

# Failure Investigation And Analysis

## Case Histories (1/10)

### Failure analysis of inner pipe leak in spool piece of jacketed pipeline

**MOC:** Inner pipe is 3" Sch.40, ERW, SS316 and jacket pipe is 4" M.S. class C **Service Life:** NA

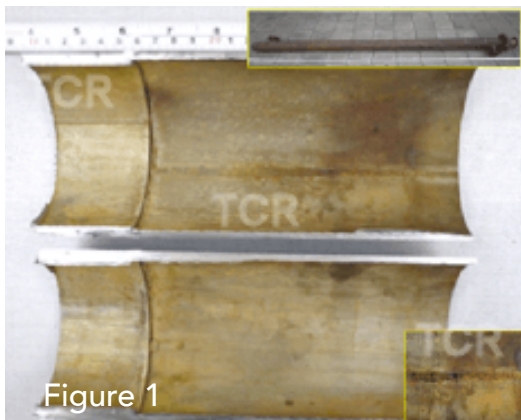


Figure 1

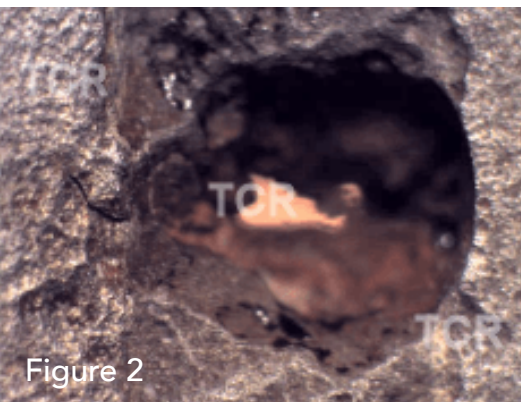


Figure 2



Figure 3

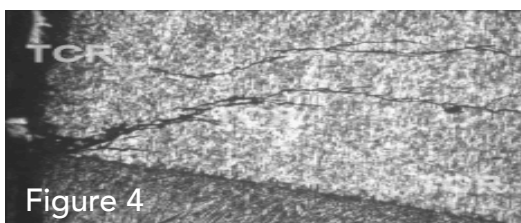


Figure 4

**DESCRIPTION OF FAILURE:** A leak was observed in the inner pipe of the 2.2 meter long spool pieces forming a 25 meter long jacketed pipeline of plant 2/B manufacturing unit of PMV acid. The fluid on jacket side is HNP. The leak was found out by conducting pressure test on each individual segment of 2.2 meters with pressurized water filling on jacket side. The suspected spool revealed a leak under the jacketed length through a circumferential weld joint made on inner pipe at about 400mm from top flange end. A leak was observed in the inner pipe of the 2.2 meter long spool pieces forming a 25 meter long jacketed pipeline of plant 2/B manufacturing unit of PMV acid. The fluid on jacket side is HNP.

#### INVESTIGATION:

Figure 1 shows close-up view at the surface of one of the broken pieces of impeller. Fracture contours with random orientation are seen. At some places, contours are deformed indicating their secondary nature of failure.

Figure 2 shows low magnification view at puncture on inner side weld. The puncture is by way of pit. The pit surface is dark brown in colour. Puncture contours towards OD are uneven.

# Failure Investigation And Analysis

## Case Histories (1/10)

### Failure analysis of inner pipe leak in spool piece of jacketed pipeline

**MOC:** Inner pipe is 3" Sch.40, ERW, SS316 and jacket pipe is 4" M.S. class C **Service Life:** NA

The butt weld joint between the pipe in longitudinal section shows different section thickness of two pipes. Also the edge of thicker pipe is not properly prepared before welding that left improper fusion (Figure 3).

Figure 4 shows outer edge microstructures of weld and HAZ region which is worked austenite with scattered delta ferrite stringers. Transgranular cracks which are branched in nature are observed originating from outer edge. The crack is confined to the weld and HAZ.

The increased hardness and microhardness of the failed pipe indicates enhanced cold worked condition since manufacturing stage. The cold worked condition has adverse influence on the corrosion resistance. Thus, it is conclusive that pipeline used in PMV acid service was containing incompatible material of 304L spool piece that was susceptible to pitting corrosion. During the operation it failed by way of pitting corrosion and inter-dendritic corrosion at weld led to puncture.

#### CONCLUSION:

The puncture of the inner pipe of spool is because of use of wrong material, poor fabrication issues, and corrosion as explained below.

- The use of 304L instead of 316L.
- Weld metal indicated carbide precipitation and got susceptible to inter-dendritic corrosion.
- Instead of using single inner pipe, it is fabricated by joining two pipes to meet to the required segment length and the thickness of the supplementary pipe piece was not compatible with the 316L.

The failure of the superheater tube by way of cracking at weld between inlet header and tube is because of improper PWHT.

# Failure Investigation And Analysis Case Histories (2/10)

## Failure analysis of water-wall tube of boiler

**MOC:** SA 210 grade C

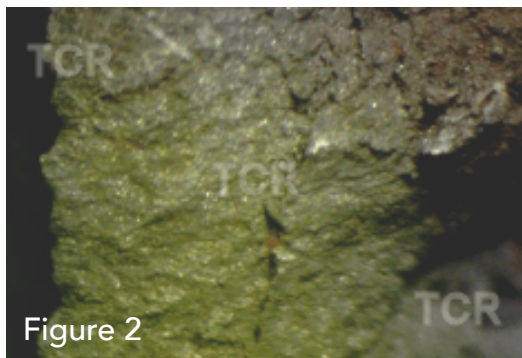
**Service Life:** About 2½ years



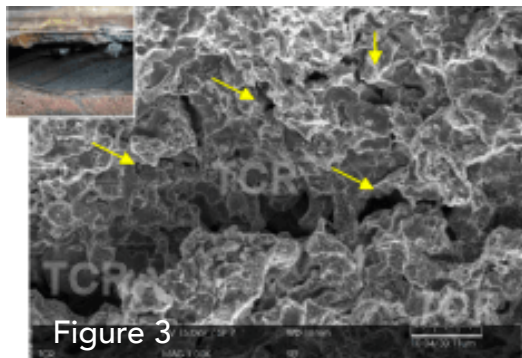
**DESCRIPTION OF FAILURE:** The window type rupture has taken place as primary failure on parent metal, and there was secondary nature of erosion failure on the adjacent tube.

### INVESTIGATION:

Figure 1 shows the failed portion of water wall tube samples of tube no. 150 and 151. Tube no. 150 is having primary failure which is window opening type. Figure 2 shows rupture lip surface at some other location on one corner.



During failure the metal seems to have been partly caved out from the inner side of the rupture surface. Faint nuances of crack like discontinuities remaining present on the rupture lip which are towards inner side are indicative.



Fractograph of Inner edge of fracture surface rupture lip (Figure 3) indicates inter-granular nature of brittle fracture surface. Discontinuous fissures and grain boundary cracking is also seen (1000X).

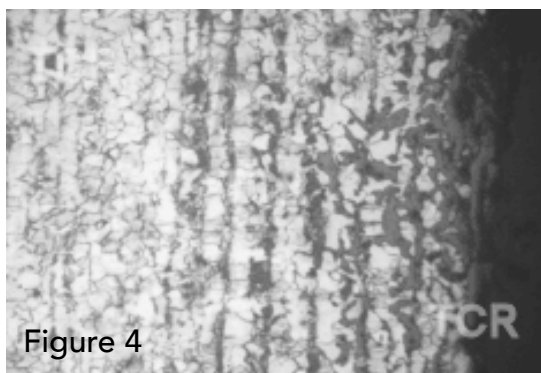
Figure 4 shows inner edge microstructure. Surface decarburization is noticed. Also, there is grain boundary fissures filled with scale and preferential attack on pearlite colonies. Inner surface is covered with porous scale (200X).

# Failure Investigation And Analysis Case Histories (2/10)

## Failure analysis of water-wall tube of boiler

**MOC:** SA 210 grade C

**Service Life:** About 2½ years



### CONCLUSION:

The failure of water wall tube is essentially due to hydrogen damage leading to formation of fissures and micro-cracks that weakened the tube matrix at failure location. The hydrogen damage occurred due to under-deposit corrosion at localized region.

# Failure Investigation And Analysis Case Histories (3/10)

## Failure analysis of heat exchanger tube

**MOC:** Grade 410S

**Service Life:** About 4 Years



Figure 1



Figure 2

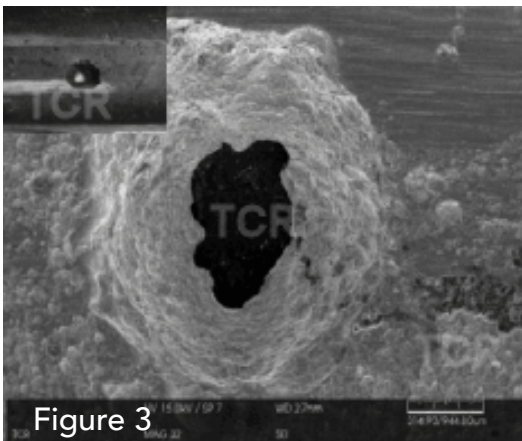


Figure 3

**DESCRIPTION OF FAILURE:** The heat exchanger was installed in 2009. For the first time it was opened in Feb 2013 for routine maintenance. The leakages were noticed when it was opened for the second time in Nov 2013. The heat exchanger tube containing crude with identification number ME-RDZ312-S15AB in SEZ Crude sub-section started showing leakage after hydro-testing. More than 400 tubes leaked out of 1054 tubes.

### INVESTIGATION:

Figure 1 shows half portion of the cut tube having pinhole puncture that was received for investigation. Scattered pitting corrosion damage is noticed in longitudinal direction in line with the pinhole puncture.

Figure 2 shows low magnification close up view on inner surface at puncture location. Puncture is conical in nature with decreasing cross section towards outer surface. The puncture surface is dark brown in color. The puncture contours are uneven but sharp and the surrounding area is free from any corrosion. On surface at away location, there are scattered shallow pits.

Figure 3 shows close up view at puncture location from inner surface. Area surrounding the puncture is heavily corroded. There is thinning at puncture contours.



# Failure Investigation And Analysis Case Histories (3/10)

## Failure analysis of heat exchanger tube

**MOC:** Grade 410S

**Service Life:** About 4 Years

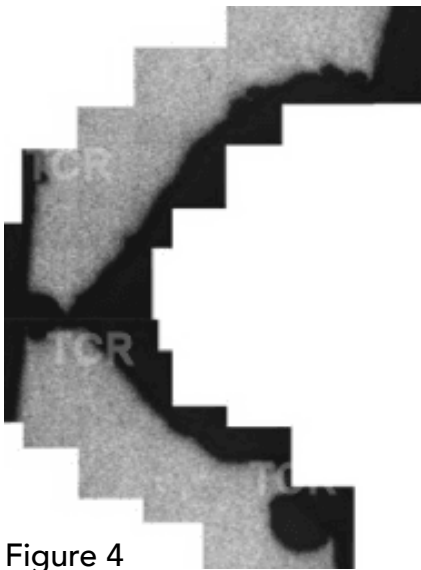


Figure 4

Figure 4 shows panoramic view of the puncture. Puncture is with large opening at inner edge which tapers down towards outer surface with non-uniform contours. There is slight increased opening on outer edge, this seems to be caused by corrosive fluid oozing out under slight pressure resulting into ventury like shape.

### CONCLUSION:

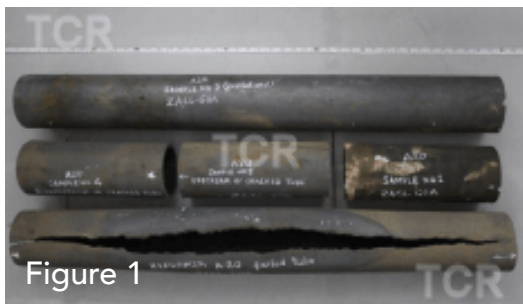
The premature puncture of the exchanger tubes appears to be on account of pitting corrosion damage which was under the influence of oxygen, moisture, sulphur and chloride ions as contaminants in the crude that was being carried.

# Failure Investigation And Analysis Case Histories (4/10)

## Failure analysis of reformer tube of refinery

**MOC:** ManuritexM

**Service Life:** 1,42,000 hours



**DESCRIPTION OF FAILURE:** The primary reformer catalyst tube A20 of primary reformer, A-BA-101 found to have failed by way of rupture during operation. The failure occurred at a distance 3.8 to 4.8 m length from the top and the rupture length was 1 meter.

### INVESTIGATION:

Figure 1 shows the photograph of reformer tube. The bottom most sample is cut portion having the crack area. In the middle the sample from left end side belongs to away from crack tip end marked with star. The middle one belongs to away from the crack tip marked with arrow. The one on right end belongs to inlet side. The one above is sample 5 from outlet end. The rupture has taken over the longer length up to approximate 1 meter length. Bulging is not observed except at the cracked region.

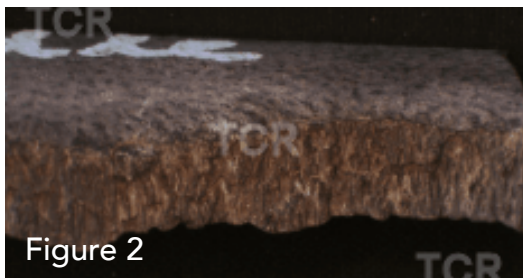


Figure 2 shows low magnification view of the fracture surface. The columnar nature of grain structure is highlighted on the brittle fracture surface.

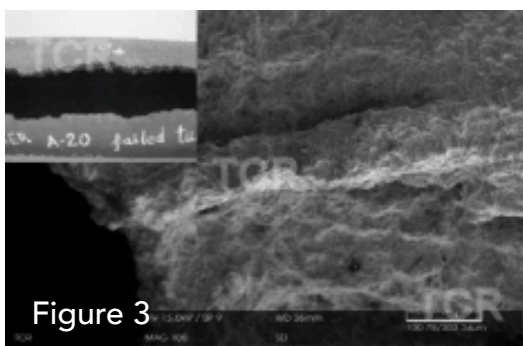


Figure 3 shows ID surface fractograph which highlights quasi cleavage nature of fracture surface, which is on the inter-dendritic columnar structure (100X).

# Failure Investigation And Analysis Case Histories (4/10)

## Failure analysis of reformer tube of refinery

**MOC:** ManuritexM

**Service Life:** 1,42,000 hours

Figure 4. The top inlet sample shows primary carbides in the austenite matrix. Very few secondary precipitates are observed around inter-dendritic region. The failed region shows microstructure comprises of primary carbides at inter-dendritic region along with secondary precipitation including carbides within the austenite matrix. Presence of creep at primary carbides along with coarsening and coagulation of secondary precipitation and dissolution in the matrix. Bottom location microstructure shows coarsening of primary as well as secondary carbides at the inter-dendritic region as well as within austenite matrix. This location shows maximum coarse primary carbides along with higher density of secondary precipitations.

Top (inlet) sample

Failed sample

Bottom (outlet) sample

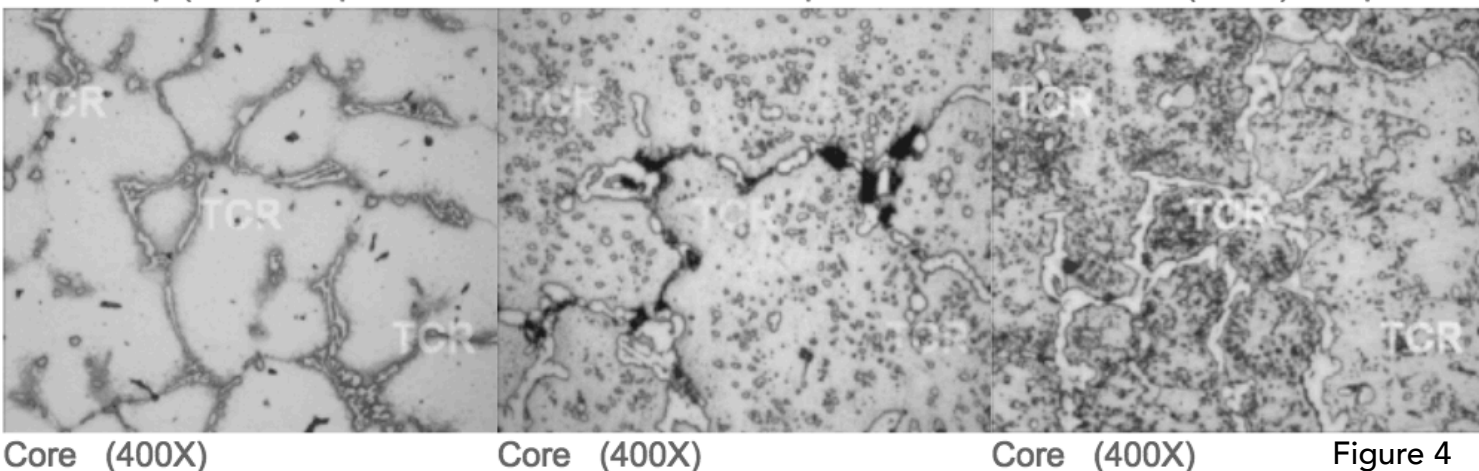


Figure 4

### CONCLUSION:

The failure of reformer tube appears to be on account of localized temperature excursions which resulted in extended creep damage due to microstructural degradations resulted in rupture..



# Failure Investigation And Analysis Case Histories (5/10)

## Failure analysis of muffler exhaust front tube of auto bike

**MOC:** IS 3074 Gr. ERW-1

**Service Life:** Short



Figure 1

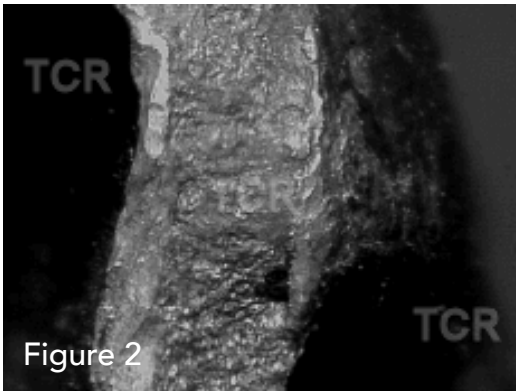


Figure 2

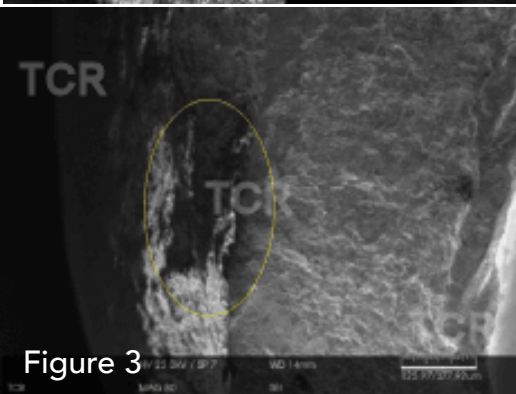


Figure 3

**DESCRIPTION OF FAILURE:** Muffler exhaust front tube of auto bike. The failure location is from bracket tack welded to exhaust tube. The muffler exhaust is attached through the tube joining engine outlet to the silencer. The heat exchanger tube containing crude with identification number ME-RDZ312-S15AB in SEZ Crude sub-section started showing leakage after hydro-testing. More than 400 tubes leaked out of 1054 tubes.

### INVESTIGATION:

Figure 1 shows the photograph of muffler assembly with KZN exhaust tube. The failure has occurred nearer to the bracket location that has been tack welded to the exhaust tube. The failure is on the tube joining engine outlet to the silencer.

Light fractograph (Figure 2) shows conspicuous porosity and weld defect are observed (25X).

SEM fractograph (Figure 3) shows fatigue crack initiation at weld porosity from outer surface. Multiple ratchet marks are observed initiating from weld defect.

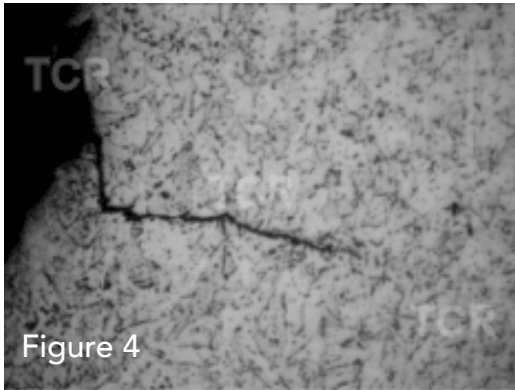
Figure 4 shows microstructure having ferrite and traces of pearlite with crack initiation from HAZ area (400X).

# Failure Investigation And Analysis Case Histories (5/10)

## Failure analysis of muffler exhaust front tube of auto bike

**MOC:** IS 3074 Gr. ERW-1

**Service Life:** Short



### CONCLUSION:

The premature failure of the KZN exhaust tube in muffler assembly is attributed to poor quality of welding done at the joint between the bracket and the tube. The welding defects coupled with HAZ with high hardness have initiated fatigue nature of failure.

Figure 4

# Failure Investigation And Analysis Case Histories (6/10)

## Failure analysis of fin-fan cooler of LAB plant

**MOC:** SA213 TP 316L

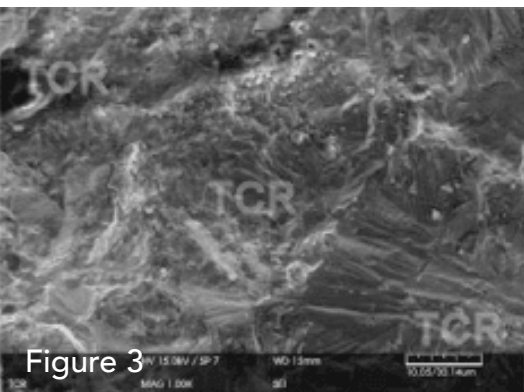
**Service Life:** 6 Years



Figure 1



Figure 2



**DESCRIPTION OF FAILURE:** Multiple failures in the form of cracking were observed from a fin-fan cooler. There are four fin fan type, stripper column overhead condensers, A to D in pre-fractionation section in n-Paraffin unit. These condensers were commissioned in 2006. It carries hydro carbons, being cooled from 175 °C to 78 °C and at 2 barg pressure.

### INVESTIGATION:

Figure 1 shows finned tubes that were damaged. Few tubes were shaved to look the damage.

Figure 2 shows outer surface in DP tested condition having multiple hairline cracks, branched in transverse direction all-over the tube surface.

Fractograph by SEM (Figure 3) shows brittle nature of crack surface. Secondary cracks are also present on the crack surface (1000X).

Figure 4 shows outer edge microstructure with trans-granular and branched cracking. Microstructure is worked austenite with twins (100X).

# Failure Investigation And Analysis Case Histories (6/10)

## Failure analysis of fin-fan cooler of LAB plant

**MOC:** SA213 TP 316L

**Service Life:** 6 Years

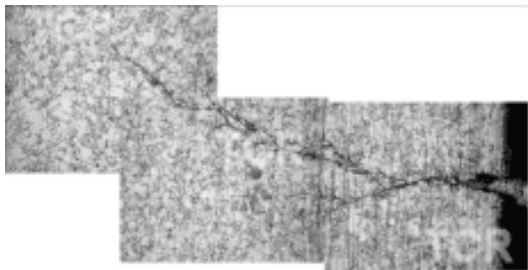


Figure 4

### CONCLUSION:

The premature failure of tubes of stripped coil overhead condenser is because of trans-granular stress corrosion cracking primarily from the inner side of the tube. Contamination of chlorine and moisture with the hydrocarbons passing through the tube shall be prevented.

# Failure Investigation And Analysis Case Histories (7/10)

## Failure analysis of connecting rod bolt

**MOC:** ASTM A540 Grade B23 **Service Life:** after 2270 running hours after last overhaul



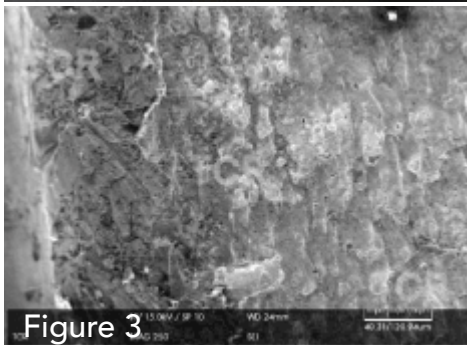
**DESCRIPTION OF FAILURE:** Connecting rod bolts of main engine of a tug boat were found broken. Prior to failure knocking sound was heard from running engine. Within about 10 minutes of it, crank case was seen damaged and oil was coming out of main engine. All the four bolts of connecting rod were broken. Besides, the engine block has cracked with oil sump at lower block having damaged both at top and bottom. The connecting rod also had damaged and twisted.



### INVESTIGATION:

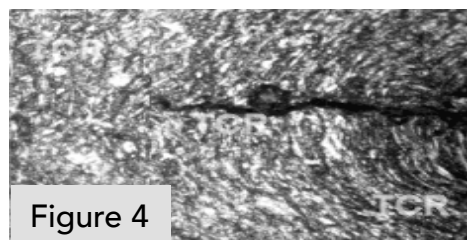
Figure 1 shows failed connecting rod bolts; all were found broken (bottom part in photo).

Figure 2 shows fracture surface shows large fatigue fracture surface from either end with small fast fracture surface in the middle portion.



Fractograph by SEM (Figure 3) shows progressive nature of failure with beach marks locating the initiation on periphery (250X).

Crack is seen (Figure 4) with transgranular nature initiating from root, it is filled with scale. Microstructure is tempered martensite.



**CONCLUSION:** Connecting rod bolts failed due to wrong assembly of bolts during last overhaul that would have resulted in bolt looseness during subsequent operation.



# Failure Investigation And Analysis Case Histories (8/10)

## Failure analysis of oil and gas production tubing

**MOC:** API 5CT - N80

**Service Life:** About 14 Years



Figure 1

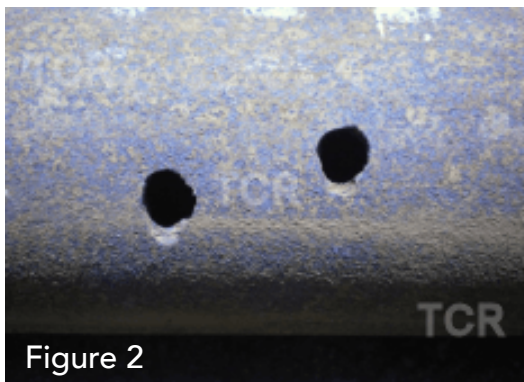


Figure 2

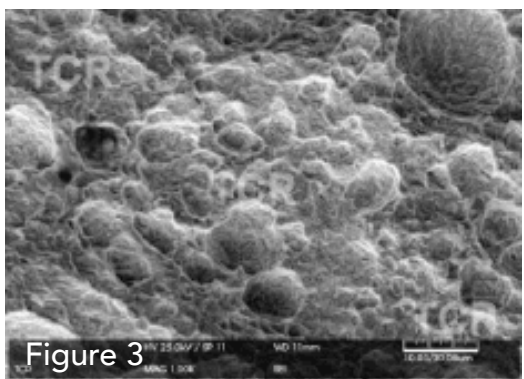


Figure 3

**DESCRIPTION OF FAILURE:** A high intensity sound from the well was reported and gas leakage was observed at various places of the wellhead. Several attempts were made to kill the well for repairing/replacement of the wellhead, but the well could not be killed following normal killing operation. During the work-over operation, 2.7/8" production tubing and 5.1/2" casing were retrieved as tubing was found punctured and severely thinned from several places. During October 2005 the well was killed with 78 lbs/cft CaCl<sub>2</sub> solution.

### INVESTIGATION:

Figure 1 shows failed tube having puncture that was received for investigation.

Figure 2 shows low magnification close up view on outer surface at puncture location.

Figure 3 shows SEM image reveals micro level pitting corrosion damage from production side (1000X).

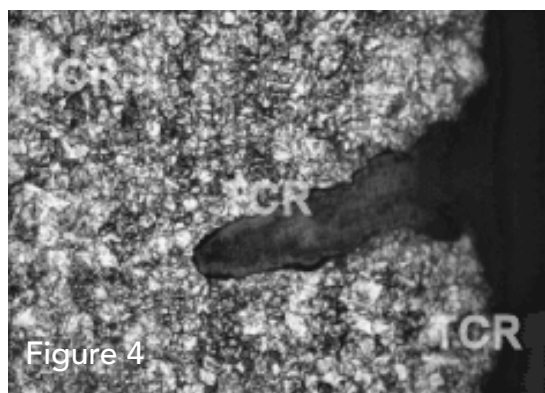
Figure 4 shows initiation of a pit filled with scales from ID side. The microstructure consists of fine tempered bainite structure (200X).

# Failure Investigation And Analysis Case Histories (8/10)

## Failure analysis of oil and gas production tubing

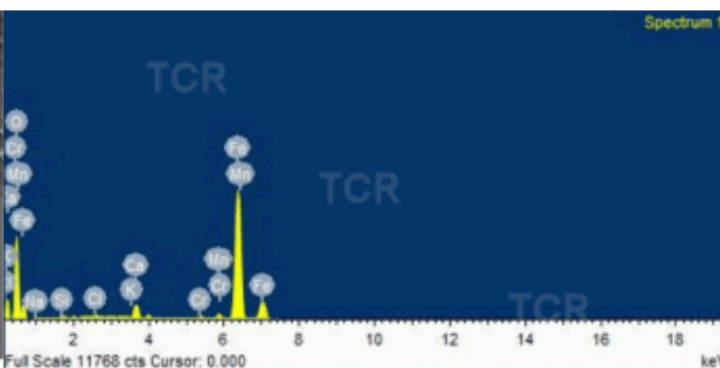
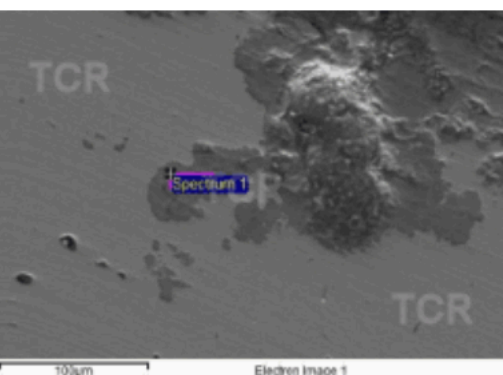
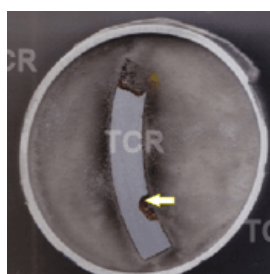
**MOC:** API 5CT - N80

**Service Life:** About 14 Years



### CONCLUSION:

The production tubing was punctured due to pitting corrosion mechanism attributed either due to CO<sub>2</sub> corrosion during shut-in period or possibly because of use of contaminated/acidic CaCl<sub>2</sub> solution. Alternative killing fluid is suggested for intermittent services / stoppages.



Element	Weight %
Carbon	12.48
Oxygen	12.94
Sodium	1.29
Silicon	0.46
Chlorine	0.45
Potassium	0.30
Calcium	0.86
Chromium	0.52
Manganese	1.87
Iron	66.84

# Failure Investigation And Analysis Case Histories (9/10)

## Failure analysis of steam turbine blade of power generation plant

**MOC:** Proprietary, equivalent to X10CrNiMoV 12-2-2    **Service Life:** 22000 Hours



Figure 1

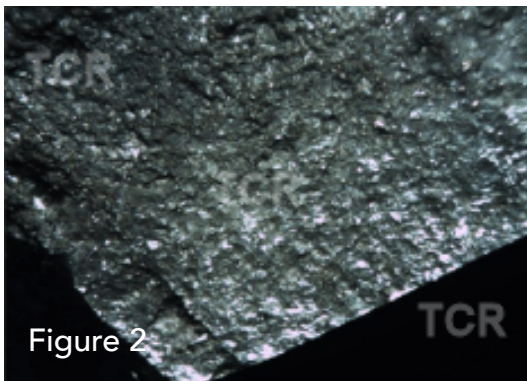


Figure 2

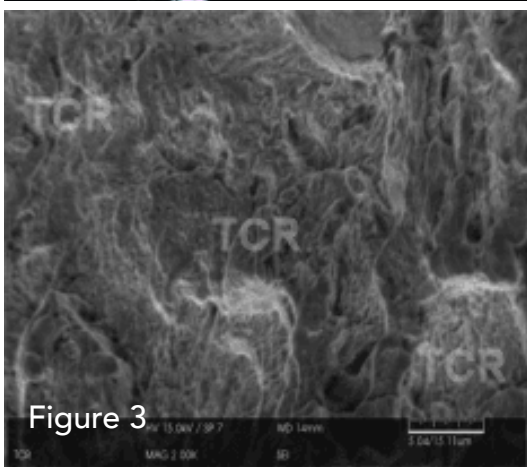


Figure 3

**DESCRIPTION OF FAILURE:** Blade number 48 of total 96 last stage blades of LP turbine-B, failed during operation. unit was running at 430 MW capacity. There were instructions to reduce generations to 280 MW. Having reached the generation level to 288 MW, abruptly the unit tripped on high vibration along with heavy noise from turbine. Turbine capacity of 600 MW was never reached. It works at throttle temperature 538 °C and final feed water temperature of 276 °C. At LP stage it operates in -88 to -89 KPA.

### INVESTIGATION:

Figure 1 shows 430MW electrical power generation turbine with failed LP stage blade from snubber area

Figure 2 shows the Chevron marks indicate crack initiation from the leading edge near snubber portion.

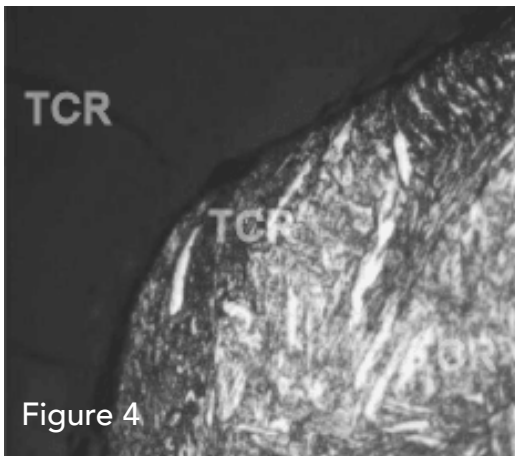
Figure 3 shows SEM fractograph of quasi cleavage nature of fracture surface (2000X).

Figure 4 shows microstructure of fracture edge which has defatation. Structure is tempered martensite (400X).

# Failure Investigation And Analysis Case Histories (9/10)

## Failure analysis of steam turbine blade of power generation plant

**MOC:** Proprietary, equivalent to X10CrNiMoV 12-2-2      **Service Life:** 22000 Hours

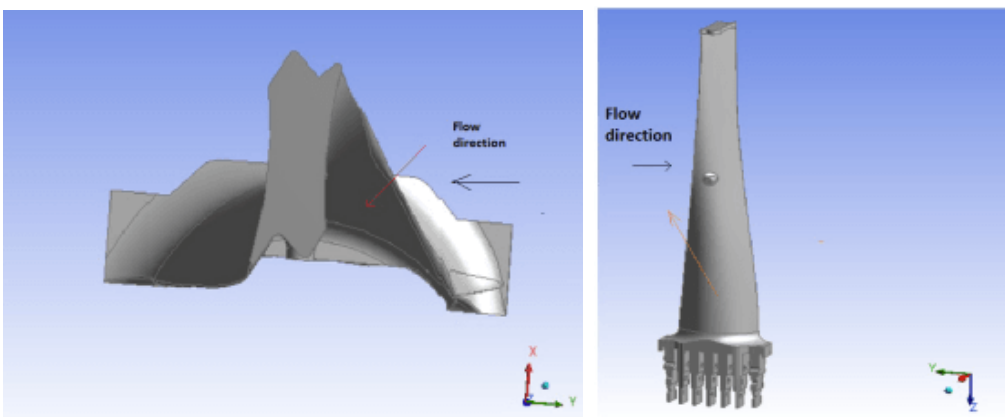


Laser scanning and profile generation indicate stress raiser point below the snubber and towards leading edge which is the location of failure. Comparison between failed blade and generated profile shows lower sectional area at failed blade. Without have any significant effect on corrosion including opposite end blades, it suggests blades of improper machined profile.

### CONCLUSION:

The failure of last stage LP turbine blade appears due to use of lower thickness of blade that combined with sudden obstructions created by condensate built-up at the bottom which is not synchronized to be drained out. Use the blades as per designed thickness and profile is mandatory.

### Profile generation, post failure





# Failure Investigation And Analysis Case Histories (10/10)

## Failure analysis of FSH tube 13, coil 20

**MOC: T91**

**Service Life: 960 hours**

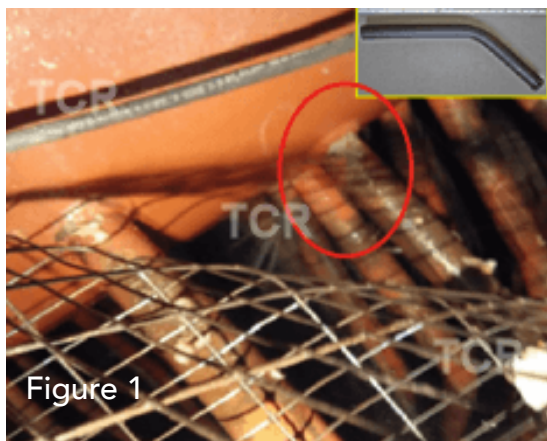


Figure 1

**DESCRIPTION OF FAILURE:** Failure in the form of leakage of final superheater (FSH) tube 13 of coil 21 connecting to inlet header occurred during operation. The failure was noticed by acoustic sensors installed in nearby area of the failure. It was verified physically by going to local spot and get sound confirmation.

### INVESTIGATION:

Figure 1 shows site photograph indicating area of failure.



Figure 2

Figure 2 shows both parent metal and weld side fracture surface views. Both of them look relatively flat without any significant deformation. Weld side fracture surface is showing blackish nature on the inside.

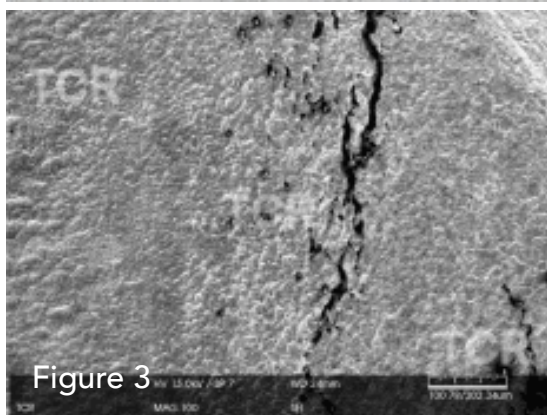


Figure 3

SEM fractograph (Figure 3) shows ID surface view near fracture. Quasi continuous cracks with irregular contours and fine tips are noticed. It is filled with oxide scale. There is fissure like opening surrounding the main crack (100X).

Figure 4 shows ID side HAZ microstructure showing intergranular cracking slightly branched in nature with fine tips. The contours are uneven. Microstructure is low- temperature tempered martensite (200X).



# Failure Investigation And Analysis Case Histories (10/10)

## Failure analysis of FSH tube 13, coil 20 (Cont.)

**MOC:** T91

**Service Life:** 960 hours

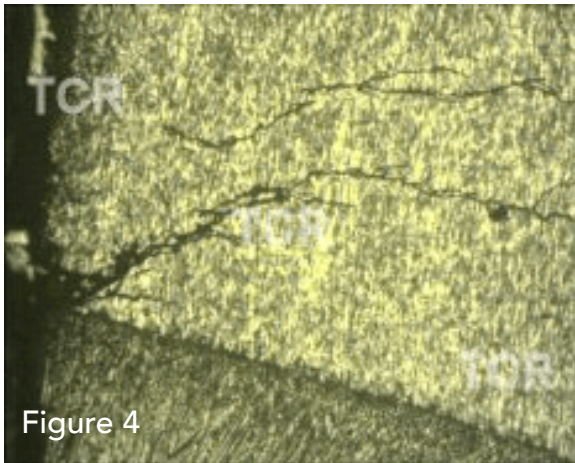


Figure 4

### CONCLUSION:

The residual stresses in weld and HAZ caused cracking under following multiple reasons:

1. Stress concentration at the metallurgical notch formed at parent metal and HAZ junction which appears to be a case here.
2. Releasing of internal stresses that are built in weld and HAZ area, during operation.
3. Additional tensile stresses in form of internal pressure during process.

The failure of the superheater tube by way of cracking at weld between inlet header and tube is because of improper PWHT.