CORROSION ATLAS

Contributed By: Isabel Diaz-Tang

Case History 01.01.01.001

Material	Carbon steel (AISI-SAE 1025)
System	Saturated steam line in autoclave for tires retreading
Part	Saturated steam pipe
Phenomenon	High-temperature corrosion

Appearance	Uniform attack (external side), thick layer of corrosion products
Time in Service	1 year
Environment	Autoclave operation conditions: 90 psi (max. working pressure), 154°C (309.2°F), saturated steam
Cause	Unsuitable material for the operation conditions, leading to uniform corrosion with formation of a thick, nonadherent layer of corrosion products. The recommended material for the pipe was carbon steel according to ASTM A106, but the used material does not correspond to those specifications The inner walls of the autoclave also showed signs of uniform corrosion, but the damage was more serious on the pipe after just 1 year of service
Remedy	Replacement of the pipe with a new one, for example, made of carbon steel ASTM A106 (Standard Specification for Seamless Carbon Steel Pipe for High Temperature Service), or similar

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.01.01.002

Material	CS
System	Steam headers
Part	Y-strainer
Phenomenon	General corrosion

Appearance	Corrosion product around the strainer of the valve with black and brown product in layers
Time in Service	6 months
Environment	Pressure: 10 bar(g) Temperature: 186°C Impurities
Cause	High carryover in boiler, high levels of oxygen
Remedy	Improve the separator of the steam and condensate the boiler by adding cyclone separators and injection of sulfite in parts per million to inhibit the corrosion

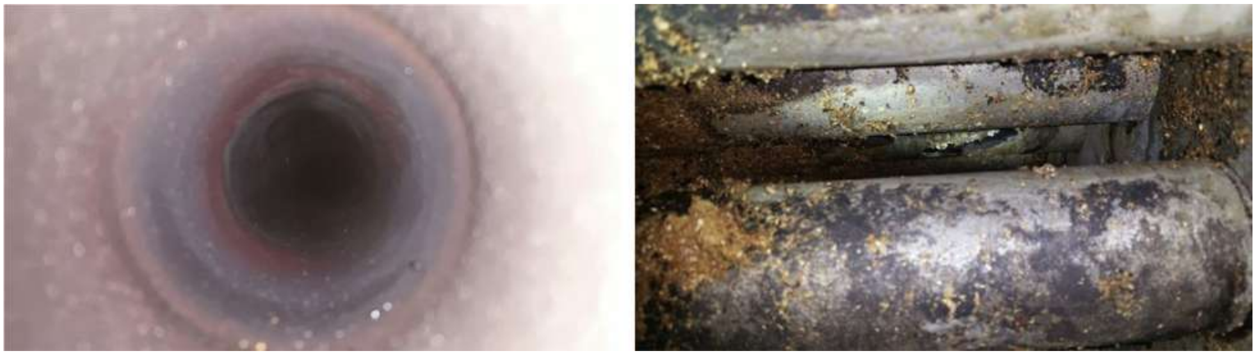
Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.01.12.001

Material	Carbon steel
System	Shell and tube heat exchanger
Part	Tube
Phenomenon	Localized corrosion



Appearance	Rupture of the tubes close to the welded points. Small accumulation of iron oxide inside the tube. Product accumulation on the outside of the tubes Cracks around the supports of the tube and shell heat exchanger
Time in Service	5 years
Environment	pH $<$ 5 outside the tube pH (5, 7) inside the tube Pressure: approx. 5 bar(g) Temperature: 120–200°C Moisture content: approx. 5% Steam and condensate fluid
Cause	Mechanical failure and caustic
Remedy	Replacing CS tubes for SS316 and improving the steam quality

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.01.15.001

Material	Carbon steel/SS shield
System	Economizer
Part	Tube bundle
Phenomenon	Under deposit corrosion and erosion

Appearance Before	The SS shield has worn dramatically at the 2 o’clock and 10 o’clock positions where the surface appears irregular. Some plates have been completed eroded. Ash is observed in some areas between the fins along with iron oxide. Pinholes were showing at the same positions with a great accumulation of ash Ash has built up in between the fins
Time in Service	3 years
Environment	Acidic, erosive. Unburned coal and flying ash High pressure, high temperature Composition of the flue gas: ash, COX, OX, SOX
Cause	Ash/coal particle average velocity: 11 m/s, max. up to 25 m/s
Remedy	Redesign the economizer spacing to reduce the flue gas velocity 14 m/s and adding a Tungsten carbide coating 0.1 mm on the first row

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.01.15.002

Material	Carbon steel
System	Boiler furnace
Part	Tubes—furnace side
Phenomenon	Iron oxide caused by uniform corrosion in the tubes

Appearance	Black sludge 3 to 5-mm-thick covering sections of the tube bank in the furnace side of the boiler CS section are exposed without any sludge
Time in Service	15 years
Environment	Fly ash Air Moisture Organic oil High temperature High pressure
Cause	Lack of sootblowers and problems with full combustions
Remedy	Cleaning the tubes and adding sootblowers

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.01.15.003

Material	CS
System	Boiler steam generation
Part	Tubes from the generating banks
Phenomenon	Under deposit/scale corrosion

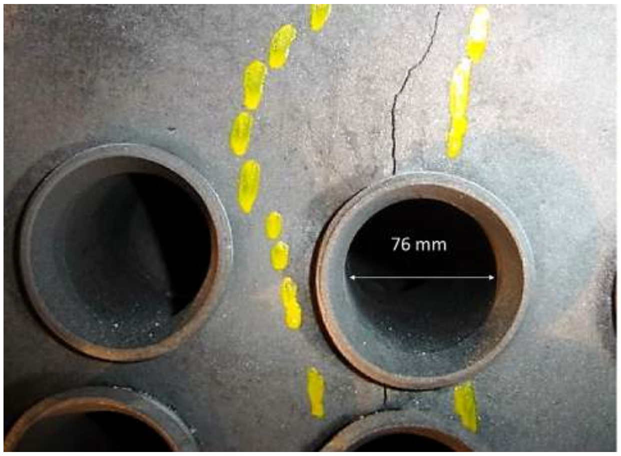
Appearance	Iron oxide with a corrosion deposit layering up inside the boiler tubes
Time in Service	12 months
Environment	Carryover and impurities. High levels of silica promoting deposition on the tube where the temperature drops
Cause	Inappropriate water treatment
Remedy	Improve the softener's performance to maintain the hardness within the recommended range
Additional References Pertaining to Case Study	ASME guidelines

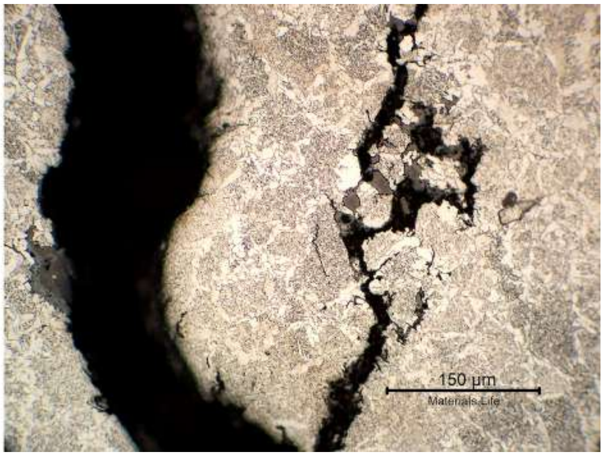
CORROSION ATLAS

Contributed By: Annelise Zeeman

Case History 01.01.18.001

Material	Low carbon steel UNS K03101 Ferritic weld metal
System	Boiler steam drum
Part	Shell plate previously repaired in a position between tube holes Thickness of the cracked vessel 37.3 mm Tube diameter of 76.2 mm
Phenomenon	Caustic stress corrosion cracking





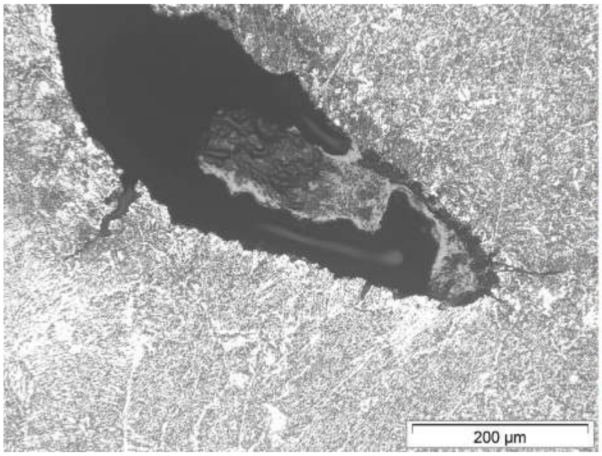
Appearance	Transgranular stress corrosion cracks in the weld repaired shell, close to tube holes
Time in Service	Months after repair
Environment	Steam
Cause	Concentration of caustic products from water treatment associated to high temperature, and a nonheat-treated condition of the weld repair, evident by the high hardness (280 HV10)
Remedy	Better control of water treatment Any weld repair requires heat treatment
Additional References Pertaining to Case Study	Materials Life Database

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.01.18.002

Material	Carbon steel
System	Hot water system (hot water (120°C) through shell and tube heat exchangers, with steam inside the pipes and hot water on the outside)
Part	Heat exchanger
Phenomenon	Stress corrosion



Appearance	Leakage at the weld from the pipe at the baffle plate
Time in Service	4 years
Environment	Demin water by reverse osmosis with sodium hydroxide dosage. pH 10.6, conductivity 117 µS/cm, Cl^- < 0.5 mg/l, p-alkalinity 0.4 meq/l, m-alkalinity 0.6 meq/l
Cause	The cracks indicate leaching corrosion. The corrosion could have taken place because the pipes were not rolled and sodium hydroxide was dosed in demin water. When a pipe is rolled the crevices between the pipe and the baffle plate are removed and accumulation of caustic in these crevices will not be possible
Remedy	The pipes in the new heat exchangers are all rolled in and the dosing of the sodium hydroxide solution and the pH control are improved (maintain pH around 9.5)

Additional References

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.01.27.001

Material	Carbon steel
System	Steam generation
Part	Boiler’s tubes
Phenomenon	Silicate scales and iron oxide

Appearance	Brown and reddish layers corrosion building up inside the tubes Substrate cover in the majority of the surface
Time in Service	3 years
Environment	pH: >8<10 Temperature: approx. 150°C Pressure: 18 bar(g) Fluid inside the tubes: softened water
Cause	Inappropriate water treatment
Remedy	Adding of hydrochloric acid (HCl) and ammonium bifluoride (ABF) chemical cleaning to clean up the tubes Monitor the system to understand the chemistry of the water and make the improvement required

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.01.30.001

Material	Carbon steel
System	Water-tube boiler
Part	Part from the membrane wall
Phenomenon	Creep caused by overheating

Appearance	Local bulging of tube
Time in Service	More than 20 years
Environment	Conditioned boiler water
Cause	Poor water circulation owing to blockage in headers caused by deposition of impurities from the condensate (organic material, iron, and hardness)
Remedy	Chemical cleaning of the boiler, improvement of condensate quality, and optimizing heat distribution

Additional References

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.02.01.001

Material	Carbon steel
System	Steam trap
Part	Shell
Phenomenon	Pitting corrosion activated by oxygen and impurities

Appearance	Pinhole on the condensate side of the steam trap, around the pinhole there was erosion and color changed around the area affected
Time in Service	2 years
Environment	Saturated steam line pH: >8<10 Pressure: 10 bar(g)
Cause	Carbonated in the water turning into CO_2 during condensation gas stream
Remedy	Improve the steam quality and water quality

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.02.01.002

Material	Carbon steel
System	Counter-flow heat exchanger
Part	Condensate outlet of the shell of the heat exchanger
Phenomenon	Pitting corrosion caused by oxygen and carbonic acid

Appearance	Pinholes in the header and wall thickness lost, iron oxide on the surface of the shell Product running of the steam box leaving residual marks
Time in Service	5 years
Environment	pH: <10>8 Pressure: 10 bar(g) Impurities Two fluid flow
Cause	Oxygen, carbonic acid in the steam
Remedy	Improving the process design to guarantee the flow direction of the condensate. Change the CS steam header boxes for SS316

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.02.32.001

Material	Carbon steel
System	Air heater with condensate
Part	Heat exchanger for heating the process air with condensate after a flash tank
Phenomenon	Erosion corrosion

Appearance	Gaps have been found at the water inlet of different tubes of the heat exchanger. The wall thickness of the tubes is locally decreased and a gap is formed in the pipe
Time in Service	After 1 year
Environment	Steam and water
Cause	This type of damage indicates that the flow velocity was too high. The damage was fatal in such a short time because the velocity was more than 10 times (almost 20 times) the maximum allowed velocity of 2 m/s Because of the high flow velocity, the steel was locally worn away. The water quality has none or a secondary influence on this process
Remedy	Minimizing the amount of flash steam through pressure stabilization and maintaining the velocity of the heat exchanger at 2 m/s through putting an appropriate controllable valve, 6.5 bar.

Additional References

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.02.33.001

Material	Carbon steel
System	Steam condensate system
Part	Upper part of horizontal condensate pipe
Phenomenon	Cavitation erosion

Appearance	Attack with sharp edges, concentrated at the upper side of the pipe, and preferential attack of the weld
Time in Service	A few years
Environment	Oxygen free and low carbonic acid steam condensate
Cause	A condensate/steam mixture from a leaking steam trap was fed in upstream at the upper side of the line. The entrained steam imploded in the relatively colder condensate present in the line, thereby causing cavitation with preferential attack to the weld
Remedy	Improved maintenance of steam traps
Additional References	

CORROSION ATLAS

Contributed By: Sanja Martinez

Case History 01.04.25.001

Material	Seamless API 5L X52 Gr.B pipe of homogenous ferrite–pearlite microstructure containing MnS inclusions
System	Piping at a hydrocarbons exploitation field
Part	Thermally insulated hot water pipeline
Phenomenon	Corrosion under insulation, corrosion at arc strike welding defect

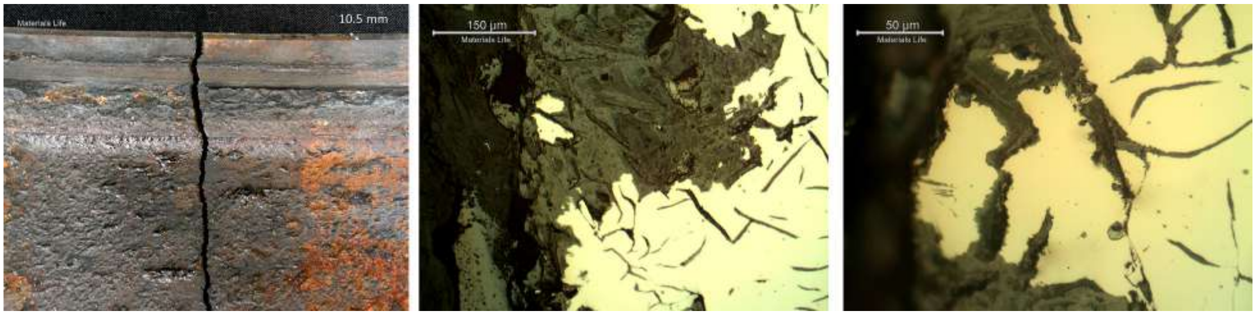
Appearance	Uniform corrosion under insulation, perforation at the location of the weld arc strike outside of the weld HAZ area
Time in Service	30 years
Environment	Degraded, minimum pigmented alkyd paint covered by thermal insulation containing 1040 ppm Cl^-
Cause	Arc strikes serving as a corrosion nucleation site due to heat-affected zone in base metal and crevice like imperfections in that area
Remedy	Replacement of perforated pipe segments. Avoiding and/or removing (grinding, repairing) of arc strikes on new construction
Additional References Pertaining to Case Study	B. Boling, Understanding arc strikes, Inspection Trends, 16, 3 (2013) 22–25.

CORROSION ATLAS

Contributed By: Annelise Zeeman

Case History 01.06.18.001

Material	Gray cast iron UNS F11701 Graphite in flakes in a ferritic–pearlitic matrix
System	Engine water cooling system
Part	Cylinder case Diameter: 1500 mm Thickness: 10.5 mm
Phenomenon	General corrosion from the water side, associated to graphite to matrix interface corrosion that created a notch morphology



Appearance	Brittle fracture by graphite decohesion and cleavage of the corroded case
Time in Service	10 years
Environment	Cooling water
Cause	Overloading of the case due to the thickness loss associated to notch effect of the corrosion
Remedy	Protection of the case from the general corrosion
Additional References Pertaining to Case Study	Materials Life Database

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.08.01.001

Material	Carbon steel
System	Spray-type deaerator
Part	Shell
Phenomenon	Oxygen water treatment

Appearance	Hematite and magnetite deposited under the coating, presenting dark lines. Orange lines resemble iron oxide and potentially a waterline in the drum
Time in Service	15 years
Environment	pH: <8>10 Pressure: approx. 5 bar(g) Temperature: 120–200°C
Cause	Localized corrosion investigated by oxygen and under corrosion deposit
Remedy	Coating and improving internals

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.08.01.002

Material	Carbon steel
System	Feedwater tank for a boiler
Part	Shell
Phenomenon	Uniform corrosion accelerated by iron content in the feedwater walls

Appearance	Iron oxide build up on all the walls of the tank. Large amounts of corrosion deposits on the bottom. Some of the area exposed the substrate
Time in Service	2 years
Environment	Temperature measured °C: <60 Pick temperature estimated °C: <80
Cause	The original coating was not appropriate and high iron content in the feed of the tank
Remedy	Selection of the ceramic epoxy coating instead of the original Dulux Aperior N1
Additional References Pertaining to Case Study	Dulux coating technical specification

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.08.01.003

Material	CS
System	Decanters effluent treatment
Part	Bearings
Phenomenon	General and localized corrosion

Appearance	Corrosion build up product like iron oxide around the bearings and shaft of the pumps
Time in Service	5 months
Environment	Effluent water Operation pressure: 270 kpa Temperature: 50°C
Cause	Feeding the decanter The lubrications system was found with a lot of effluent water due to high flows during a standstill setting
Remedy	Replacing bearing, primary and secondary cycle gear

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.08.01.004

Material	CS
System	Deaerator
Part	Walls
Phenomenon	Oxygen corrosion, pitting, and uniform corrosion

Appearance	Blister in the protective coating with iron oxide around some of the pitting. Went deep in the surface
Time in Service	8 years
Environment	Condensable gases, soften water design pressure 350 Kpa, design working temperature 200°C
Cause	Insufficient separation, high concentration of oxygen in feedwater
Remedy	Addition of sulfite in parts per million to control the amount of oxygen below 7 ppb, improve the deaerator's performance

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.08.04.001

Material	Cast iron
System	Feedwater
Part	Mechanical seal, impeller
Phenomenon	Bottom of the line

Appearance	Iron oxide product bottom of the mechanical seal
Time in Service	2 years
Environment	Water pH: 7–9 Carbonates 500 Kpa
Cause	Low pH in the feedwater repetitive times
Remedy	Replacement of the impeller and mechanical seal controlling pH

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.08.04.002

Material	Carbon steel
System	Ion exchanger
Part	Shell
Phenomenon	Uniform corrosion

Appearance	
Time in Service	
Environment	Acidic
Cause	Uniform corrosion
Remedy	Refurbishment

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.10.17.001

Material	Carbon steel
System	Wet sprinkler system
Part	Pipes in a sprinkler system
Phenomenon	MIC

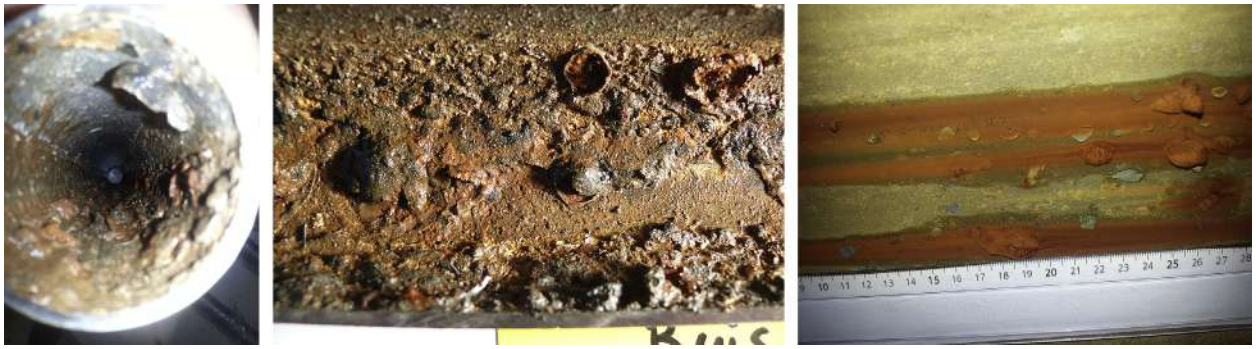
Appearance	Brown corrosion tubercles and a lot of mud
Time in Service	8 years
Environment	The sprinkler system is filled with surface water
Cause	The carbon steel is affected below the waterline near the air containment in the roof net. Surface water contains a lot of microbiology and nutrients, as a result of which MIC was formed in the stagnant water. The growth of microbiology in stagnant waters is very unpredictable, that is why corrosion was only detected when the first leaks occurred
Remedy	Use drinking water instead of surface water in combination with a corrosion inhibitor
Additional References	

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.10.17.002

Material	Carbon steel
System	Wet sprinkler system in DC
Part	Pipes in a sprinkler system
Phenomenon	MIC



Appearance	A lot of brown corrosion tubercles and mud
Time in Service	14 years
Environment	The sprinkler system is filled with drinking water
Cause	The carbon steel is affected below the waterline near the air containment in the roof net. The drinking water contains an enough microbiology and nutrients, as a result of which MIC may have formed in the standing water
Remedy	Using steel with an inhibitor or nitrogen. Another option is to use stainless steel also with an inhibitor against MIC

Additional References

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.10.17.003

Material	Carbon steel
System	Wet sprinkler system
Part	Pipes in a sprinkler system
Phenomenon	MIC

Appearance	Brown corrosion tubercles, a lot of mud and tubes
Time in Service	24 years
Environment	The wet sprinkler system is filled with surface water
Cause	The carbon steel is affected below the waterline near the air containment in the roof net. The surface water contains a lot of microbiology and nutrients, as a result of which MIC may have formed in the standing water. The microben formed tubs
Remedy	Use drinking water instead of surface water and use a corrosion inhibitor

Additional References

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.11.01.001

Material	Carbon steel
System	Saltwater pump
Part	Shaft and mechanical seal
Phenomenon	Pitting, erosion, localized corrosion

Appearance	Iron oxide, breakdown of the seal in different layers, coating peeling off and corrosion product around the seal
Time in Service	3 years
Environment	Saltwater, pressure: 7 bar Temperature: 45°C Flow Q: 250 lps TDH: 48 m/h Static lift: not provided
Cause	Oxygen and chloride ions
Remedy	Replace the shell for the CS with Belzona coating to surfaces, Impeller in SS, Anodes fitted, Duplex volute bolts Supply of a spare bronze impeller for the saltwater pumps

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Marko Stipanicev and Bing Han

Case History 01.11.02.001

Material	Carbon steel
System	Electrical submersible pumps (ESP) in upstream well production zone. ESP located at 6000 ft in 7-in casing.
Part	Electrical submersible pumps housing, 5.62-in OD
Phenomenon	Sweet and flow-induced corrosion
	
Appearance	Corrosion pattern and metal loss corresponded to flow-induced corrosion. Cavities along the ESP casing with maximum depth of approx. 1 cm, width of 1—10 cm, and length 1—50 cm. Cavities flow in the flow direction
Time in Service	80 days run life
Environment	- Multiphase flow (oil, formation water, and gas) with 44%—50% WC - Reservoir conditions: 120°C, 100 bar, 0.36 mol% CO_2, pH 5.5 - Production tubing flow parameters: superficial liquid velocity 1.2—3.3 m/s, superficial gas velocity 0.14—0.30 m/s, share stress 7—35 Pa - ESP location conditions: 84°C, 39.6 bar, superficial liquid velocity of >20 m/s, pH 5.7 - 10—20 mm between casing internal diameter and pump motor housing - No downhole corrosion inhibitor injection
Cause	Expected CO_2 corrosion of 0.44—0.53 mm/year could not explain the observed damage. The observed type of damage was probably due to turbulent-driven erosion (turbulent eddies) in particular locations. Corrosion pattern and metal loss corresponded to flow-induced corrosion. Investigation pinpointed to an element installed on the housing of UT motor under the pothead, which reduced the clearance between the motor housing and the casing, resulting in the higher local velocity and even turbulence locally
Remedy	The recommendation was the upgrading of metallurgy to 9Cr1Mo housing and 416SS or 410SS h&b plus thermal spray Monel coating on ESP equipment
Additional References Pertaining to Case Study	n/a

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.11.04.001

Material	Structural steel
System	External plant section
Part	Structure, tank
Phenomenon	Uniform and acid corrosion

Appearance	Iron oxide, coating protection worn out, strength and structure lost in the steel
Time in Service	25 years
Environment	pH: <3 Temperature and pressure: ambient Moisture: 45%
Cause	Acid corrosion
Remedy	Replacement of the structural and protection coating

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.11.15.001

Material	Carbon steel
System	Mixed-bed vessel
Part	Shell
Phenomenon	Under-deposit corrosion

Appearance	Pitting on the walls of the tank and iron oxide deposit
Time in Service	8 years
Environment	High levels of chlorides above 2000 ppm pH: <5 Temperature: approx. 50°C
Cause	Acid corrosion
Remedy	Solid epoxy tank coating replacement for a 304L SS vessel and coating

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Isabel Diaz-Tang

Case History 01.11.17.001

Material	Low carbon steel (API 5L Grade ×42)
System	Crude oil conveying line
Part	Pipe sections
Phenomenon	Microbiologically influenced corrosion (MIC)

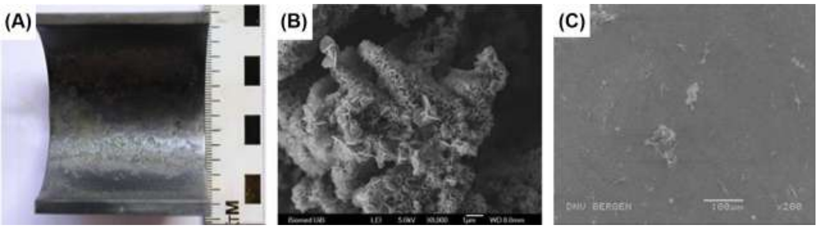
Appearance	Large cavities, perforations in many zones of the pipeline
Time in Service	21 months
Environment	Crude oil, water, and gases (exact chemical composition of the fluid is unknown). External side: humid atmosphere
Cause	The first perforation of the pipe was detected after 21 months of service. In the next 3 months 17 perforations were detected in several tubes along the 15 km pipeline. The failure analysis of some failed pipe sections showed typical morphologies of microbiologically influenced corrosion. All cavities and perforations appeared at 6 o'clock position; some rests of sediments were also found. No crude oil, water, or sediment samples were provided for further analysis
Remedy	Use of new tubes with protection of the inner surface (e.g., high-density polyethylene jacket), or selection of a more suitable material

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Marko Stipanicev and Øystein Birketveit

Case History 01.11.17.002

Material	S235JR carbon steel
System	Oilfield seawater injection system. Risk of microbial corrosion indicated in laboratory studies indicating a need for biocide treatment
Location	Pipe sections downstream chemical injection pump and seawater booster pump and upstream of injection zone. Laboratory study conducted on 60-mm ID pipe steel sections and using carbon steel electrochemical probes
Phenomenon	Microbially influenced corrosion (MIC)
	
Appearance	Materials exposed to abiotic environment were featured by green rust deposits under which uniform corrosion was revealed. Materials exposed to biotic environment were featured by black slimily deposits consisting of FeS and biological material, under which uniform corrosion was revealed
Time in Service	100 days
Environment	Deoxygenated and sulfate-rich North Sea coastal seawater at 15–25°C environments with contrasting presence or absence of microbial flora and associated metabolic activity
Cause	Conducted work has shown that under representative sulfate-rich seawater injection conditions, metabolic activity of sessile sulfide and carbon dioxide–producing bacterial populations dominated by *Caminicella* generated both an abundant sulfide film on the steel surface layer as well as carbonaceous mineral precipitates on the carbon steel samples. However, the overall impact of the bacterial consortium on the corrosion rate of S235JR carbon steel specimens was minimal. The presence of a microbial flora and associated metabolic activity causing deposits at metal surfaces resulted in similar corrosion rates to that observed in the control (sterile) microbe-free environment over 100 days of exposure. Clearly, the release of biogenic sulfide does not necessarily lead to extensive localized pitting attack. It is apparent that metabolic activities of cells are likely to influence the chemistry of bioinorganic corrosion products and should be considered when evaluating MIC risk
Remedy	Investigation concluded that biocide treatment is not necessary in short run. However, as the microbiological activity is postulated to accelerate with service time and biofilm abundancy to increase, it is recommended to use glutaraldehyde-based biocide treatment one time per week at 500 ppm concentration and for duration for 2 h
Additional References Pertaining to Case Study	https://www.sciencedirect.com/science/article/abs/pii/S1567539413000984 Stipanicev et al., Corrosion of carbon steel by bacteria from North Sea offshore seawater injection systems: Laboratory investigation, Biocorrosion (2011).

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.11.24.001

Material	Cast iron
System	Cylinders in paper machine
Part	Cylinder wall around the manhole
Phenomenon	Mechanical stress cracks

Appearance	Crack indications in the support for the manhole clamps
Time in Service	More than 49 years
Environment	Crack indications are on the outside where ambient air is present
Cause	The construction of the manhole in the front plate of the cylinders where a crack indication is found is unfavorable for distributing the mechanical stresses
Remedy	Because cracks in cast iron cannot be easily repaired, it is advisable to replace the front plates. For the purchase of the new front plates, a different closure and construction of the manhole and the manhole cover must be chosen in consultation with the supplier. It must be investigated in which way the mechanical stresses can best be distributed over the front plate

Additional References

CORROSION ATLAS

Contributed By: Isabel Diaz-Tang

Case History 01.13.32.001

Material	Ductile cast iron
System	Liquid-ring vacuum pump
Part	Impeller rotor
Phenomenon	Erosion corrosion

Appearance	Wide pits at impeller rotor blade ends, related to the flow direction. Brownish-red corrosion products in the cavities. Blackish corrosion products layer on the blades
Time in Service	6 months
Environment	Water vapor and process water (average chemical composition: pH = 8, chloride = 45 mg/L, sulfates = 185 mg/L, total suspended solids = 4 mg/L)
Cause	Loss of vacuum led to the failure analysis. A pump generating higher vacuum than the expected for the system design was installed 6 months prior to the failure, leading to erosion corrosion problems at the rotor impeller blades, due to too high fluid velocities. The system was used 12 h a day for dehumidifying soap paste; the rest of the time remained humid (process water), which caused the formation of brownish-red corrosion products
Remedy	Replacement of the pump (using a pump suitable for the system design). Consider the use of a different material for the rotor impeller (e.g., stainless steel)

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Isabel Diaz-Tang

Case History 01.13.33.001

Material	Gray cast iron
System	Liquid-ring vacuum pump
Part	Port plate (side facing the impeller)
Phenomenon	Cavitation

Appearance	Small pits and cavities
Time in Service	6 months
Environment	Water vapor and process water (average chemical composition: pH = 8, chlorides = 45 mg/L, sulfates = 185 mg/L, total suspended solids = 4 mg/L)
Cause	Loss of vacuum led to the failure analysis. The original pump of the system was replaced by a pump generating higher vacuum, which caused further increase of the temperature of the water forming the ring, diminishing the boiling point of the water, and increasing the risk of cavitation (see also Case 01.13.32.001)
Remedy	Replacement of the pump (using a pump suitable for the system design)

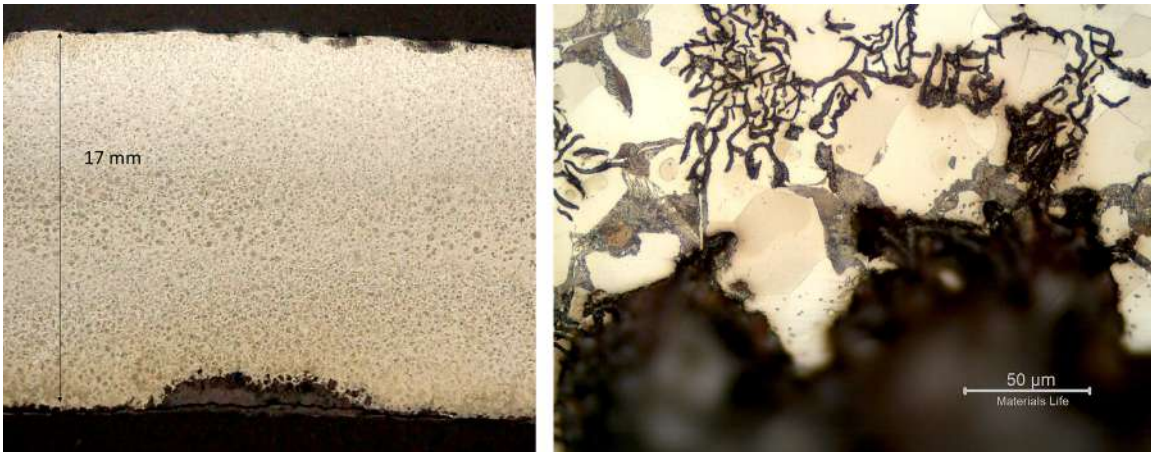
Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Annelise Zeeman

Case History 01.16.01.001

Material	Gray cast iron UNS F11701 Graphite in flakes in a ferritic–pearlitic matrix
System	Buried aqueduct
Part	Several meters long Centrifugally cast pipe Nominal diameter: 1524 mm Actual thickness: 17 mm
Phenomenon	General corrosion from the water side



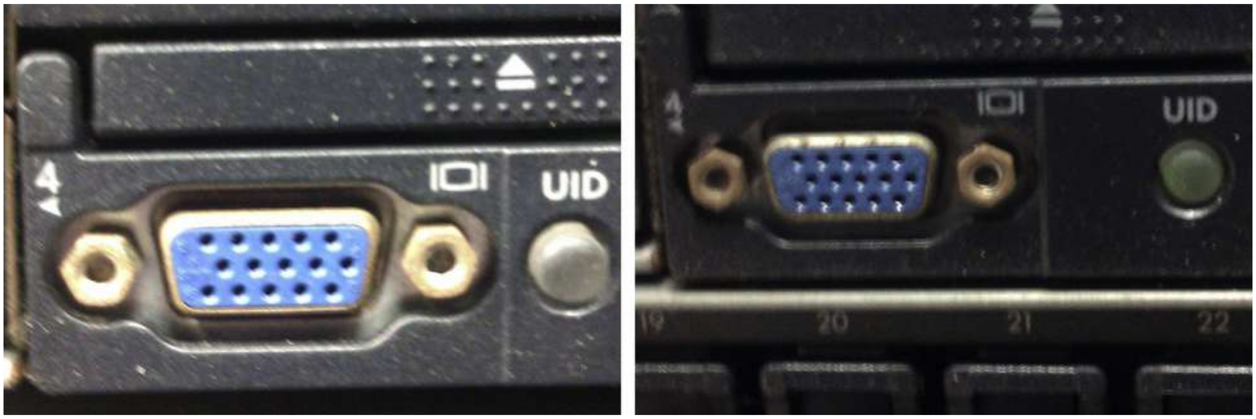
Appearance	2 mm thinning from the original 19.05 mm
Time in Service	45 years
Environment	External soil and internal water
Cause	End of life
Remedy	Not required
Additional References Pertaining to Case Study	Materials Life Database

CORROSION ATLAS

Contributed By: Mascha van Hofweegen and Frank de Vos

Case History 01.16.24.001

Material	Carbon steel
System	Data center
Part	Metal parts of the computers
Phenomenon	Oxygen corrosion through microcondensation



Appearance	Corroding various metal parts of the servers and computer parts
Time in Service	0.5 year
Environment	Air with traces of chloride and sulfur
Cause	The observed corrosion on some metal parts of some computers is most likely due to microcondensation. The combination of large air temperature fluctuations and a high relative humidity of the supply air causes this microcondensation, causing corrosion of the metal parts that are sensitive to this. The traces of chloride and sulfur in the air, and the possible presence of dust/dirt, may have further affected the process
Remedy	By placing meters, insight is gained into the air temperature and the relative humidity per room. This provides insight when microcondensation can take place. Working with a narrower bandwidth in terms of temperature. A far-reaching measure is further conditioning of the supply air. That means not only regulating the temperature, but also the relative humidity. Our advice is to control the temperature at 23 ± 1°C and the relative humidity between 30% and 60%

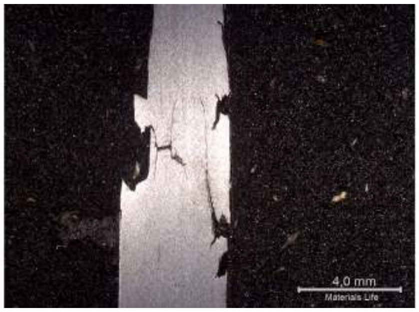
Additional References

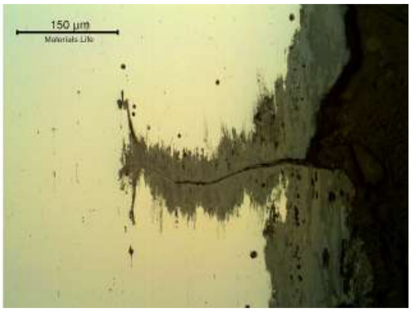
CORROSION ATLAS

Contributed By: Annelise Zeeman

Case History 01.16.28.001

Material	High carbon steel UNS G10700 Strain-hardened (predominantly) pearlitic microstructure
System	Prestressed concrete strand
Part	Wire rope 5 mm diameter Hardness 500HV1
Phenomenon	Fatigue corrosion



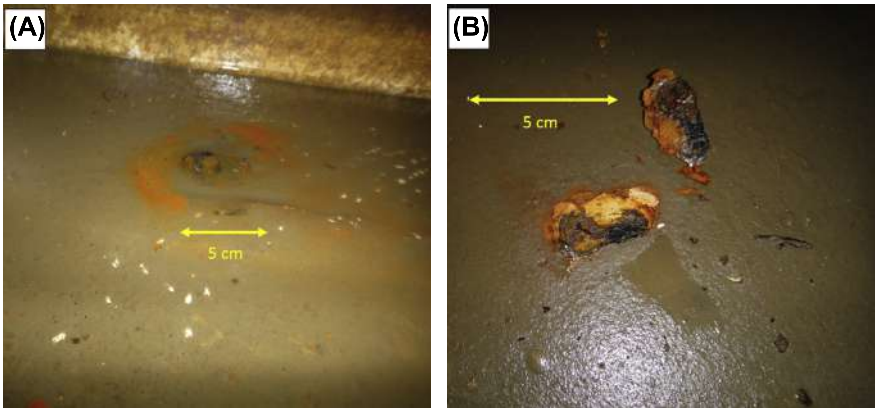


Appearance	Multiple fractures in the ropes in the region out of the concrete The analysis indicated that the rope broke by corrosion fatigue in 50% of the wires, 27% fatigue, and 23% overloading
Time in Service	Several years in service
Environment	Urban atmosphere, wet
Cause	Synergic effects associated to loads and environment
Remedy	Corrosion control
Additional References Pertaining to Case Study	Materials Life Database

CORROSION ATLAS

Contributed By: Gareth Williams and Graham C. Hill

Case History: 01.21.17.001

Material	Steel
System	Very large crude carrier (VLCC) ballast tank and ballast piping
Part	Tank floor and ballast piping. Epoxy coated carbon steel.
Phenomenon	Microbiologically influenced corrosion (MIC)
	
Appearance	Coating appeared to be in good condition both where exposed and examined under sediments. However, hemi-spherical orange "tubercles" observed on the ballast tank floor (Figure A). Evidence of a rusty, orange corrosion deposit emanating from the tubercles. Removal of tubercles revealed that they covered black deposit and, in numerous cases, pits with a 2–3 mm depth (Figure B).
Time in Service	Less than 5 years
Environment	Seawater ballast tank
Cause	The appearance of the corrosion deposits and pits were typical of MIC caused by Sulfate Reducing Bacteria (SRB). Corrosion deposits associated with the pits were analyzed on-site by acidification and checking for release of hydrogen sulfide using lead II acetate indicator papers; this confirmed a high iron sulfide content, a strong indicator of SRB activity. On-site analysis of deposit samples using Sig Sulfide Tests (ECHA Microbiology Ltd.) detected high numbers of sulfide generating bacteria (including SRB). No Sulfur Oxidising Bacteria (SOB) were detected in subsequent laboratory culture tests. It was concluded that the pitting was caused by the activity of SRB. It is believed that poor surface preparation and/or inadequate application of protective coating was a factor in the incidence of corrosion.
Remedy	Corrosion sites were ground out to remove corrosion deposits and repaired by welding and grinding to a smooth finish. In some cases, ballast piping had to be physically removed from the vessel to accommodate this. Affected areas were re-coated following a final finishing grit blast.
Additional References Pertaining to Case Study	• B.J. Little and J.S. Lee (2007). Microbiologically Influenced Corrosion. Wiley-Interscience (ISBN 978-0471-77276-7). • G.C. Hill (2003). Microbial Problems in Bilge & Ballast, in Microbes in the Marine Industry, Ed. E.C.Hill, Inst. Marine Engineering Science & Technology (ISBN 1-902536-46-0). • P. Bos and J.G. Kuenen (1983). Microbiology of Sulphur Oxidising Bacteria, in Proceedings of Microbial Corrosion, National Physics Laboratory, Teddington and the Metals Society, London. • NACE Standard TM0-194-2014. Field Monitoring of Bacterial Growth in Oil and Gas Systems.

CORROSION ATLAS

Contributed By: Gareth Williams and Graham C. Hill

Case History: 01.21.17.002

Material	Steel
System	Very large crude carrier (VLCC) seawater-lubricated stern tube system
Part	Stern tube and forward and aft flanges. Epoxy-coated carbon steel.
Phenomenon	Microbiologically influenced corrosion (MIC)
	
Appearance	Coating covered in orange deposits. Fractures and holes were observed in flange's epoxy coating (Figure A). Chipping away the coating (Figure B) revealed orange deposit covering black deposits. Removing black deposit revealed severe wastage of steel which had a dull grey pitted surface. A viscous brown acidic (pH 2) liquid, believed to be sulfuric acid, exuded from some corrosion sites.
Time in Service	Less than 5 years.
Environment	Filtered seawater flow through system for stern tube lubrication. There were extensive periods of lay up during commissioning of the vessel, during which stagnant conditions are likely to have developed. It is believed anoxic regions would readily develop underneath coating fractures which is where worst corrosion was observed.
Cause	The appearance of the corrosion was typical of that caused by Sulfate Reducing Bacteria (SRB) but the amount of highly acidic orange deposits (pH 2–5) suggested simultaneous activity of Sulfur Oxidising Bacteria (SOB). Black corrosion deposits associated with the pits were analyzed on-site by acidification and checking for release of hydrogen sulfide using lead II acetate indicator papers; this confirmed high iron sulfide content, a strong indicator of SRB activity. On-site analysis of deposit samples using Sig Sulfide Tests (ECHA Microbiology Ltd.) detected high numbers of sulfide generating bacteria (including SRB). Subsequent laboratory analysis for culturable SOB detected moderately high numbers of aciduric *Thiobacillus* spp.
Remedy	Stern tube was grit blasted, corrosion sites ground out to remove corrosion deposits and repaired by welding and grinding. In some cases polymeric composite filler was used to restore substantial metal loss. The system was re-coated after a final grit blast. Seawater lubrication was replaced with a closed loop fresh water system using ship's distilled water in order to reduce levels of nutrients and sulfate to minimize the opportunity for microbial activity and sulfate reduction. A routine microbiological condition monitoring program was implemented.
Additional References Pertaining to Case Study	See references for case history 01.21.17.001

CORROSION ATLAS

Contributed By: Isabel Diaz-Tang

Case History 01.21.24.001

Material	Carbon steel
System	Stored steel bars
Part	3/8″ corrugated bars
Phenomenon	Atmospheric corrosion in marine environment (uniform corrosion)

Appearance	Red-brownish layer of corrosion products, with small zones of yellow-brownish corrosion products
Time in Service	1 year
Environment	Marine atmosphere (approximately 1 km away from the seashore)
Cause	Several batches of steel-corrugated bars were stored outdoors. The most affected bars were located on the top of the piles of bars. A distance of 1 km of from the seashore is close enough for corrosive attack due to marine aerosol
Remedy	Corroded bars treatment: pickling, rinsing, neutralizing, phosphating, drying. Store under roof, and dry conditions

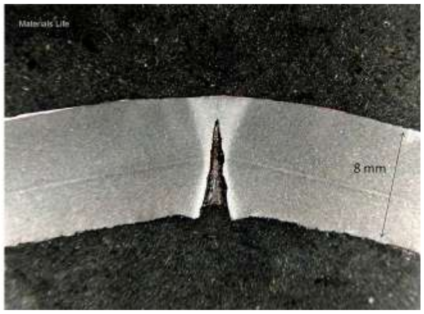
Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Annelise Zeeman

Case History 01.21.38.001

Material	Carbon steel pipe API 5L grade B UNS G10200 Ferritic—pearlitic microstructure Longitudinal seam weld, autogenous
System	Seawater piping in a ship.
Part	Piping several meters long Pipe outer diameter: 114 mm Pipe thickness: 8 mm
Phenomenon	Localized seam weld corrosion due to the galvanic effect between the low hardness ferritic—pearlitic base metal (180 HV 100 g—Vickers microhardness) and the bainitic weld metal (230 HV 100 g)



Appearance	Localized dissolution at the longitudinal seam weld
Time in Service	8 years
Environment	Nontreated seawater
Cause	Seam welded joint presenting, at the autogenous weld, a nonheat-treated microstructure of higher hardness than the rest of the pipe
Remedy	Adoption of seamless pipes ASTM A106
Additional References Pertaining to Case Study	Materials Life Database

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.001

Material	Cold rolled carbon steel—Urban site, Riyadh, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen attack

Appearance	Uniform corrosion with brown nodules
Time in Service	One year
Environment	Dry and hot weather; temperature varies from 10 to 43°C
Cause	Atmospheric corrosion instigated by oxygen and hot temperature
Remedy	Coating

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.002

Material	Cold rolled carbon steel—Marine industrial site, Khobar, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen and acid rain attack

Appearance	Pitting, rough surface, dark brown spots
Time in Service	One year
Environment	Marine industrial site (CO_2, H_2CO_4, SO_X, NO_x)
Cause	Exposed to corrosive environment, i.e., CO_2, H_2CO_4, SO_X, NO_x
Remedy	Coating or use cathodic protection (CP) system

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.003

Material	Cold rolled carbon steel—Marine industrial site, Jubail, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen attack

Appearance	Pitting, rough surface, dark brown spots
Time in Service	One year
Environment	Marine industrial site (CO_2, H_2CO_4, SO_X, NO_x)
Cause	Exposed to a corrosive environment, i.e., acid rain
Remedy	Coating or use cathodic protection (CP)

Additional References Pertaining to Case Study

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.004

Material	Cold rolled carbon steel—Marine site, Jubail, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Uniform corrosion, dots, very rough surface, dark brown
	
Appearance	Pitting corrosion, very rough surface, dark brown
Time in Service	One year
Environment	Marine industrial site (CO_2, H_2CO_4, SO_X, NO_x)
Cause	Exposed to a corrosive environment, i.e., acid rain, very humid environment
Remedy	Coating or use cathodic protection (CP)
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.005

Material	Cold rolled carbon steel—Rural site, Bisha, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen attack

Appearance	Light uniform corrosion, some dark brown spots
Time in Service	One year
Environment	Samples exposed to mild rural site with average temperature around 30°C
Cause	Oxygen
Remedy	Coating
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.006

Material	Cold rolled carbon steel—Urban site, Abha, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen attack

Appearance	Uniform corrosion, dark brown
Time in Service	One year
Environment	Samples exposed to atmospheric wet and dry cycle during the year
Cause	Oxygen with presence of 40%–70% of humidity. Temperature varies from 7 to 30°C
Remedy	Coating
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.007

Material	Cold rolled carbon steel—Marine site, Khafji, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen and chloride

Appearance	Pitting corrosion, rough white and golden surface
Time in Service	One year
Environment	Marine site
Cause	Sample exposed to oxygen and chloride in the site. The average of humidity and temperature is 60% and 35°C
Remedy	Coating or cathodic protection (CP)
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.008

Material	Cold rolled carbon steel—Urban site, Makkah, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen and pollutant attack

Appearance	Uniform corrosion, dark brown spots
Time in Service	One year
Environment	High pollutants with high temperature in the summer
Cause	Sample exposed to high temperature with presence of quite high automobile pollution
Remedy	Coating
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.009

Material	Cold rolled carbon steel—Marine industrial site, Jeddah, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	

Appearance	Uniform and localized corrosion, large corrosion layer due to high corrosion rate
Time in Service	One year
Environment	High humidity and pollutants level (such as SO_2 and chloride ion)
Cause	High humidity with the presence of corrosive acid rain
Remedy	Coating or apply cathodic protection (CP)
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.010

Material	Cold rolled carbon steel—Marine industrial site, Yanbu, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	

Appearance	Uniform and localized corrosion, golden and dark brown corrosion product
Time in Service	One year
Environment	High humidity and pollutant level (such as SO_2 and chloride ion)
Cause	Oxygen and chloride ion attack in the presence of acid rain
Remedy	Coating or cathodic protection (CP)
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.011

Material	Cold rolled carbon steel—Marine site, Hakhal, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen and chloride ion attack

Appearance	Uniform and localized corrosion
Time in Service	One year
Environment	High chloride concentration
Cause	Localized corrosion due to the presence of high chloride ion concentration
Remedy	Cathodic protection (CP) or coating
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History 01.24.24.012

Material	Cold rolled carbon steel—Rural site, Gassim, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen attack

Appearance	Light and uniform dark brown
Time in Service	One year
Environment	Exposed to mild temperature around 30°C in average
Cause	Light uniform corrosion instigated by oxygen attack
Remedy	Coating
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History 01.24.24.013

Material	Cold rolled carbon steel—Urban site, Hail, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	Oxygen attack

Appearance	Light uniform corrosion as dark brown spots
Time in Service	One year
Environment	Mild temperature
Cause	The uniform corrosion activated by the variation of temperature between summer and winter. The temperature difference reached 25°C
Remedy	Coating
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Talal Aljohani and Abdullah I. Almarshad

Case History: 01.24.24.014

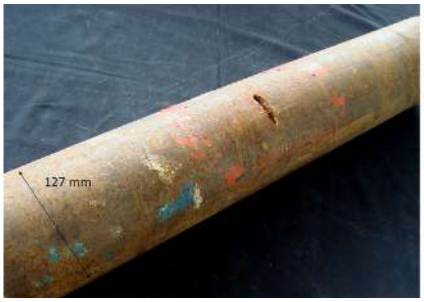
Material	Cold rolled carbon steel—Rural site, Muzahniah, Saudi Arabia
System	Test rack for atmospheric corrosion
Part	Sample
Phenomenon	
	
Appearance	Uniform corrosion, golden brown spots
Time in Service	One year
Environment	High temperature in the summer around 46°C
Cause	Uniform corrosion due to oxygen attack instigated by large variation in temperature during the year
Remedy	Coating
Additional References Pertaining to Case Study	

CORROSION ATLAS

Contributed By: Annelise Zeeman

Case History 01.25.28.001

Material	Low alloy steel UNS G41300 Martensitic microstructure
System	High strength drill pipe
Part	Drill pipe API 5D grade S135 Nominal diameter: 127 mm Pipe thickness: 12.7 mm
Phenomenon	The tool marks at the external diameter of the pipe created localized corrosion in notches and corrosion-fatigue propagation



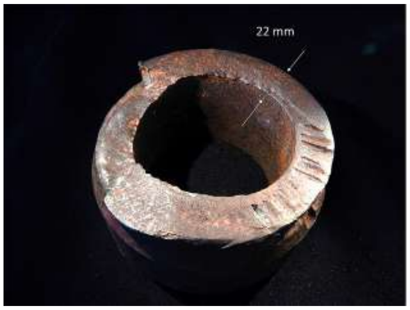
Appearance	Corrosion fatigue cracks are notches created by a tool (with plastic deformation)
Time in Service	More than 10 years in service
Environment	Drilling environment
Cause	Synergic effects associated to loads and environment
Remedy	The drill pipe was close to the end of its life All other drill pipes from the same column were inspected to identify if they were still acceptable
Additional References Pertaining to Case Study	Materials Life Database

CORROSION ATLAS

Contributed By: Annelise Zeeman

Case History 01.25.28.002

Material	Low alloy steel (Ni-Cr-Mo-V) AISI/SAE 4330V Martensitic microstructure
System	Oil and gas well drilling
Part	Tubular drilling tool Nominal diameter: 120.7 mm Pipe thickness: 22 mm
Phenomenon	The tool marks at the external diameter of the pipe corroded and created multiple cracks propagating by a corrosion-fatigue mechanism, through thickness



Appearance	Fracture with washout
Time in Service	More than 10 years in service
Environment	Drilling environment
Cause	Synergic effects associated to loads and environment
Remedy	The drilling tool was close to the end of its life
Additional References Pertaining to Case Study	Materials Life Database

CORROSION ATLAS

Contributed By: Bensabeth Merchan

Case History 01.25.28.003

Material	Carbon steel AS3597—1993 Grade 700
System	Hammer mill #3
Part	Pellet
Phenomenon	Fatigue cracking

Appearance	
Time in Service	Corrosion occurs in 11 months, but the part was designed to last 5 years.
Environment	
Cause	The ingress of a foreign object which had either cracked or introduced a severe stress concentration in the profile cut HAZ. Subsequently fatigue cracking had propagated under normal operating conditions
Remedy	Procedures and guarding should be installed to prevent the ingress of foreign objects into the hammer mill

Additional References Pertaining to Case Study