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Failure Investigation of Super Heater Tubes of a Boiler in Oil Refinery

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ABSTRACT

Ruptures were observed in the ASTM SA213 T22 & SS 347H super heater tubes of a boiler in an oil refinery after a service period of two years. Cut sample tubes from the failed regions were investigated for analysing the root cause of failure.

From the extensive Laboratory investigations carried out, tube internal deposits rich in 'Na' associated with the microstructural degradation of tube material was seen. The boiler feed water carryover to the steam side is seen to have led to the precipitation of 'Na' salts on the internal surfaces. The high heat flux regions of super heater coil tubes having localized Na deposits experienced reduced heat transfer and thereby overheating of tube causing rupture and leaks. The findings have been corroborated with the microstructural evidences. The detailed laboratory investigations carried out and the root cause analysis are enumerated in this paper.

Keywords: SA213 T22 & TP 347H; BFW carry over; Na deposit; Localized bulging/Overheating

INTRODUCTION

Boiler after approximately 2 years of commissioning experienced multiple failures in Primary Super Heater Coil tubes. Failures in the form of localized bulging / tube opening were observed in the region of bottom U loops / partial straight tube portion (high heat flux region). Total 10 no's of tubes (out of 42) were found affected from localized bulging / failure.

EXPERIMENTAL PROCEDURE

Visual observation, Metallography of tube samples at failed region of both 2.25Cr-1 Mo & SS 347H tube samples as well as SEM-EDX analyses of internal deposits in the failed region were carried out.

RESULTS

The Primary Super Heater coils are laid vertically & bottom portion of coil directly face burner flame indicated failed regions exposed to high heat flux zone receiving both radiation & convection heat.

Viewing tube sample at higher magnification (under stereo microscope) revealed thickening of magnetite layer/oxidation damage respectively on tube internal / external surface contributing to thickness loss on T22 tube sample where as such observations were missing for SS 347H tube sample. Refer Figs 1 A/B/C & Fig 2.

Multiple bulges in the U bend & longitudinal crack in connected straight portion were observed in both failed region of T-22 & SS 347H metallurgy tubes & failed locations were not found aligned vertically rather distributed in tube half circumference indicating impact of random internal deposit followed by differential overheating in the high heat flux zone. Refer Figs 4A/B.

On Metallography, polished 2.25Cr-1Mo & SS 347H specimens revealed presence of creep voids, micro cracks in both the tube metallurgy samples & additional sensitization in SS specimen.. Refer Figs 5 A/B/C, Figs 6A/B/C & Figs 7 A/B/C.

Metallography of specimen after etching revealed ferrite matrix, bainitic carbides transformed to globular form and carbide precipitation in both at Grain boundaries and inside the grain suggesting localized overheating / metallurgical degradation of material & Creep voids / micro cracks suggesting progress of creep phenomenon in 2.25Cr-1Mo specimen. Refer Figs 8 & 9 A/B/C

Etched specimen SS 347H revealed grain-boundary carbide precipitation (Sensitized microstructure) as well as small carbide precipitates within the individual austenite grains and oxide penetration & creep voids / micro cracks suggesting progress of creep in the overheated zone. Refer Figs 10 A/B.

SEM / EDX analysis of whitish random deposits inside the tube indicated appreciable amount of sodium suggesting possibility of soluble salt deposition from BFW carry over. Refer Figs 3 A/B/C & Fig 11.

Fig 1A

Fig 1A: Shows multiple localized bulging on tube preferentially at 5-7 O' Clock position & not aligned in single plane.

Fig 1B Fig 1C

Fig 1B/C: Shows failure as thick lip opening.

Fig 2

Fig 2 : Shows bulging / severe localized oxidation / exfoliation of oxide scale.

Fig-3A

Fig 3A: As received tube sample shows appreciable whitish deposits inside the tube.

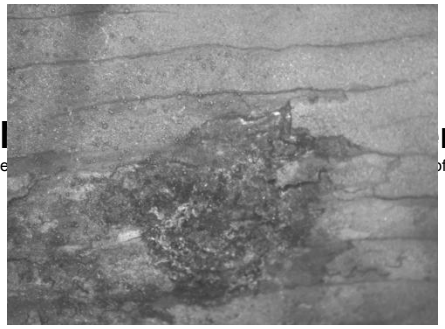


Fig – 3B

Fig 3B: Shows some corrosion marks/deposits on tube ID surface on viewing at a high magnification under stereomicroscope.

Fig 3C

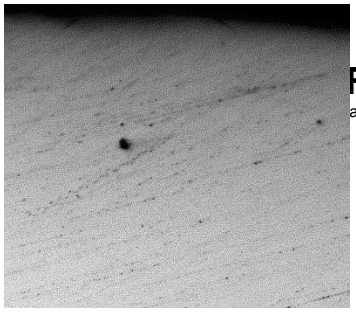
Fig 3C: Shows randomly distributed  whitish deposits on tube ID surface.

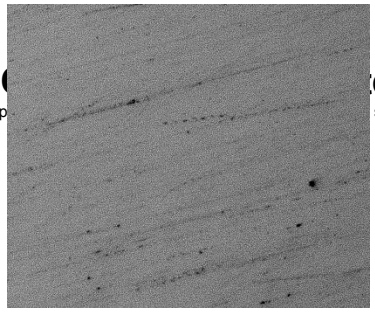
Fig-4A:

Fig 4A : As received photograph of failed SS 347H tube shows multiple localized bulges on tube U-bend, preferentially at 5-7 O' Clock position.

Fig-4B:

Fig 4B : As received photograph of failed SS 347H tube shows thick lip opening.





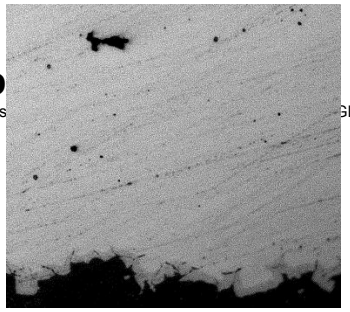
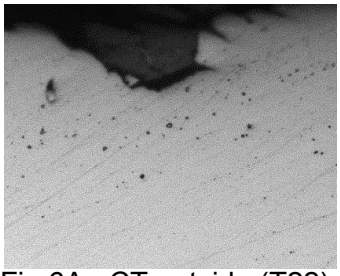


Fig 5A: LT outside (T22) Fig 5B: LT middle (T22) Fig 5C: LT inside (T22)



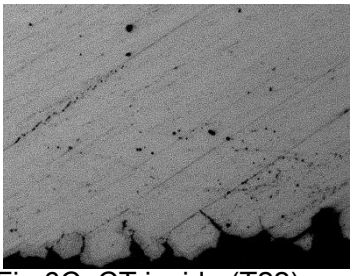


Fig 6A: CT outside (T22) Fig 6B: CT middle (T22) Fig 6C: CT inside (T22)

Fig 5A/B/C & 6 A/B/C: 2.25Cr-1Mo Tube: specimens under optical microscope (200X) in the bulged region showed presence of creep voids / oxide penetration on polished surface of CT (Circumferential Thk) & LT (Longitudinal Thk) cross-sections of specimen.

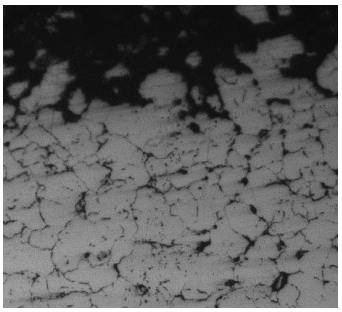
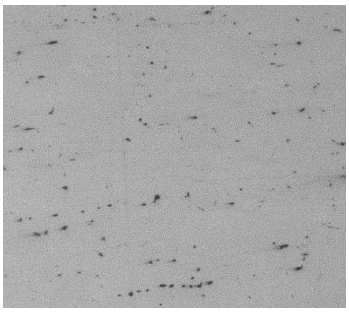
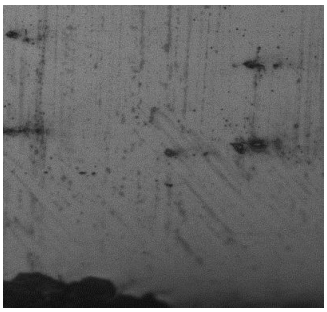




Fig 7A: SS347 (LT) outside edge Fig 7B: SS 347 (LT) middle Fig 7C: SS 347 (LT) inside edge

Fig 7A/B/C: Policed surface (200 X) of SS 347H specimens showed presence of creep voids on polished surface. Oxide penetration & sensitized grain boundaries can also be seen in the specimen at outside edge.

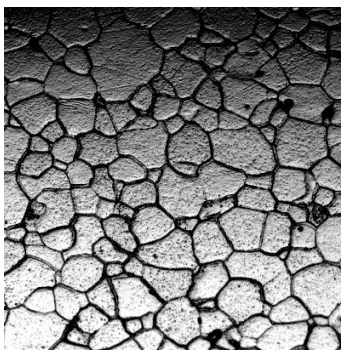
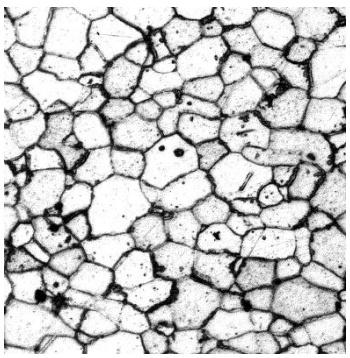
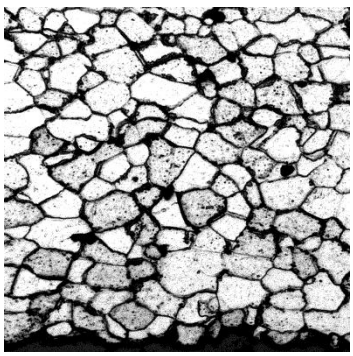




Fig 8A: CT outside

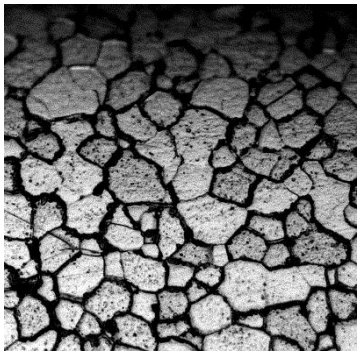


Fig 8B: CT middle

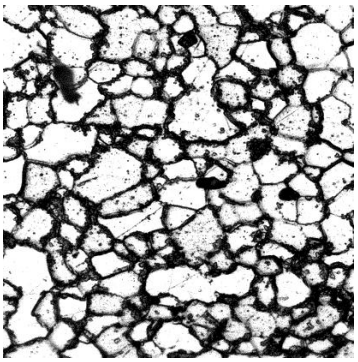


Fig 8C: CT inside

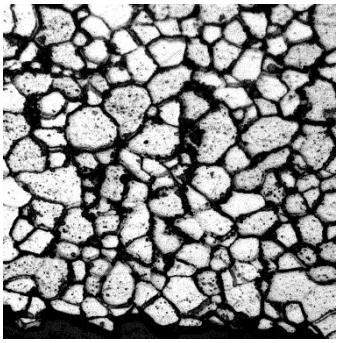


Fig 9A: LT outside

Fig 9B: LT middde

Fig 9C: LT inside

Fig 8A/B/C & 9A/B/C: Ferrite matrix with most of the bainitic carbides transformed to globular form & considerable carbide precipitation both at Grain boundary and inside the grain as well as Creep voids & micro cracks at grain boundaries on etched specimen of CT & LT cross-sections on viewing under optical microscope at 200X.

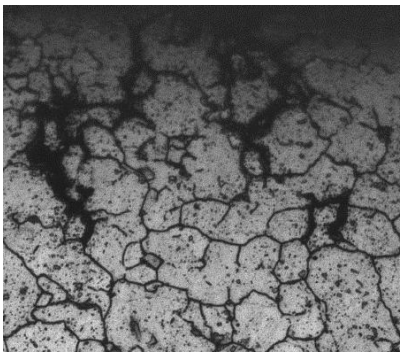


Fig 10A: SS CT outside

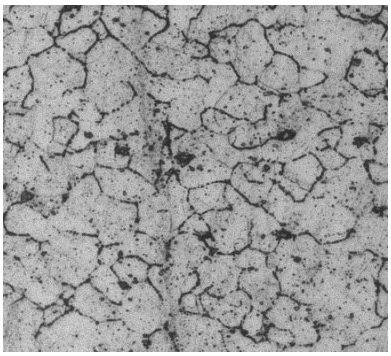


Fig 10B: SS CT middle

Fig 10 A/B: Tube specimen under optical microscope showed sensitization in SS 347, Creep voids / micro cracks in etched condition.

SEM-EDX Analysis of Deposits inside the Tube:

Analysis revealed presence of Na, Ca, P etc as high as Na (40.1%), Ca (51.5 %), Cl (3.5 %), P (7.7 %) suggesting possible BFW carry over along with saturated steam & soluble salt deposition on tube ID surface.

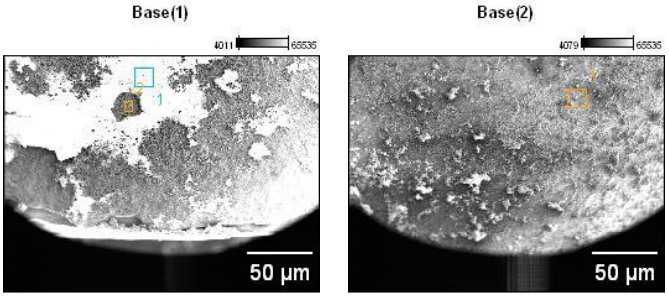


Fig 11: SEM-EDX Analysis of Internal tube deposit shows high percentage of Na, Ca, P etc. indicative of BFW carry over along with saturated steam and deposition of soluble salts inside primary super heater coil.

Table 1: Wt %

	Na-K	Al-K	P-K	S-K	Cl-K	Ca-K	Fe-K
Base(1)_pt1	34.1		7.7	3.8	2.6	51.5	0.2
Base(1)_pt2	35.6	3.4	5.9		3.5	51.5	0.1

	Na-K	Al-K	P-K	Cl-K	Ca-K
Base(2)_pt1	40.1	10.2	1.8	2.8	45.1

CONCLUSIONS

Based on observations & findings, the failure of tubes were found attributed to,

- long term randomly localized overheating arising out from BFW carry over along with saturated steam to the Super Heater coils favouring, deposition of soluble salts in BFW at hot areas inside the tube & thereby inducing reduction in heat transfer / overheating of tube at internal deposit locations & failures of tube from accelerated creep phenomenon.
- High temperature material degradation like Creep, oxidation & micro structural degradation at above overheated locations were found contributing to the failure of tubes in the form of thick lip rupture.

In view of above, it was recommended to identify the possible causes of Boiler water carry over along with saturated steam & necessary remedial measures to avoid such premature failures in future.

ACKNOWLEDGMENTS

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