direct effect on the efficiency of combustion in order not to have partial combustion conditions that generate combustion products which might generate localized concentration cells and initiating the corrosion phenomenon. Therefore it is worthy of mention in this regard that the maintenance technician shouldn’t build his judgment on the efficiency of the burner just by visual evaluation of exhaust smoke and the flame .

Case Studies

There should be a log book for each boiler in order to have a historical record that reflects both normal and abnormal operating condition as well as shut downs , periods of preventive maintenance and what kind of notifications were recorded during maintenance or during overhaul. In this regard a preventive maintenance management software's could be utilized in an efficient way.

Having special devices to monitor the water quality (i.e. digital pH meter, TDS meter , Oxygen meter and TH meter) in order to have a snap shot on the conditions of the water before and after treatment. Because water analysis conducted at RSS laboratories showed an obvious deviation from the analysis conducted by the water treatment company .On the other hand the type of inhibitors used by the water treatment company are working as anti scale and anti corrosion (i.e. Oxygen scavenger) inhibitors, and it has no effect against the formation of biological corrosion due to aerobic and anaerobic Bacteria as well as Algae. Therefore biocide should be added to the scale and corrosion inhibitors.

Second Case Study

Case Studies

Case Studies

The following study was conducted on the four Stainless Steel tanks (Water, Concentrate 1, Concentrate 2 & Syrup) as well as on a sample of the stainless steel piping network .

1.Stainless Steel tanks (Water, Concentrate 1, Concentrate 2 & Syrup):

Fig.(1) represents the external surface of the water tank which showed an extensive corrosion phenomena underneath the surface of the external stainless steel sheets as shown in fig.(2).This phenomena was also obvious in the other three tanks (Concentrate 1, Concentrate 2 & Syrup).

Case Studies

Fig.(1) : External surface of the water tank.

Case Studies

Fig.(2) : Corrosion products are very obvious below the external surface of the stainless steel sheets which appeared in the four above mentioned tanks.

Case Studies

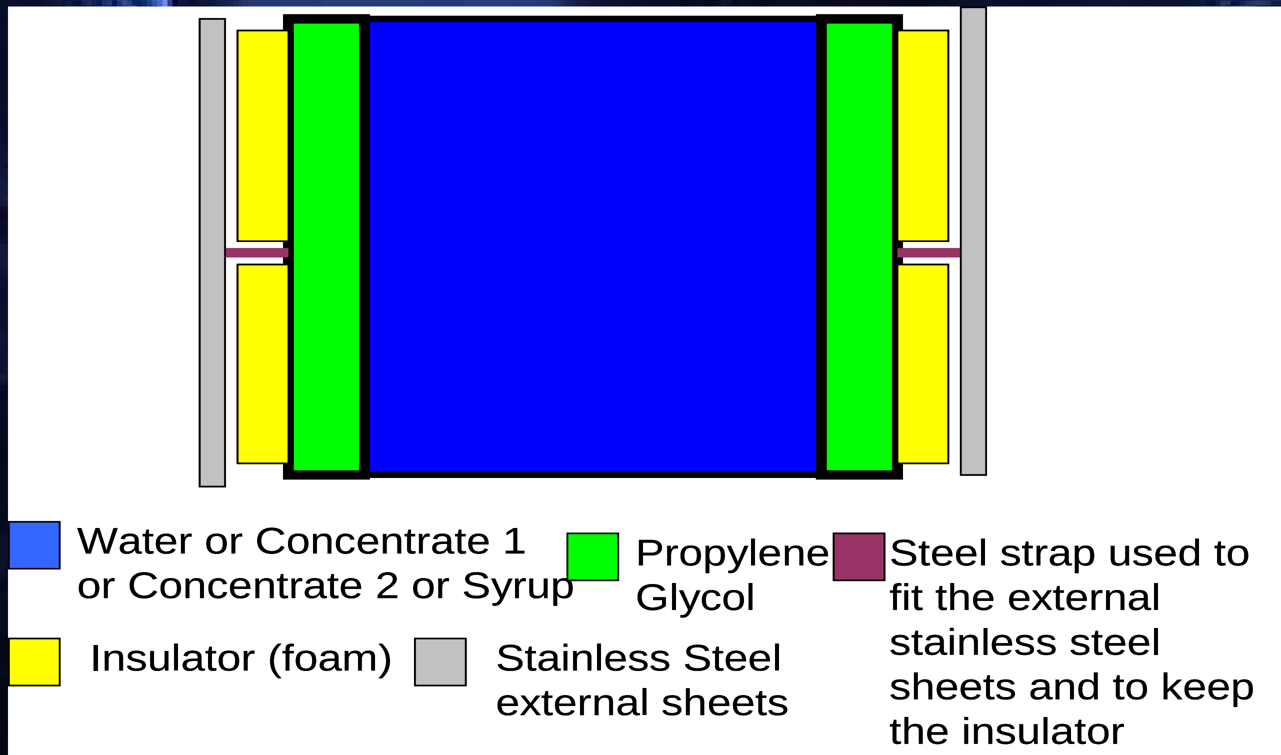


Fig.(3) : Crrossectional area of the tanks

Case Studies

The following table (1) shows the chemical analysis by EDX of the material of each species used to construct the tanks, which revealed that the type of stainless steel was of grade 304.The straps were of carbon steel.

Table (1) Type of the material used to construct the tanks

No.	Type	Material
1	Inner surface of the tank attached to the solution (Water,Conc.1,Conc.2 & Syrup) from one side and the propylene glycol from the other side	Stainless Steel 304
2	Outer surface of the tank attached to the propylene glycol from one side and the insulator from the other side	Stainless Steel 304
3	External Sheets	Stainless Steel 304
4	Straps	Carbon steel
5	Welds	Stainless Steel 304

Case Studies

Chemical analysis of the Propylene Glycol revealed that the pH was 7.1 ,while biological analysis revealed traces (< 1 CFU/ml) of aerobic and anaerobic bacteria which have no significant effect from corrosion stand point of view on the material of the tank.

- Chemical analysis of the Water showed that the pH was equal to 3.05 with TDS equal to 39 mg/L and TH as ($CaCO_3$) equal to 9 mg/L.

-Chemical analysis of the Syrup and the Concentrate revealed pH values of (4.3 & 4.4) respectively.

-Corrosion tests were conducted using the cell given in fig.(4) in order to implement accelerated corrosion tests on the metallic specimens in various environments (Water , Conc.1,Conc.2 & Syrup) using the Potentiostat given in fig.(5) .Tests results shown in table (2) below.

Case Studies

Fig.(4) : Corrosion Cell

Fig.(5) : Potentiostat

Case Studies

Table (2) Corrosion rate results using potentiostatic test

No.	Working Electrode	Electrolyte	Time hour	Corrosion Rate (mm/y)	Comments
1	Inner surface material (SS 304) of the Syrup tank 1	Syrup	1	3.6×10^{-3}	Very good corrosion resistance to the electrolyte
2	Inner surface material (SS 304) of the Syrup tank 2	Syrup	1	3.0×10^{-2}	Good corrosion resistance to the electrolyte
3	Inner surface material (SS 304) of the Water tank	Water	1	3.323×10^{-3}	Very good corrosion resistance to the electrolyte
4	Inner surface material (SS 304) of the Concentrate tank	Concentrate	1	1.335×10^{-2}	Good corrosion resistance to the electrolyte
3	External sheets (SS 304)	Water	1	5.396×10^{-3}	Very good corrosion resistance to the electrolyte

Case Studies

The mechanism given in fig.(6) was verified using the Galvanic Corrosion Monitoring & Analyzing System which indicated that the carbon steel straps shown in figs.(2 & 3) were galvanically corroded due to the coupling with stainless steel sheets (SS 304) and stainless steel (SS 304) of the outer surface of the jacketed tank using stainless steel welding rods (SS 304).This was obvious in fig.(7) which showed the graphs of(E1(stainless steel sheet) and E3(stainless steel outer surface of the jacketed tank) with negative galvanic currents against time (1 hour), while graph (E2 (carbon steel strap)) revealed positive galvanic current against time (1 hour) which means that it was sacrificially corroded in order to protect E1&E3.

Case Studies

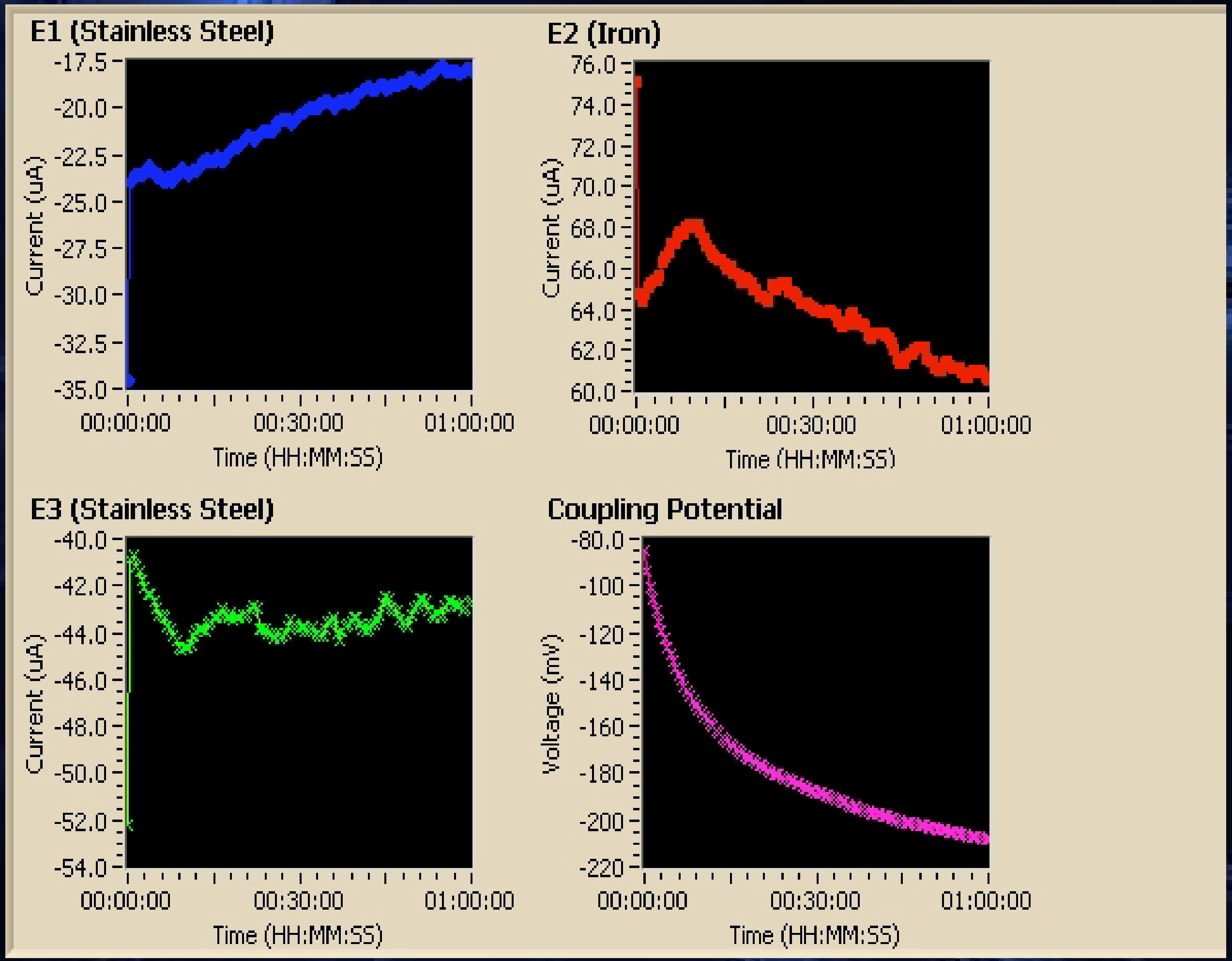
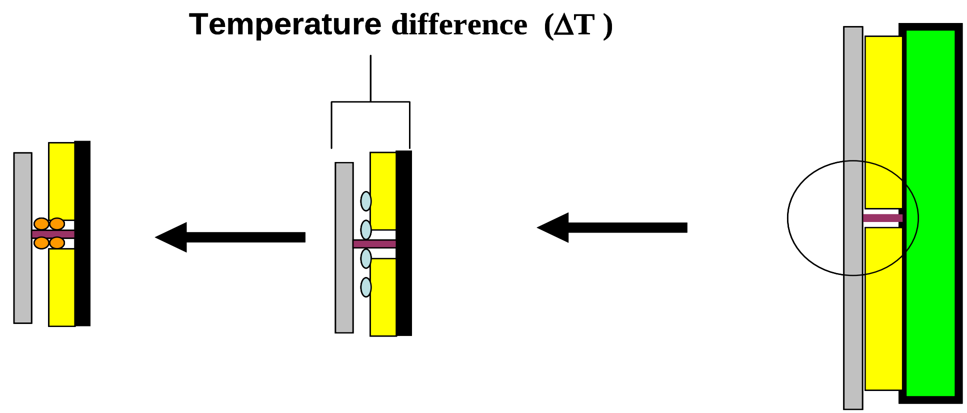


Fig.(7) :Galvanic corrosion result due to the coupling of stainless steel sheets (SS 304) , stainless steel (SS304)of the outer surface of the jacketed tank and carbon steel straps.

Case Studies

Corrosion rates given in table (2) deviated between (Good to excellent) corrosion resistance to the environment at stagnant conditions.

But what actually caused the corrosion to occur beneath the stainless steel sheets shown in fig.(2) is the mechanism shown in fig.(6).



Due to the temperature difference between the ambient temperature and the coolant (propylene glycol) temperature, Condensation process will occur followed by initiation of water droplets over the T connection among the carbon steel straps , stainless steel sheets and stainless steel outer surface of the jacketed tank .Water droplets work as an electrolyte to conduct GALVANIC current and causing Galvanic Corrosion to occur

- Insulator (foam)
- Stainless Steel external sheets
- Steel strap used to fit the external stainless steel sheets and to keep the insulator
- Corrosion Products
- Water droplet

Fig.(6) :sketch shows the major cause of corrosion beneath the stainless steel sheets

Case Studies

Third Case Study

Case Studies

This study is based on verifying the causes of cracking due to corrosion in the expansion joints shown in fig.(1) below:

Fig.(1): Expansion joints

Case Studies

Chemical analysis of the of the expansion joint material sample showed the following:

Table(1):Chemical analysis of the expansion joint material

Element	Chemical Composition, %
Carbon	0.04
Sulfur	0.006
Silicon	1.042
Chromium	17.464
Nickle	10.112
Manganese	1.548
Iron	69.834

Case Studies

Chemical composition given in table(1) showes that the expansion joint material of Stainless Steel type 304 according to the ASTM (A666) as follows:

Element	Chemical Composition, %
Carbon max.	0.08
Sulfur max.	0.03
Silicon max.	0.75
Chromium	18.00-20.00
Nickel max.	8.00-10.50
Manganese max.	2.00

Case Studies

Cutting the sample of the expansion joint given in fig.(2) showed multiple layers of stainless steel sheets compressed together as shown in fig.(3).

Fig.(2):Sample of expansion joint

Case Studies

Fig.(3):Sample of expansion joint showing the stainless steel 304 layers compressed together.

Case Studies

Analyzing the chemical composition using SEM of the corrosion products given in fig.(4) showed the following:

Table(2):Chemical analysis of the corrosion products given in fig.(4)

Corrosion Product	Wt%
Cr_2O_3	22.86
FeO	61.071
SO_3	0.486
Cl	0.264

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Case Studies

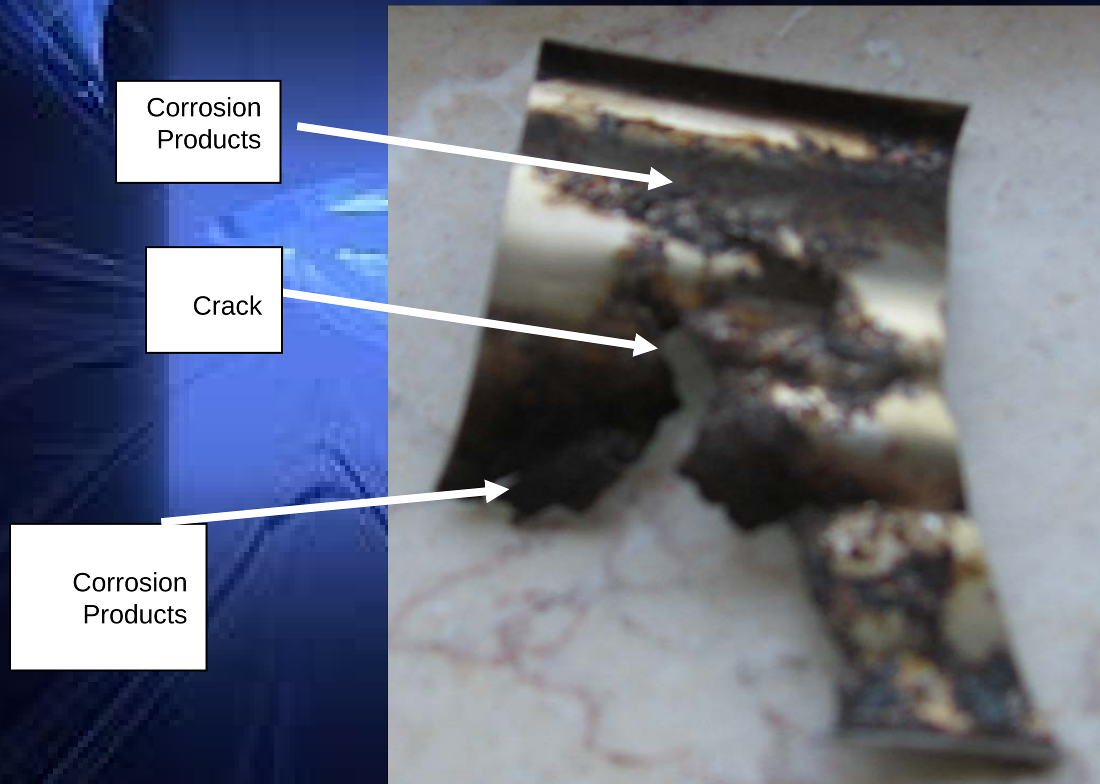


Fig.(4):Sample of one of the corroded layers in the expansion joint given in fig.(3).

Case Studies

Fig.(5):SEM photo of one of the corroded layers in the expansion joint showing a crack occurred due to the Stress Corrosion Cracking (SCC).

Case Studies

Analyzing the chemical composition using SEM of the corrosion products in the cracked area given in fig.(5) showed the following:

Table(3):Chemical analysis of the corrosion products given in fig.(4)

Corrosion Product	Wt%
Cr_2O_3	15.983
FeO	45.13
SO_3	3.782
Cl	2.943

Tables (2&3) showed percentages of (SO_3 & Cl) which give the evidence that these elements came from the surrounding environment and Acidic Rain which is mainly diluted sulphuric acid (H_2SO_4).

Case Studies

These percentages of (SO_3 & Cl) ,played an important role in the initiation of what is called "Concentration Cells" after a normal evaporation process, adding to it the thermal stresses which in combination with the concentration cells started the corrosion phenomena causing a crack in what is called the Stress Corrosion Cracking (SCC) in the first layer of the expansion joint , taking into consideration that the material of the expansion joint given in table(1) doesn't resist corrosion , which opened the path for the acidic rain to enter to the second layer and initiating again the "Concentration Cells" repeating what is happened in the first layer ,then the same process will occur to the third ,fourth etc….Fig.(6) give a schematic hypothetical assumption of the given process process

Case Studies

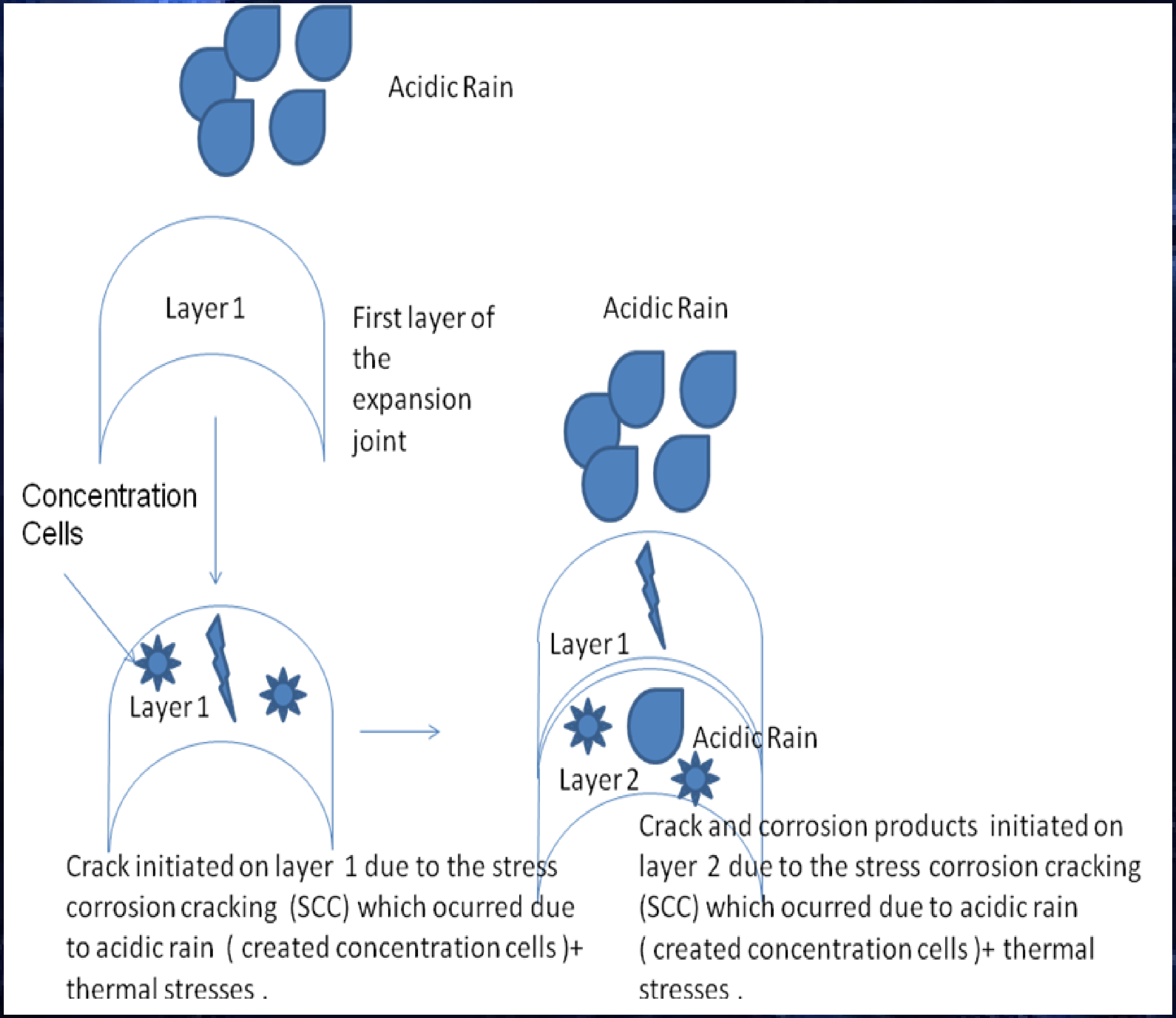


Fig.(3):Schematic representation to what have happened to the expansion joint.

Fourth Case Study

Case Studies

Fig.(1) below represents the steam drum which showed pitting corrosion on the internal suface.

Fig.(1) : Steam drum

Case Studies

Standard replica procedure according to ASTM E 1351 was used to obtain metallurgical information from selected locations (1,2 &3) at the internal surface of the steam drum. The replication procedure involved initial surface preparation by grinding discs. The grinded areas were polished successively with Alumina followed by diamond polishing pastes(30,12 & 1 micrometer).Microstructural features were revealed by etching the surface with Nital (3% Nitric acid in 97 % Ethanol).Cellulose acetate film moistened with acetone was used to replicate the microstructure. At least four replicas were taken from each position to ensure optimum results. Figs (2,3,4 , 5,6& 7) show large pits of different dimensions obtained from replicas .

Case Studies

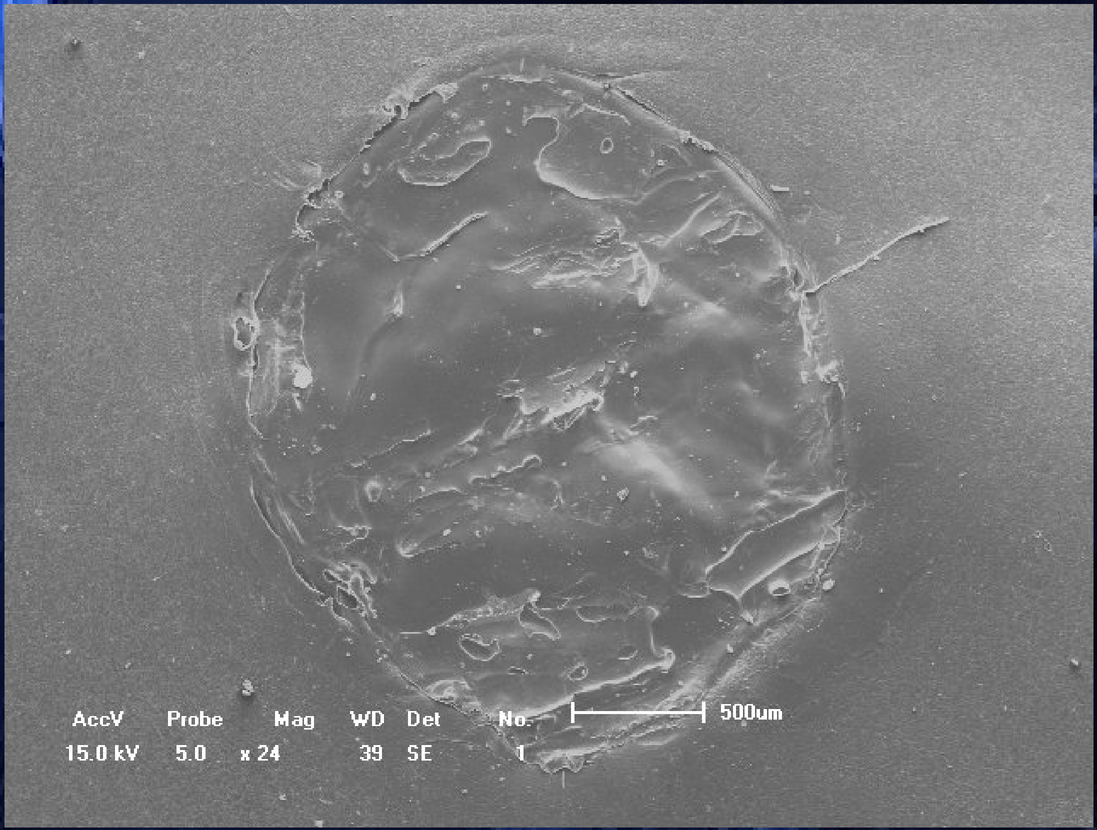


Fig.(2) SEM photo shows a large pit in location 1 of the internal surface of the steam drum

Case Studies

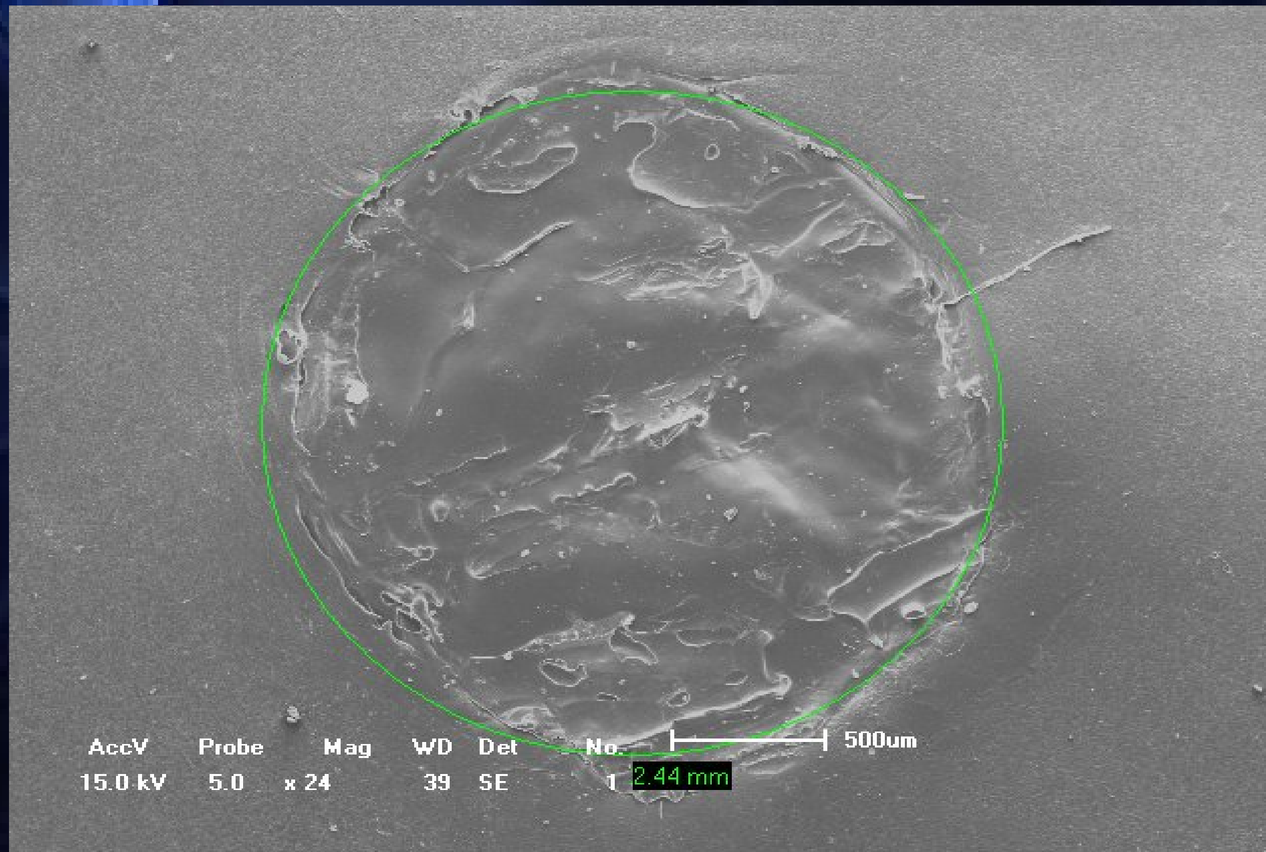


Fig.(3) SEM photo shows the diameter of the pit in location 1

Case Studies

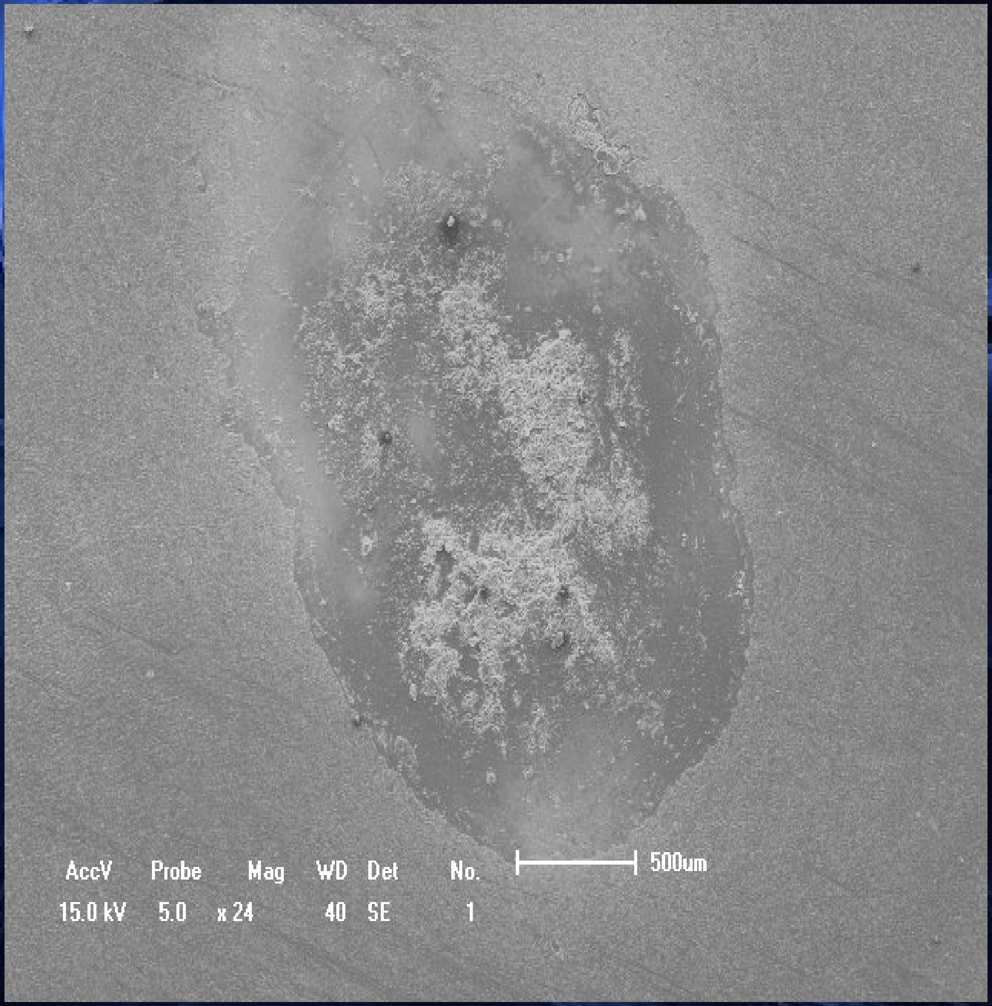


Fig.(4) SEM photo shows a large pit in location 2 of the internal surface of the steam drum.

Case Studies

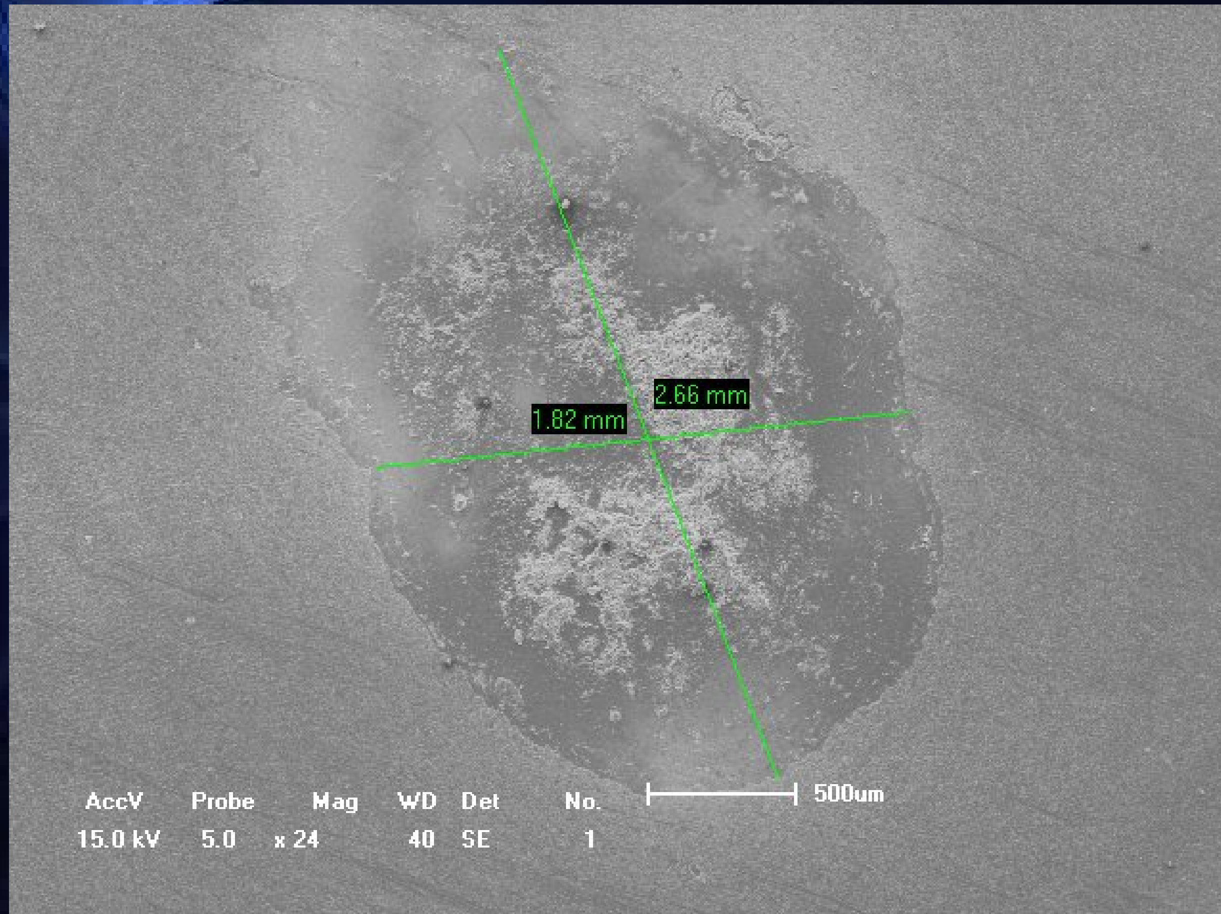


Fig.(5) SEM photo shows the dimensions of the pit in location 2

Case Studies

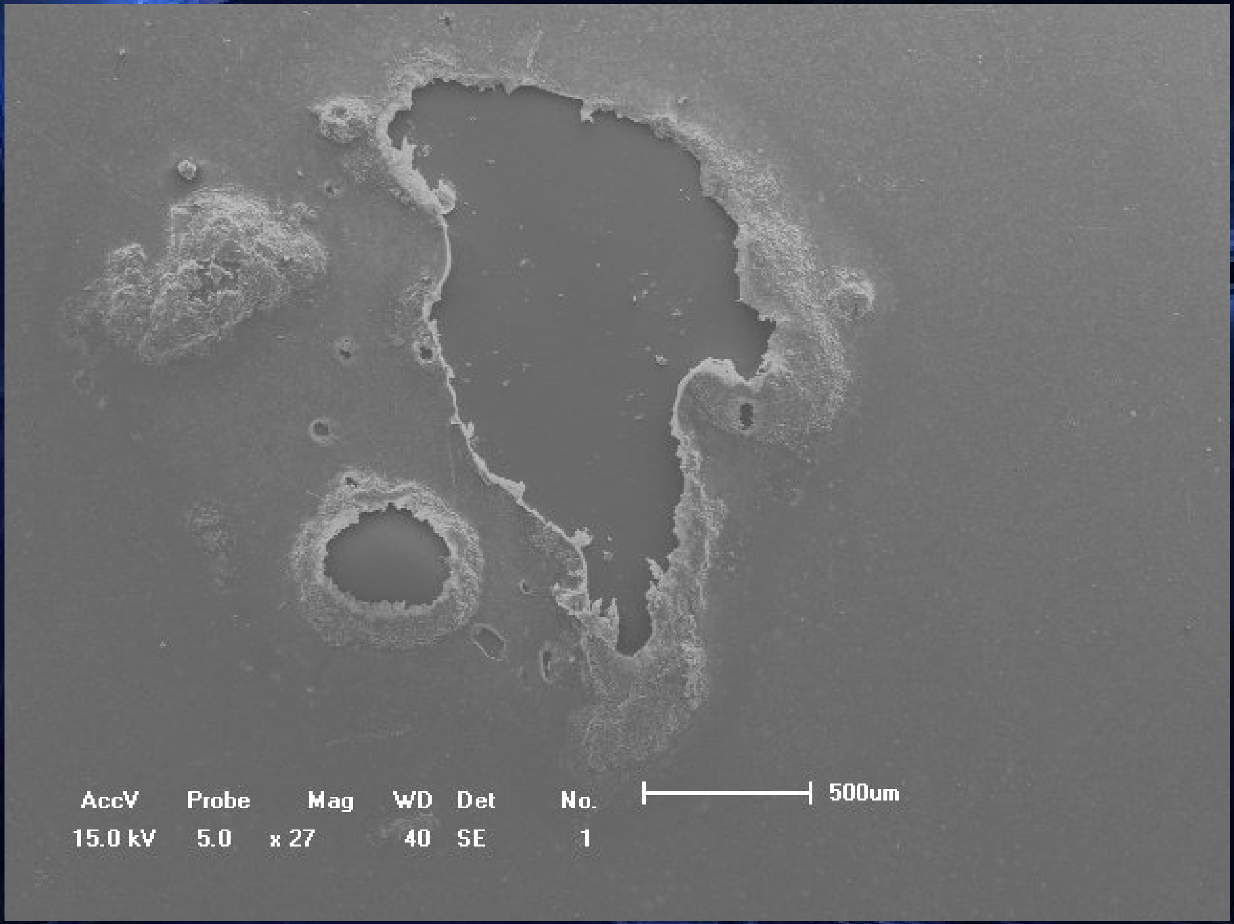


Fig.(6) SEM photo shows the dimensions of the pit in location 3

Case Studies

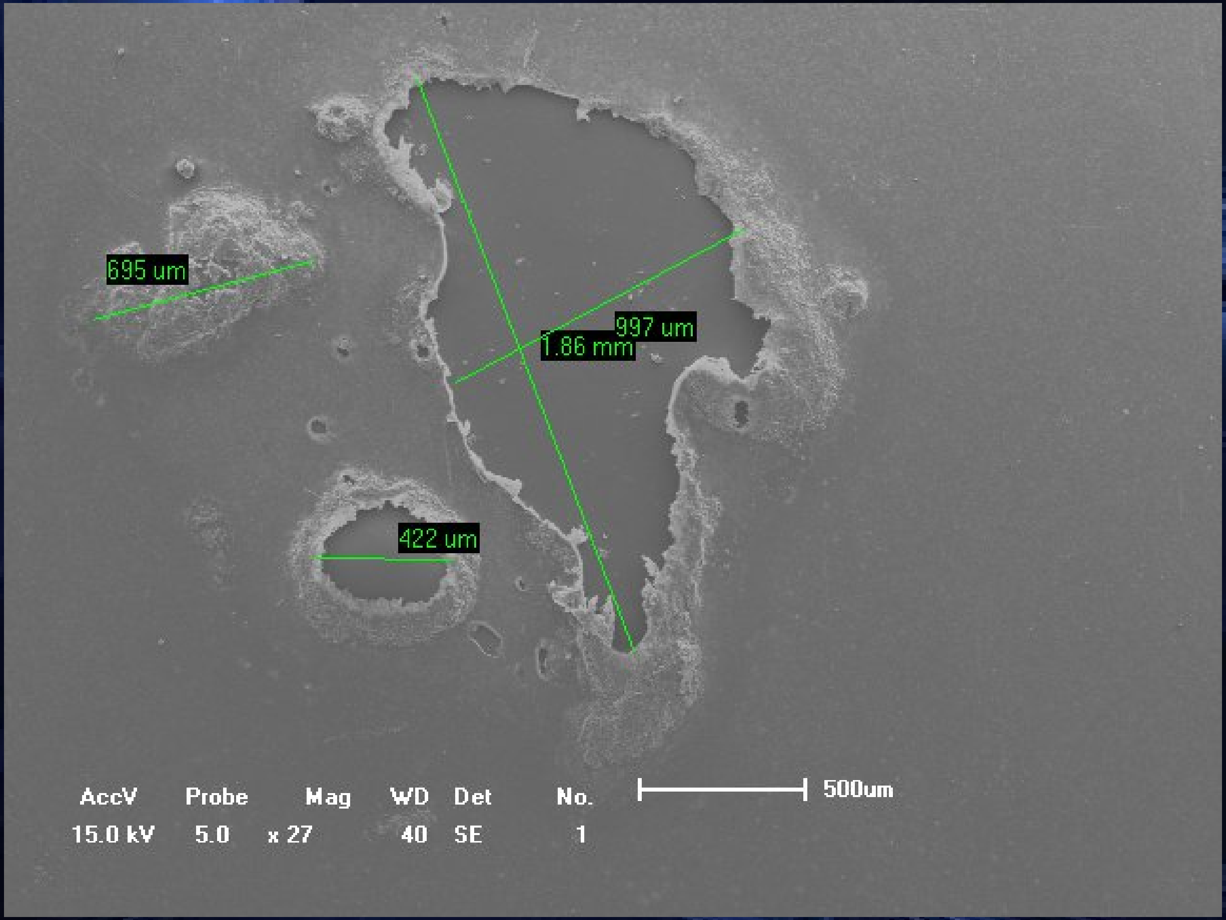


Fig.(7) SEM photo shows the dimensions of the pit in location 3

Case Studies

<u>Conclusion</u>

It can be concluded from the above figs(2 to 7) that phosphate induced corrosion as well as formation of Caustic Soda have initiated the pits shown in the above figures according to following reaction mechanism :

$$Na_3PO_4 + H_2O \rightarrow Na_2HPO_4 + NaOH$$

$$2Na_2HPO_4 + Fe + \frac{1}{2}O_2 \rightarrow NaFePO_4 + Na_3PO_4 + H_2O$$

$$2NaOH + Fe \rightarrow Na_2FeO_2 + H_2$$

Case Studies

It is clear from the above chemical reactions that the formation of **maricite** (i.e. **$NaFePO_4$)** is due to the attack of the acidic phosphate salt (i.e. $NaHPO_4$) to the internal surface of the steam drum at elevated temperature (i.e.250 C) ,because phosphate is known to affect the crystalline structure of the steel structures. Formation of Caustic soda (NaOH) causes Caustic corrosion (gouging) which results from the reaction of caustic soda with the internal surface of the steam drum. In order to minimize this phenomena continuous monitoring of the PO4 concentation, pH and Na/PO4 ratio which should remain constant in the steam drum.

Fifth Case Study

Case Studies

Case Studies

In order to verify the root causes of the failure in bearing no.1 of the steam turbine given in fig.(1 , 2) below :

Fig.(1) : Steam Turbine of the National Sugar Company.

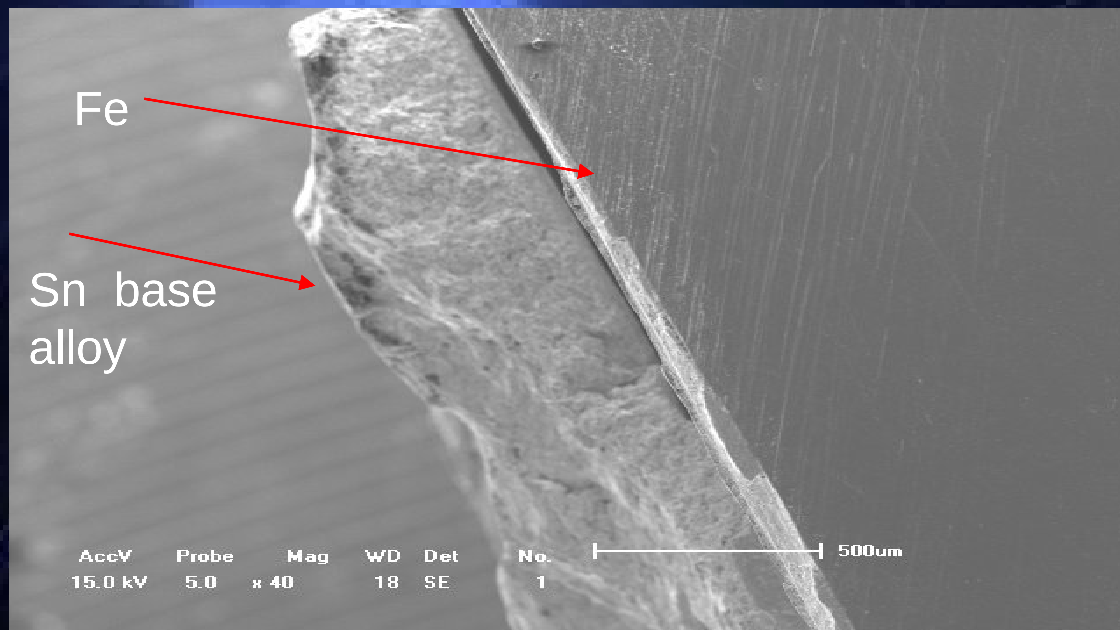
Case Studies

Fig.(2) : Part of the failed bearing no.1

Case Studies

A thourogh investigation was conducted on the failed parts of the given bearing as follows:

Chemical analysis using EDX on the part given in fig.(2) showed that the failed part was consisted of two main materials : Iron (Fe = 97.4 wt.%) & Tin base alloy (Sn = 94.81 wt.%) known commercially as babbitt metal as follows :



Fig(3) : Part of the failed bearing no.1 magnified using SEM (40 X) showing the layer of Tin base alloy covering the base metal constructed of Iron (Fe)

Case Studies

Surface analysis using SEM showed that a layer of Tin base alloy ≅ 1834 μ m in thickness was combined to a base metal made of Iron as mentioned in the above chemical analysis using cladding process without heating and this is clear in fig.(4) in which the layer of Iron is very well distinguished from the layer of Tin base alloy at the metal – metal interface shown in the red elliptical shape or in other word there is no interaction between the materials of the both faces (i.e. negligible bonding force) .

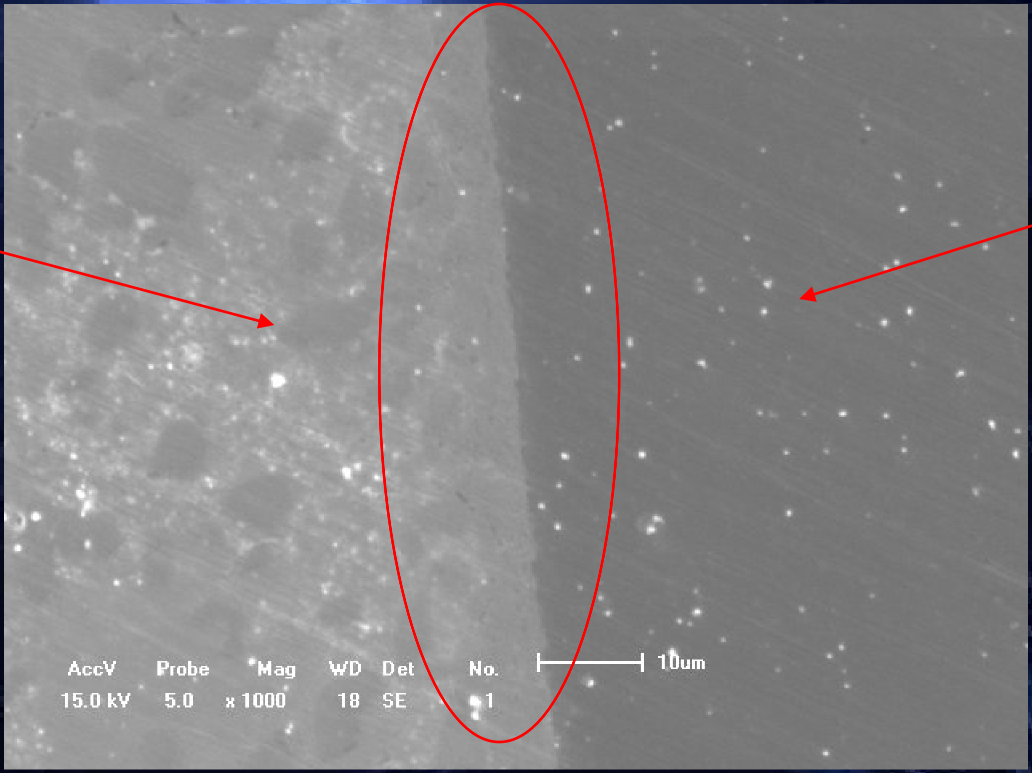


Fig.(4) : Part of the failed bearing no.1 magnified using SEM (1000 X) showing the Iron-Tin base alloy interface.

Case Studies

Hardness analysis for the failed bearing was conducted on random selected spots on the Iron –Tin interface from the Iron side as shown in the red circles in fig.(5) :

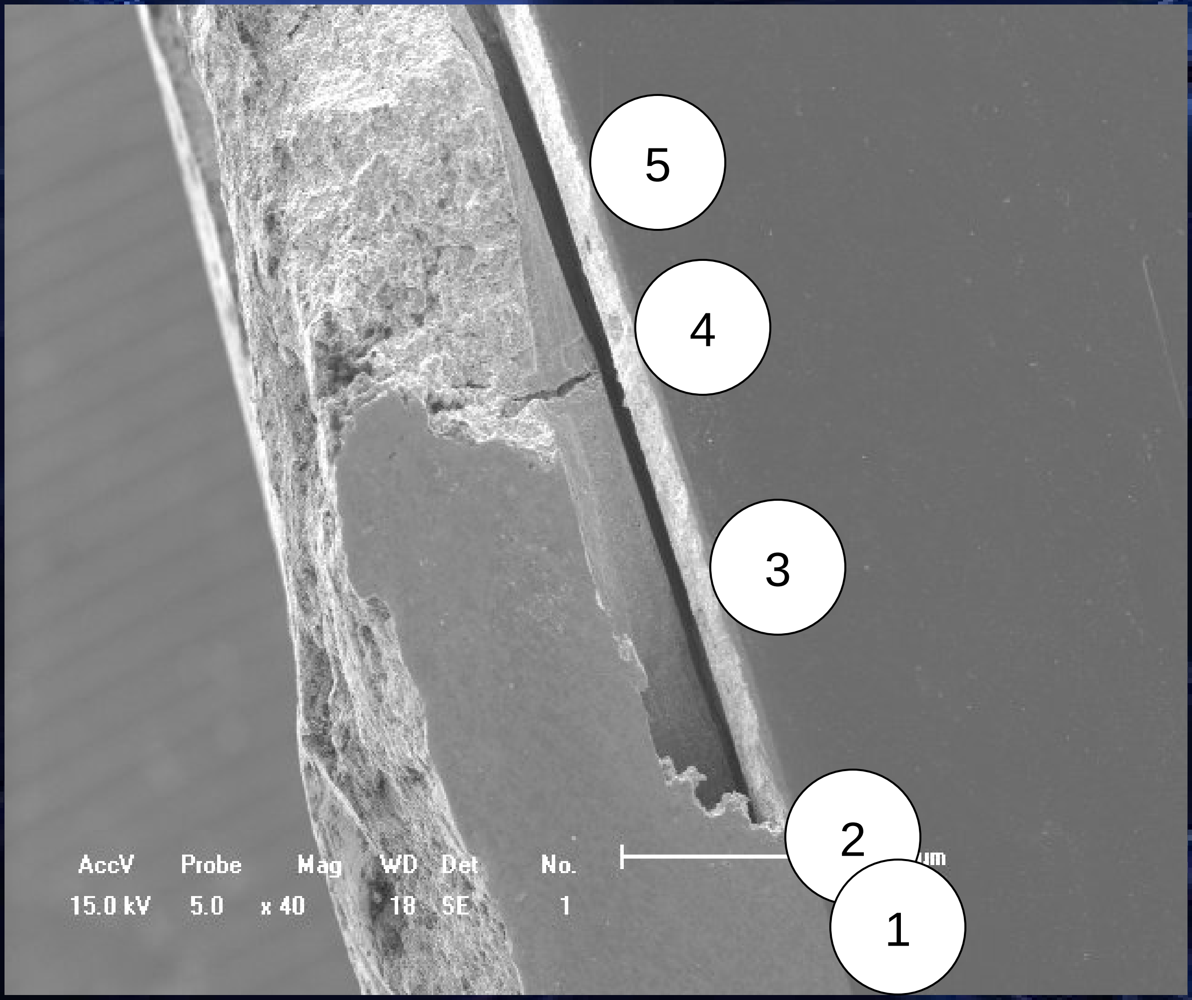


Fig.(5): Selected positions at the metal - metal interface to conduct Hardness testing.

Case Studies

Table (1) : Measured Vickers Hardness on the random selected spots on the Iron –Tin base alloy interface from the Iron side

Position No.	Measured Vickers Hardness
1	228
2	230
3	240
4	242
5	245

Case Studies

Finite Element Method to determine the maximum and minimum stresses subjected on the failed bearing using VON MISES method revealed the following results given in fig.(6) below:

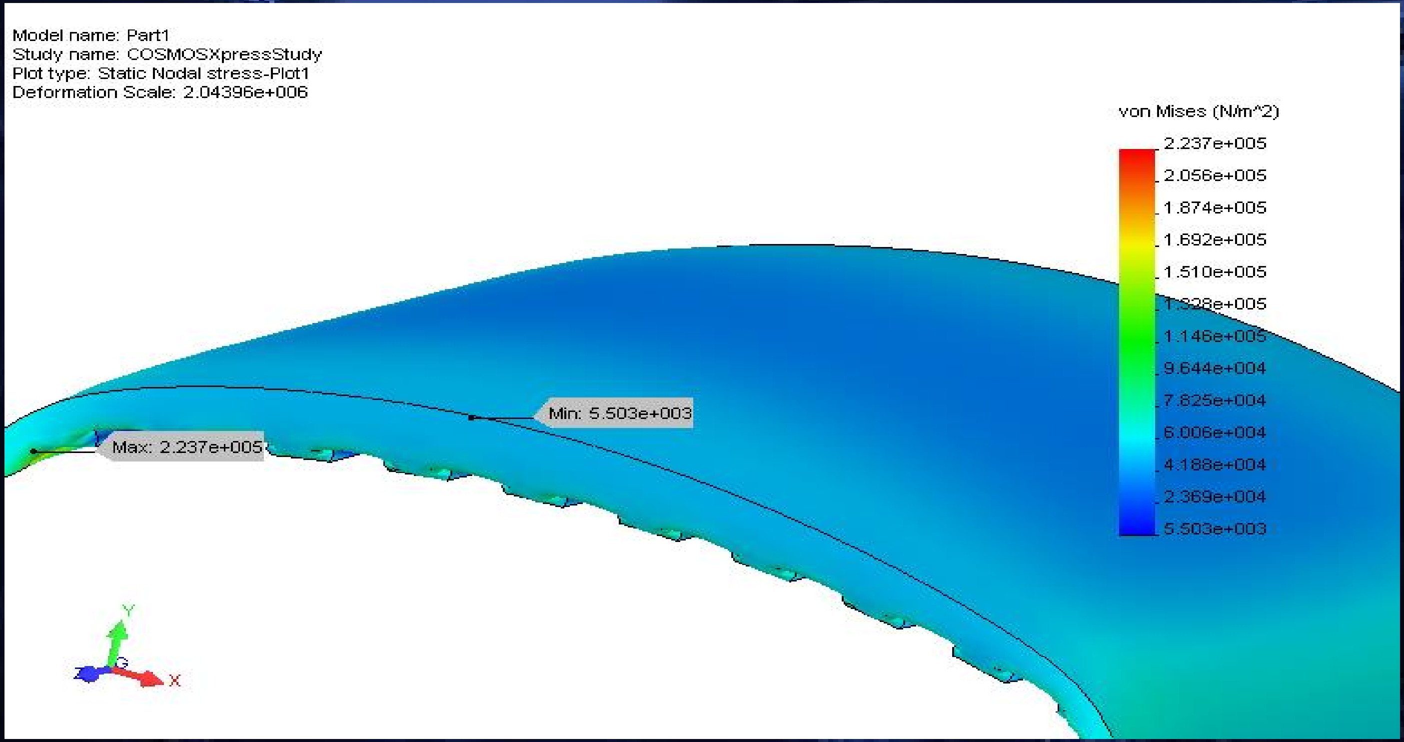


Fig.(6) : Finite Element Method using VON MISES method to determine the stresses subjected on the failed bearing revealed that the maximum stresses were concentrated at the left and right edges of the bearing while minimum stresses were concentrated near the middle of the bearing .

Case Studies

Thickness analysis of the deteriorated Tin base alloy layer in the failed bearing revealed the followings as shown in table (2) below:

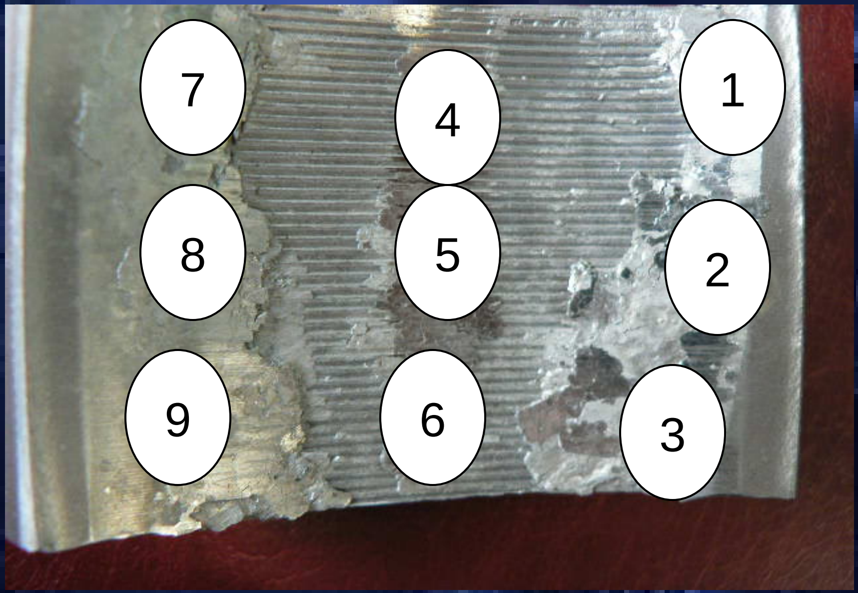


Fig.(7) : Part of the failed bearing no.1 showing the random selected spots in order to measure the thickness of the Tin base alloy layer

Case Studies

Table (2) : Thickness measurement on the random selected spots of the Tin base alloy layer

Position No.	Tin layer thickness , μ m
1	782
2	794
3	794
4	42.2
5	100.0
6	52.3
7	622
8	757
9	735

Case Studies

6.Chemical analysis on the used oil supplied by your side to identify the wear metals as follows:

Type of metal	Unit	Result
Fe	ppm	0.12
Sn	ppm	< 0.1

Conclusion:

The above results showed the following :

A.Surface analysis using SEM showed that the cladding process used to combine the Tin base alloy layer to the base metal (i.e. Iron) was done without heating.In other word this process has left weak points at the metal – metal interface .

B.Hardness results revealed an obvious increase in the hardness at the points near the failure (i.e. 240,242 & 245) in comparison with the points far from the failure (i.e 228-233) .

C.Stress analysis on the failed bearing showed that maximum stresses were concentrated at the left and right edges of the bearing while minimum stresses were concentrated near the middle of the bearing .

D.The lowest thickness measurement of the Tin base alloy layer were recorded near the middle of the bearing (i.e . 42.2 ,100,52.3 μm) while the maximum thickness measurment were recorded near the right and left edges (i.e. 1438,794 ,757 μm).

So it is obvious from (A,B,C & D) that the scenario of the failure in the given bearing happened due to the de-attachment of the layer of Tin base alloy at the Middle points of the bearing due to manufacturing insufficiency causing an increase in the friction forces which enabled an accelerated wear and tear process to occur with increasing the temperature of the Tin base alloy layer to the melting point of the alloy (≅ 232 ^{o} C) and as a result the layer dissolved partially at the middle points.

Sixth Case Study

Case Studies

Case Studies

Case Studies

Case Studies

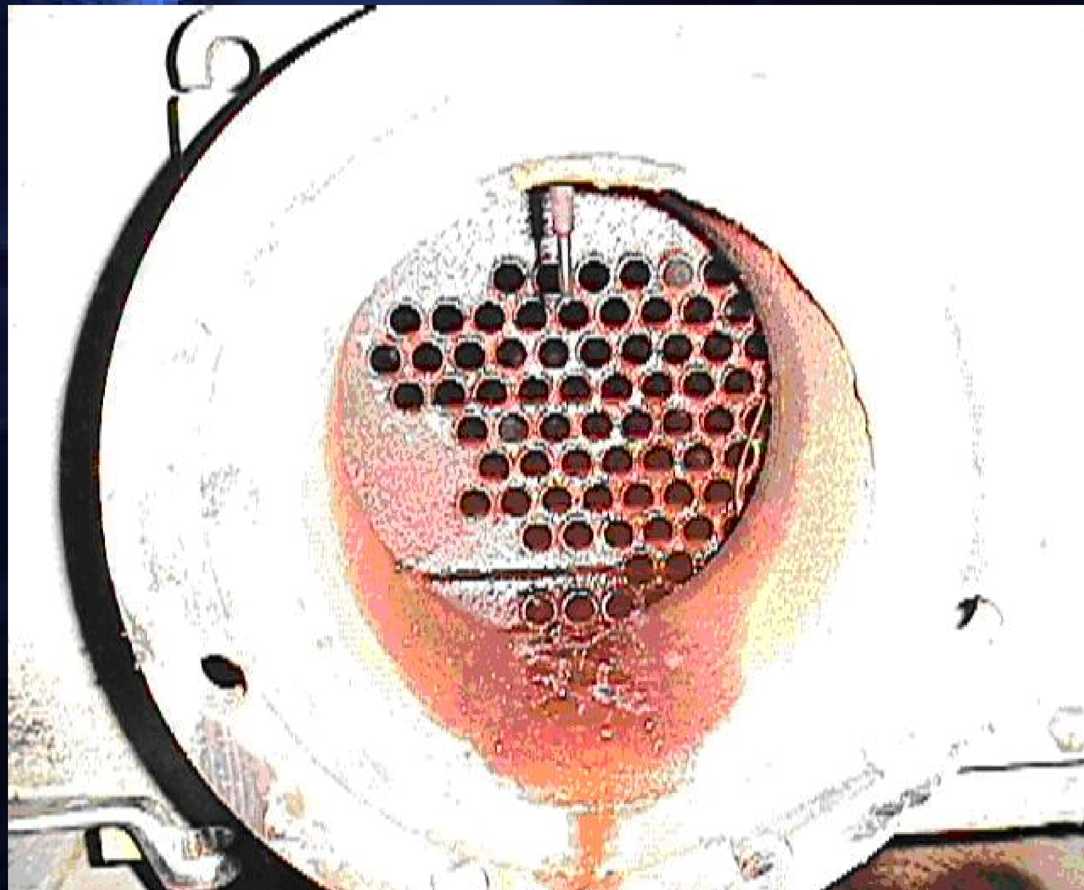
Seventh Case Study

Case Studies

Case Studies

Case Studies

Case Studies



Case Studies

Case Studies

Eighth Case Study

Case Studies

Case Studies

Case Studies

NinthCase Study

Case Studies

Biological Corrosion

Biological corrosion is not a form of corrosion; it is the deterioration of a metal by corrosion processes which occur directly or indirectly as a result of the activity of living organisms. These organisms include microforms such as bacteria and macro types such as algea. Microscopic and macroscopic organisms have been observed to live and reproduce in mediums with pH values between 0 to 11 ,at temperatures between 30 and 180 F, under pressure up to 15000 lb/in 2.

Case Studies

Aerobic Bacteria: Sulfur oxidizing bacteria, which oxidize elemental sulfur to sulfuric acid 5 % in conc.

$2S+3O_2+2\ H2\ O$ -------------- $2\ H_2SO_4$

Macrorganisms such as Fungus produces quantities of organic acids such as oxalic,lactic,acetic and citric acids which can initiate crevice attack of metal surfaces.

Algae also attach themselves to metallic structures causing corrosion

Case Studies

Living organisms are sustained by chemical reactions. These processes can affect corrosion behavior in the following ways:

1. By directly influencing anodic and cathodic reactions
2. By influencing protective surface films.
3. By creating corrosive conditions.
4. By producing deposits.

These effects may occur singly or in combination ,depending on the environment and the organism involved.

Case Studies

6inch Pipe

Case Studies

Shows the installation of the Corrosion Coupon and Scale Coupon in 12 inch pipeline

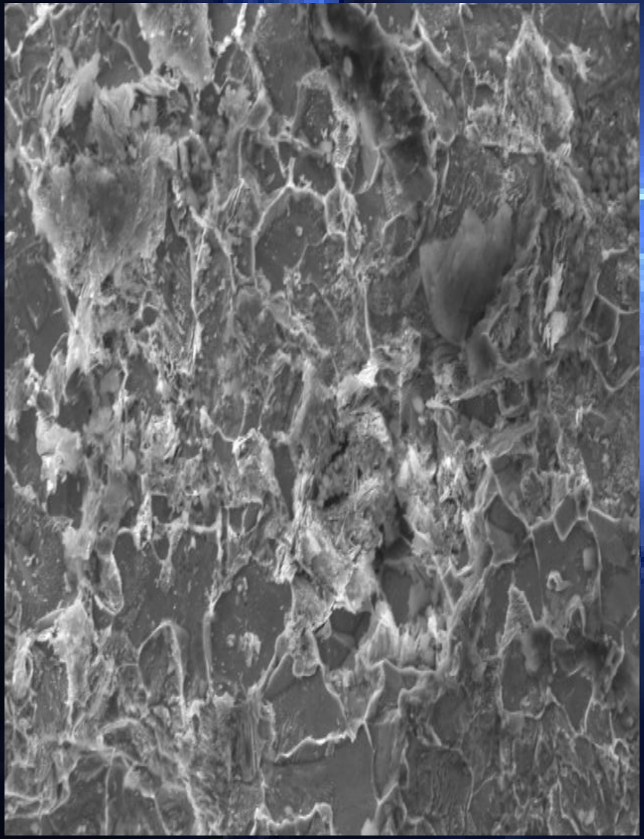
Case Studies

Corrosion Coupon before exposure

Case Studies

Corrosion Coupon after exposure for six months

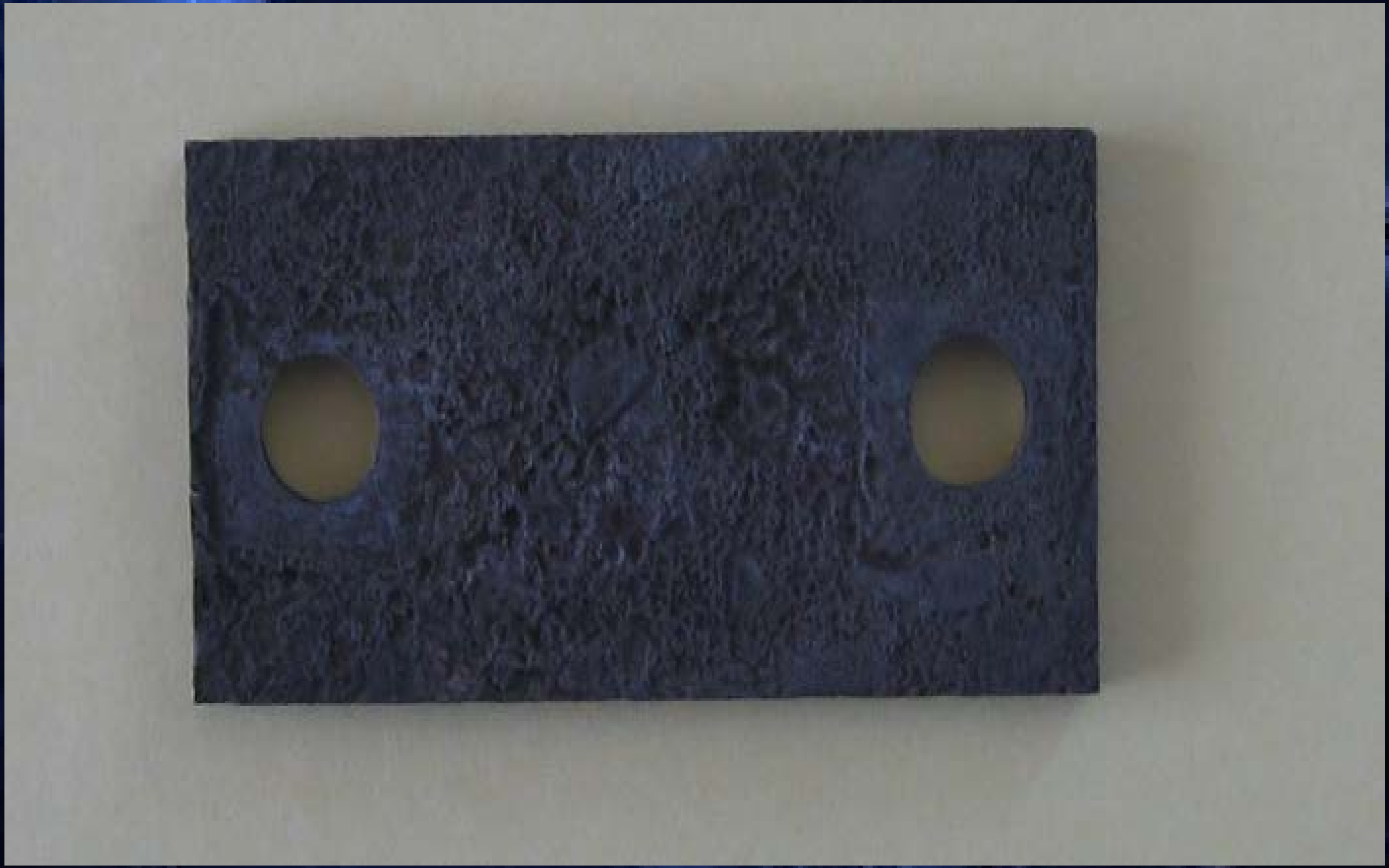
Case Studies



SEM photo of the surface of Corrosion Coupon after removing products from the surface

Corrosion rates of the Corrosion Coupon equal to 0.09 mm/y or 3.54 mpy

Case Studies



Corrosion Coupon after removing products from the surface

THANK YOU All