# Failure Characteristics Of Boiler Pipes In Al-Emsaeb Electric Power Plants

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## Abstract

Boilers are a main part of electric power plants , which mostly suffer from different types of failures. Overheating & corrosion are considered to be the most important causes of failures in boiler pipes in power plants. These Failures can be categorized as long- term & short term overheating . Failures also caused by collection of corrosion products, deposits or other foreign material on the inner surfaces of tubes boiler. Several failed samples from different locations in the boilers was tested. The microscopic examination of failure areas of the pipes, showed different types of distortion and clear appearance of corroded area in the microstructures of the pipe metal. The micro structural analysis of failure and the causes of the failure have been determined and the mechanism of corrosion in one of Iraqi electric power plant has been discussed in this work.

**Keyword :** overheating , emrittlement , thin lip , thick lip , mouth rupture , swelling ,cobra pearlile , bainite , martinsite.

## الخلاصة

المرجل هو الجزء الرئيسي في وحدات الطاقة الكهربائيةو الذي غالبا ماتعاني انابيبه من انواع مختلفة من الفشل. يعتبر الافراط بالتسخين والتاكل من اسباب الفشل . يتمثل الفشل بفترات الافراط بالتسخين الطويلة والقصيرة. يحدث الفشل احيانا بسبب تجمعات من الرواسب الناتجة من التاكل او المواد الغريبة على السطوح الداخلية للانابيب. اختيرت في هذا البحث عينات فاشلة من مواقع مختلفة من انابيب مراجل وحدات الطاقة الكهربائية العاملة في المسيب وتم تحليل الفشل ودراسة انواع التاكل ومحاولة التعرف على اسبابه .

## Introduction

Failures of boiler tubes caused by one of four reasons as recorded by Ludwig Hohenberger {2005}, Heyes {2001} and according to Annual book of ASTM standard {1990} as following:

1- overheating.
2-Corrosion or scaling.
3-embrittlement.
4-stressing above their ultimate strength or repeated stressed above their fatigue limits.

A survey of failure in power plant boiler compiled by one (U.S.A.) laboratory over a period of 12 years, encompassing 413 investigations, listed that , overheating caused 48.7% of those investigations, 21.5% caused by fatigue & corrosion fatigue , 16.5% caused by corrosion , stress corrosion and material was accounting 13.3% .{Chattopadhyay,1998}.

Overheating failures can be categorized as long- term & short term overheating. Long- term overheating is used to describe a tube damage due to an exposure to temperature too high for the operating stress even though the stress levels are well below the material yield strength. Presence of thick, brittle, dark oxide layers on both internal and external surfaces indicate the occurrence of long term overheating.{ Ludwig Hohenberger {2005}. The tubes will slowly deform due to creep and failure occur even in the absence of corrosion , oxidation or other active damage mechanisms {Chattopadhyay,1998}.

Short-term overheating usually characterized by failure considerable creep elongation and rapid plastic deformation of tube.During operation ,a wide variety of deposits can form on both sides of boiler tube. Under deposit , pitting, crevice and chemical corrosion were the three common causes of severe waterside corrosion { Islam & Riad, 1989}. Corrosion is most often a result of exposure of the tubing to oxygen – saturated water when raw water used for initial filling ,for make up feed and during out- of- service periods. Under normal circumstances, water is the principle reactant for the corrosion of boiler steel. If the feed and boiler water chemistry parameters,[ such as cation conductivity, dissolved oxygen , sodium, pH, chlorides, phosphate( for drum boilers using sodium phosphates for boiler water control ) and other anions { Radian, 1988}] are maintained within accepted industry standards and circulation is properly balanced with the heat absorption rates, fluid side corrosion and deposition should not limit the life of boiler tubing { Chernoff, Wade, 1996}.

Boiler tube failure caused by embrittlement of the metal result from metallurgical changes with in the tube metal. Hydrogen is one of the normal products of the basic corrosion reaction between iron and water. It may also be a major constituent of service environments. Hydrogen damage in boiler occurs primarily in steel components when atomic hydrogen pass into the metal and combine with other hydrogen atoms to form molecular hydrogen .Once inside the material , hydrogen can affect the mechanical performance of material in several ways{ Radian, 1988}:-

1- The formation of internal hydrogen blisters.
2- The process of hydrogen – assisted micro void coalesce can occur during plastic straining.
3-An extreme case of ductility loss from hydrogen is the brittle failure of susceptible materials under applied or residual tensile stresses. This form of failure is normally referred to as hydrogen embrittlement cracking {Kihara,1989}.

In high temperature hydrogen damage discontinuous cracking occurs because of the precipitation of molecular hydrogen (or methane resulting from hydrogen decarburization of the steel ) along grain boundaries { Ludwig Hohenberger {2005}.

A boiler stress failure can occur also as a result of higher than anticipated stresses. The combined effect of creep – fatigue interaction may act to lower stress rupture.

## Experimental Work

This work was conducted in one of Iraqi electricity power plant. It is a drum type boiler with 1320 MW capacity. It is oil fired and it can deliver 1980 ton/hr of steam. The boiler parts are hanged by a supported structure from its top. The tubes of the water walls contain helical fins at its inner side.

The drum of the boiler is located at the top of the boiler and four hinges, two at each side, hang it.

The boiler and its tubes made of low alloy steels. Table(1) was shown the chemical composion for these alloys.

The specimens were cut from failed tubes to specimens with dimensions of 4*15*30 mm and prepared by machining according to ASTM. MicroHardness values were obtained by using Vickers method.

The specimens were prepared for microstructure study by mechanically polished y with emery paper of grades 220, 320, 500 and 1000, followed by degreasing in acetone under ultrasonic vibration, then polished with alumina No.1 & No.2 . Some specimens were etched in 2% natal and other were etched electrolytically in 60% HNO3. The microstructures were investigated by optical microscope type JUNY RICHERT. X-ray tests were done by Phillips X-ray difractometer ( type P.W. 1050 Holland ) . These tests were conducted from chemical analysis of the deposits taken from external surfaces of the failed pipes.

**Table.1. The chemical composion of the standard alloys (SA-209) and tested alloys.**

| wt% | Fe | C | Si | Mn | P | S | Mo |
|---|---|---|---|---|---|---|---|
| **Standard alloys** | **Rem.** | **0.1-0.2** | **0.1-0.5** | **0.3-0.71** | **<0.04-0.02** | **<0.045** | **0.44-0.65** |
| **Test ed alloys** | **Rem.** | **0.2** | **0.3** | **0.7** | **<0.02** | **0.03** | **0.27** |

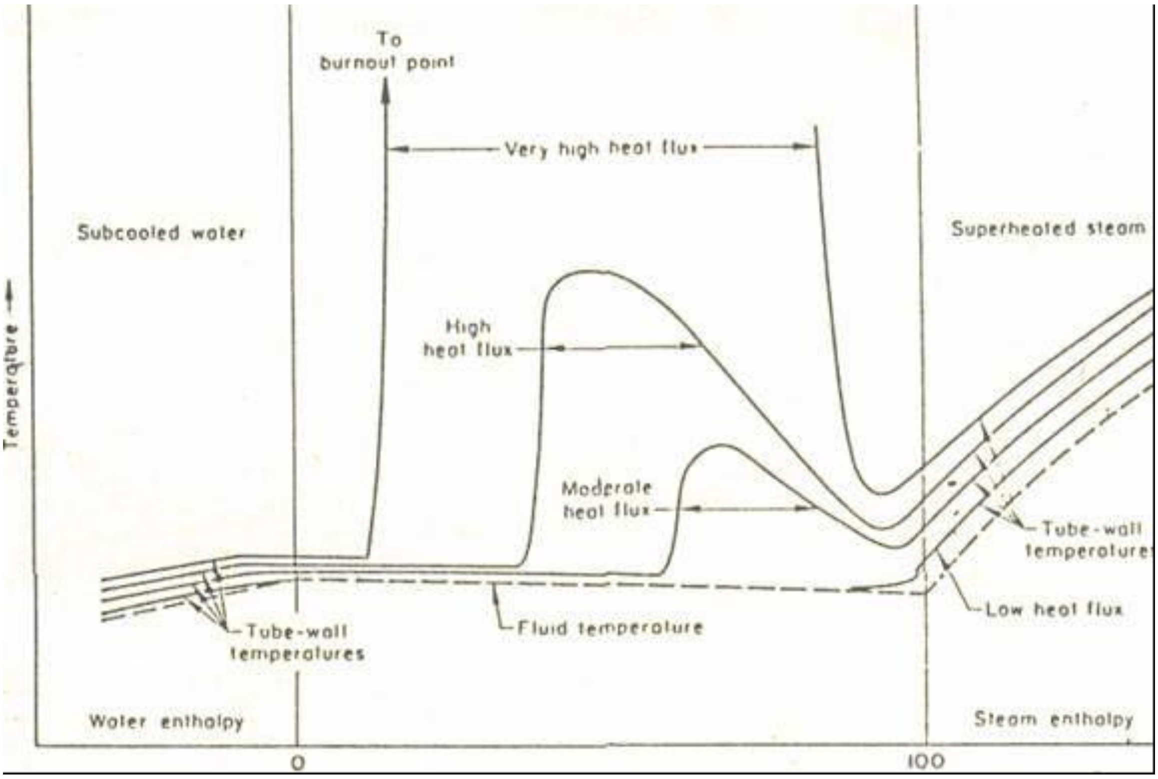
## Result & Discussion

When water is boiled in a tube having uniform heat flux ( rate of heat transfer ) a long its length under conditions that produce a state of dynamic equilibrium : various points along the tube will be in contact with sub-cooled water , boiling water , low quality steam , high quality steam steam & superheated steam .{ Ludwig Hohenberger {2005}.A temperature gradient between the tube wall & the fluid within the tube provides the drive force for heat transfer at any point.

Fig. 1 explain the effects of different heat- fluxes on tube wall temperature . Higher heat fluxes required higher tube wall temperature to sustain heat transfer deposits have a greater effect on tube wall temperature and therefore on overheating{ Calannino 1993}. However , the conductance of a vapor film in steam of low quantity is relatively low therefore , at the onset of film boiling a large temperature difference between the tube wall & the bulk fluid is required to sustain a high heat flux a cross the film . { Calannino 1993}.

A tube failure caused by overheating can occurs within few minutes or can take several years to develop. A failure caused by overheating generally involves fracture a long a longitudinal path , with some detectable plastic deformation prior to fracture). There are only a small amount of reduction in tube thickness at the fracture. The main fracture usually has a { FISH MOUTH} appearance as shown in Fig.2 . The surface fracture characteristics either as a { thick lip } or as a { thin lip } rupture.

Visual inspection revealed that the cracks had initiated at the steam side of the tube . Some of the cracks had crossed the entire thickness of the tube and had opening at the fire-side.




**Quality, percentage of steam by weight**

**Fig.1**. Variation of fluid temperature and tube-wall temperature as a water is heated through the boiling point with low, moderate, high and very high heat fluxes (rates of heat { Jackson,1980}.

Thick lip rupture occur mainly by stress rupture as a result of prolonged overheating at a temperature slightly a above the maximum working temperature for tube material {Islam & Riad, 1989}. Fracture surfaces of such failures are rough {crystalline} in macroscopic appearance and are oxidized or hot gas corroded because of exposure to a high temperature corrosive environment following the rupture.

The macroscopic examination reveals that the direction of fractures is normally to the tube surface(flat – face fracture) and parallel to the tube axis as shown in Fig. 2.

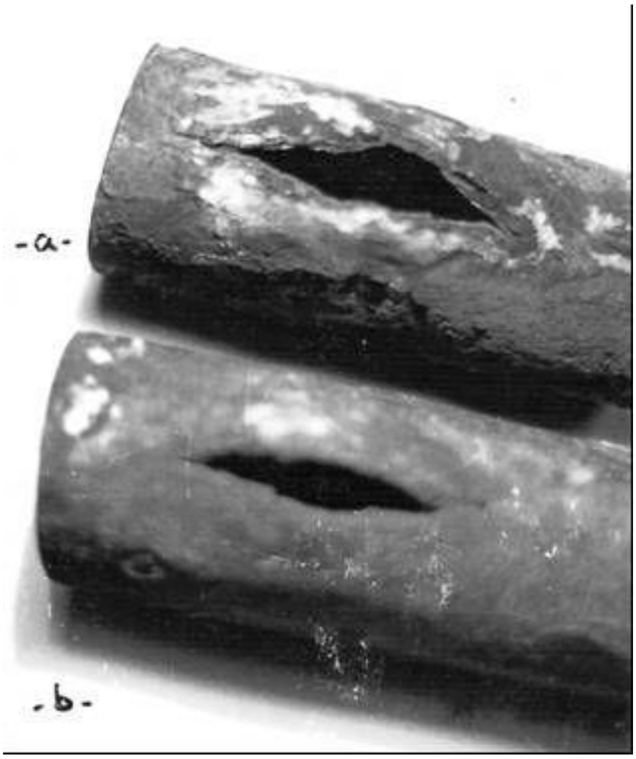



**Fig.2**. Over – all view of rupture. Atypical Fish Mouth rupture.
a- Thin LIP Fracture.
b- Thick Lip Fracture.

Examination of a polished transverse section through the tube at the center of the fracture usually reveals extensive secondary transverse cracking adjacent the main fracture (Fig.3) and when etched , the section will exhibit intern granular separation as show in micrograph in Fig.4.

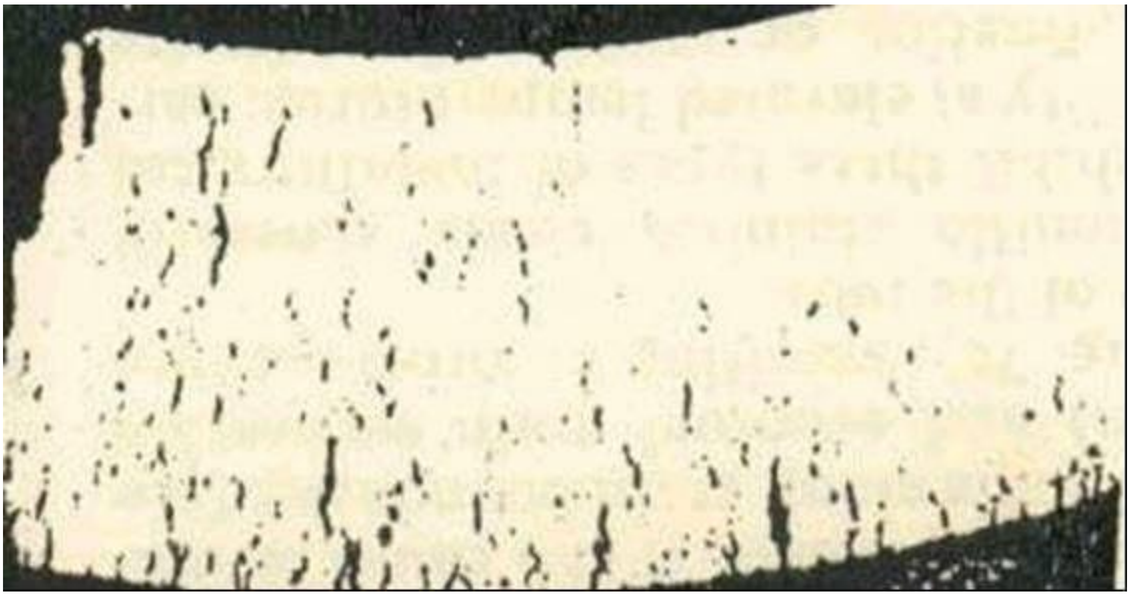


**Fig. 3** Extensive transvers cracking a adjacent to the main fracture.

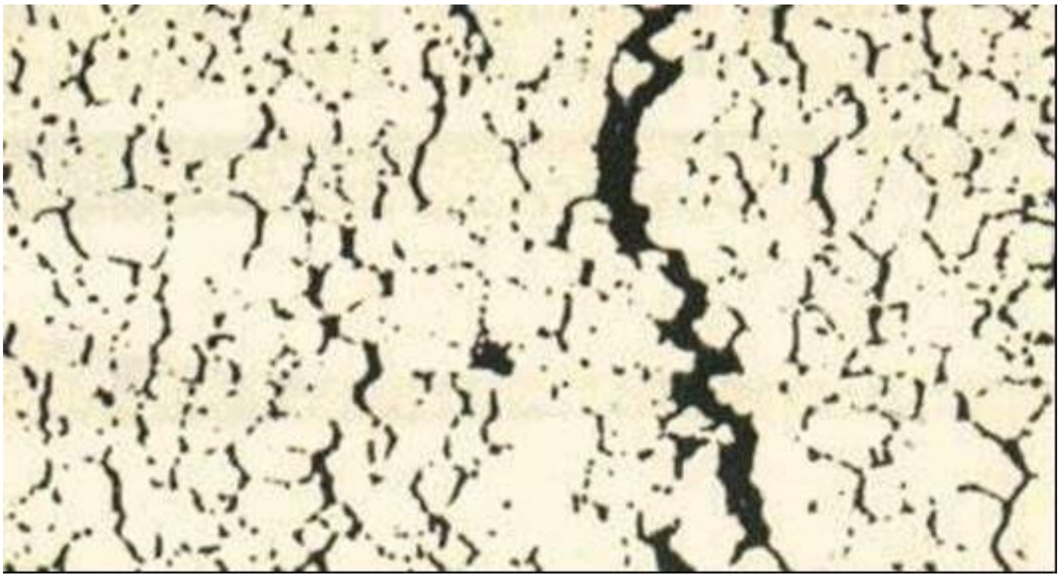


**Fig.4** Intergranular nature of cracking for etched specimen electrolytically in 60% $HNO_3$**.**

Thin lip fracture (Fig.2) usually are Tran granular tensile fracture , occurring at metal temperature from 650-870 $C^0$ ( 1200-1600 $F^0$ ){ Islam & Riad, 1989} . A tensile fracture results from rapid overheating to a temperature considerably a above the working temperature . This fracture is accompanied by considerable swelling of the tube in the region adjacent to the rupture that, have been exposed to the highest temperature.

Some times steam escaping at high velocity through the rupture will impose a reaction force in the tube sufficient to bend it laterally { Jackson,1980}. As a result of later bending , the tube- wall is thinning adjacent to the failure and appear as a knife-edge. This rupture exhibits as a (cobra) appearance ( Fig.5).

Thinning also occurs in areas of swelling adjacent to rupture. The tube wall was 67% as thick as it was opposite the rupture, where the tube was shielded from exposure to hot gas.

**Fig. 5** The fracture exhibits {Cobra } appearance

Visual examination revealed noticeable swelling and high oxidation was visible. Thick black oxide scales deposited on the steam- side surface face of the tube and brown oxide scale formed on the fire-side surface. Analyses by X-ray diffraction ( Fig. 6 ) identified that the oxide scales deposited on the steam side surface is composed of iron oxide ( $Fe_3O_4$) while the scales on fire-side surface contains haemetite and wustite. The major constituent in the black deposits was mixed with complex structure of thenardite ($Na_2SO_4$, Glauberite { $Na_2Ca(SO_4)_3$ and Gypsum ( $CaSO_4.2H_2O$) .

Fig.7 indicates that iron hydroxide forms due to interaction between the OH produced by the cathodic reaction and the corrosion product. This is further oxidized by the dissolved oxygen in the solution to $Fe(OH)_3$. $Fe_3O_4$ .$Fe_2O_3$. and other oxides. This { rust } rims grows in the form of a tube as shown in Fig.7.

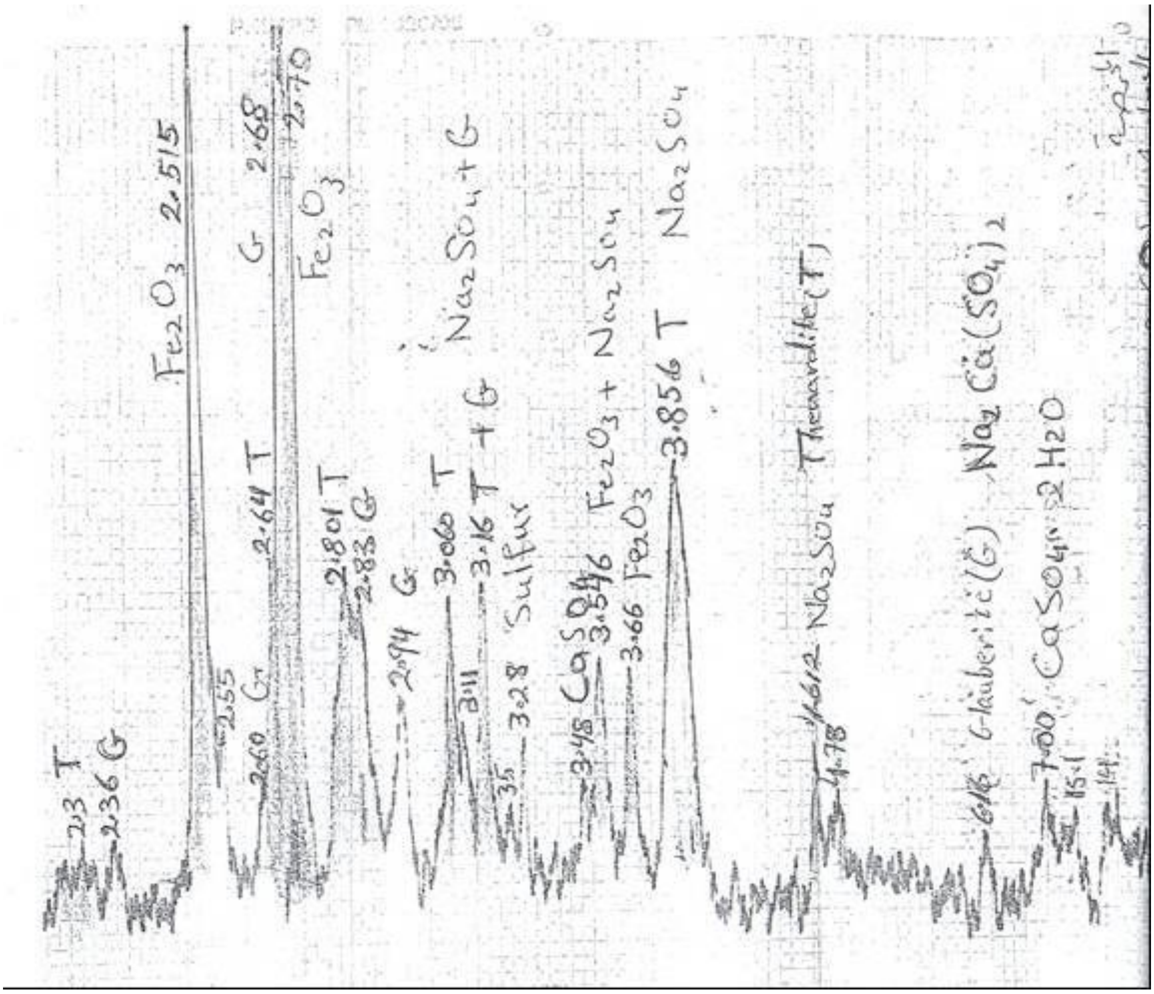



**Fig. 6** X-ray diffraction of surface deposits.

The outer surfaces of all of the tubing exhibited a general oxidized condition. The inner surfaces were covered with an evenly distributed thin tightly adherent scale. The nature and extent of the scale did not suggest that, it was a contributory factor in the failure.

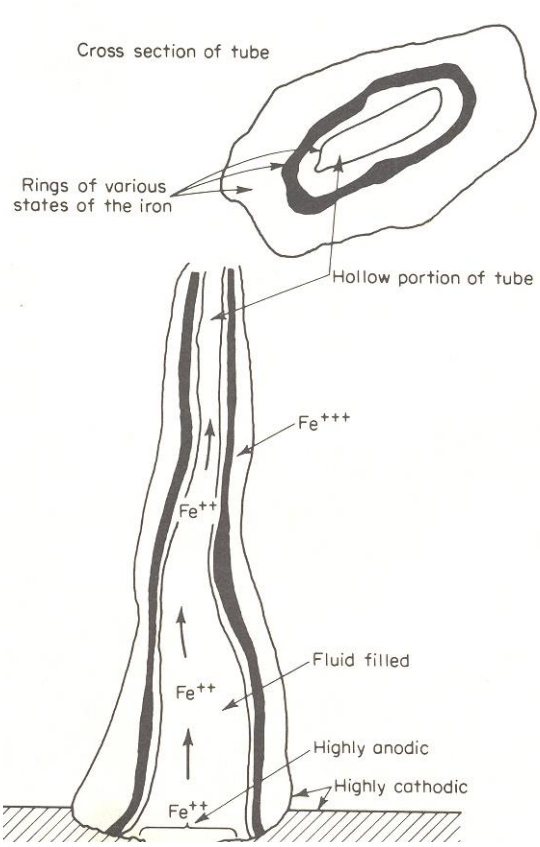



**Fig.7** Corrosion tube growth mechanism **{** Fontana & Greene,1987)**.**

Polished & natal – etched specimens of the metal in the both rupture and unruptured tubes were examined metallographically . The microstructure near the failure edge consisted of a considerable a mount of martensite or bainite in a ferrite matrix as shown in Fig.8. There were no indications of a cold worked structure in this area but there were good a appearances of localized corrosion . Hardness of the metal in this area was 187-197 Hv.. The microstructure and the present of corrosion indicated that a temperature had been reached in some areas to localized overheating (above the transmation temperature of 727 C° ). When carbon steels were exposed to temperatures above 482 C° but less than the lower critical temperature 723 C° this steel is subjected to spheroidization. The carbides present in the steel in annealed condition are not in their lower energy state and exposure to higher temperature results in the coalescence of these carbides into spheroidal form.

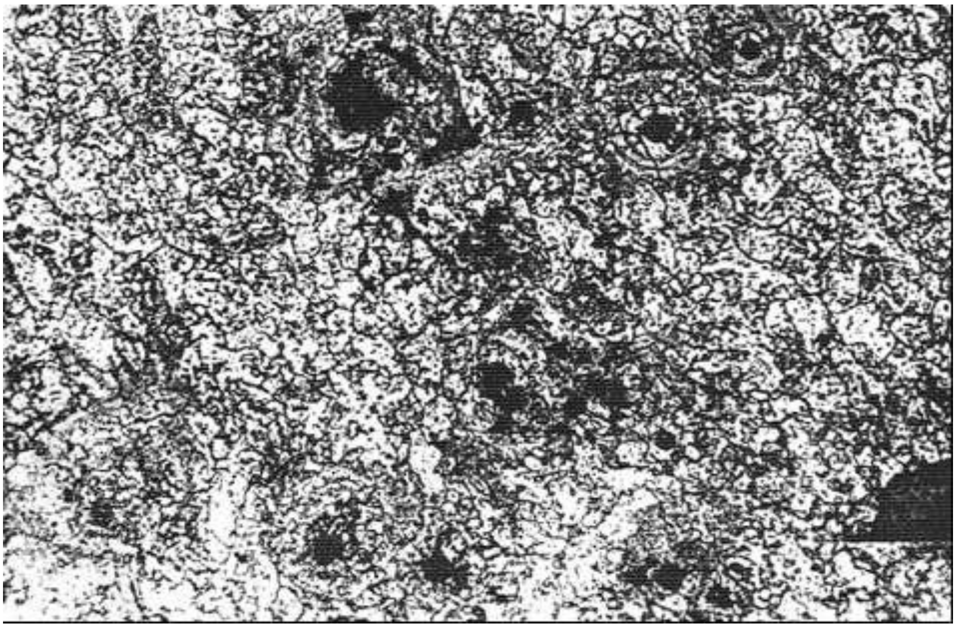


**Fig.8** The microstructure of the metal near the rupture edge**.**

Microscopic studies of cross- section of failure zone of boiler tube show quenched microstructure with small amount of carbides present at the grainboundaries. Other microstructure of failure zone of tube shows coalescence of the carbides into a spheroidal from and elongation of the grains at the end of the knife edge failure opening. wWhen comparing the two microstructures of failed area with unfailed area of tube , the former appears as quenched overheated microstructures. This shows that the exposure temperatures of the above failed areas have exceeded the lower critical temperature and were exposed to this temperature for quite long time.

Examination of the microstructure opposite the rupture revealed a lesser a mount of lower transformation products an indication that, the max. temperature was lower in this area of the tube than the rupture area , but still was higher than 727 C° . The microstructure of the metal about (25-40) mm from the rupture edge revealed some , randomly located areas of acicular cementite in a ferrite matrix and some of corrosion areas (Fig.9). Hardness of the metal in this area was 165-170 Hv.

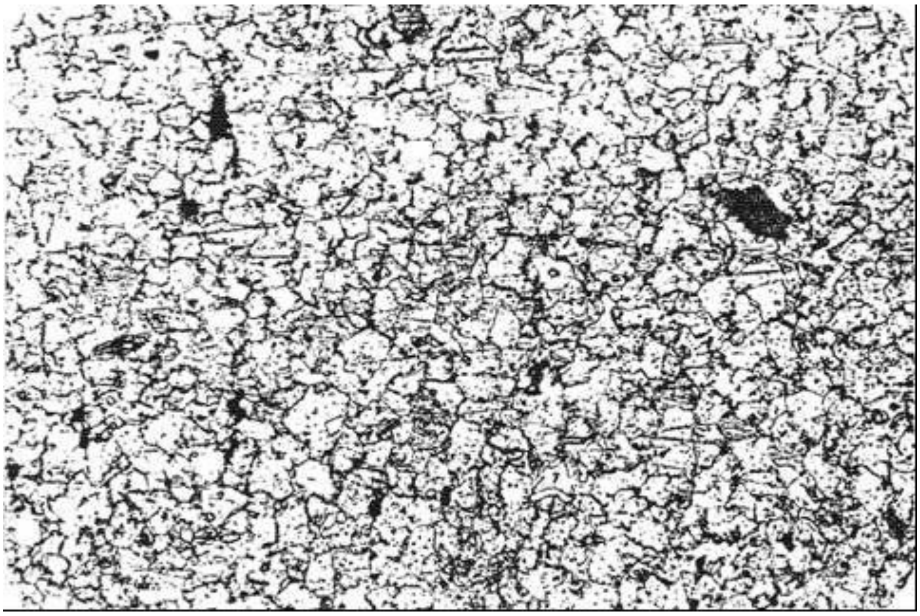


**Fig.9** The microstructure of the metal a bout 25 mm from the rupture edge**.**

The microstructure of the metal about (40-60) mm from the rupture edge revealed the same microstructure of one of the unruptured tubes ( Fig.10) which revealed a considerable a mount of cementite in a ferrite- pearlite matrix. Hardness of the metal in this area was 160-165 Hv. But the other unruptured tube had a structure of spheroidzed carbide in a ferrite matrix with 160 hardness of Vickers.

The microstructure of the ruptured tube indicated that, the metal had been heated above 727 C° .{Ludwing Hohenberger 2005} **.**

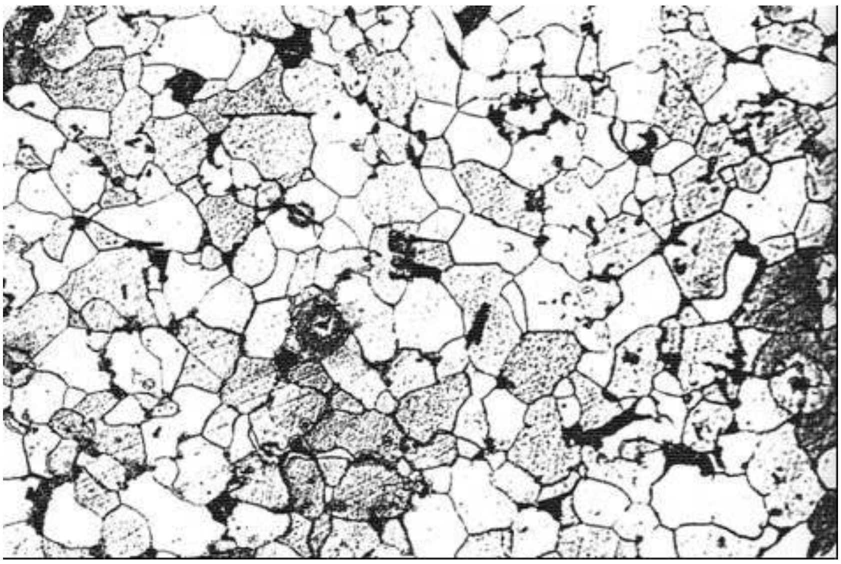


**Fig. 10** The microstructure of the metal of unruptured tube**.**

Rapid overheating of boiler tubes usually results in failure because of a decrease in yield strength . If rupture occurs at a temperature below the crystallization temperature ,microstructure will exhibit severely elongated grains (as shown in Fig.11).

Rupture that, occurs at temperature between AC1 and AC3 may exhibit a mixed microstructure of ferrite & upper transformation products { Pearlite & Bainite} resulting from the quenching effect of escaping water or steam on the partly austenitic structure existing at the instant of rupture.


**Fig.11** Elongated structure near tensile rupture resulting from rapid overheating below the crystallization temperature.

The micro structural evidence of overheating in the area of rupture is conclusive proof that, overheating occurred in service.

## Conclusions

1- Short- term overheating will occur when flow is restricted or blocked by :

a- internal tube corrosion products, deposits or other foreign materials which act as insulators.

b- an- interruption of flow.

c-increasing the tube temperature rapidly.

d- the tube metal stretches rapidly from internal pressure & rupture producing a wide mouth failure.

e- steam & water gushes out of the rupture quenching the over heated tube metal.

2- Long- term overheating will occur due to:

a- design or operating conditions temperature become moderately excessive for a signification period of time.

b- increases the tube temperature & the tube begins to deform and failure eventually occurs.

c- continuous of frequent exposure to temperatures higher than design**.**

**3-** Visual examination revealed noticeable swelling and high oxidation was visible. Black deposits mixed with complex structure of thenardite ($Na_2SO_4$, Glauberite { $Na_2Ca(SO_4)_3$ and Gypsum ( $CaSO_4.2H_2O$) . Iron hydroxide forms due to interaction between the OH produced by the cathodic reaction and the corrosion product. This is further oxidized by the dissolved oxygen in the solution to $Fe(OH)_3$. $Fe_3O4$ .$Fe_2O_3$**.**

**4-** The microstructure near the failure edge consisted of a considerable a mount of martensite or bainite in a ferrite matrix. Hardness of the metal in this area was 187-197 Hv..

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