POWER PLANT COMPONENT FAILURES INVESTIGATION AND REMEDIAL MEASURES

U.C.BHAKTA

RESEARCH AND DEVELOPMENT CENTRE
NATIONAL THERMAL POWER CORPORATION LIMITED
A-8-A, SECTOR-24, NOIDA - 201 301 (U.P.)

SUMMARY

This paper covers the reasons and remedial measures of various failed components of boiler, turbine and generators in Utility Power plants of NTPC and SEB's. Boiler tube failures are mainly due to salt deposition leading to long term overheating, stress corrosion cracking and corrosion fatigue. The factors influencing the accumulation of salts onto internal surfaces of water wall, super heater tubes have been discussed in detail. The steam turbine blades, generator retaining rings, feed water heater tubes and condenser tubes have been found to suffer due to stress corrosion cracking , corrosion fatigue , pitting corrosion and crevice corrosion. Photographs of failed components and brief discussions have been given in the paper.

CORROSION MECHANISM OF WATER WALL

The water wall made of mild steel corrodes very slowly in pure water or deoxygenated alkaline solution at boiler temperature (Figure-I.) The normal corrosion product is magnetite which forms a protective film over the steel surfaces by following reaction.

$3\,Fe + 4\,H_2O$ ------- $Fe_3O_4 + 4\,H_2$

This is the usual situation in an operating boiler. The corrosion rate decreaes with time and even after years of operation, the protective magnetite film is no more than a few micron thick.

On load corrosion results from the local formation of concentrated alkaline or acidic solution at metal surface. In either case, corrosion rates of over 1 um/day are possible at 300 C and are several times higher 50 um/day at 400 C. These rates do not deminish with time even though layers of magnetite may be produced very thick. The magnetite formed in these condition is non protective. The salt concentration increase due to ingress or raw/cooling water into the feed water due to condenser leakage which deposited on the internal surface due to wick boiling phenomenon as shown in figure 1a. The salts are concentrated due to non porous in nature of internal oxide which produce the localised high/low pH. Due to the increase in the thickness of internal oxide, the temperature of steel increases due to decrease in heat transfer as shown in figure II. Frequent tube failures at our new stations have not been observed. The tube analysis reveals that it had the internal oxide thickness more than 200 microns as shown in photograph no.1. The tube swelling due to overheating can be seen in water wall tubes as shown in photograph No.2 a. A case of graphatisation has also been observed in 60 MW boiler Thermal unit in water wall as shown in the polished sample in photograph No.2b.

Microstructure of the water wall tube indicates the spherodisation in 60 MW shown in Photograph No.3. Oxide deposition has also been observed in all the units of 100/210 MW water wall tubes. Internal surface of a water wall tube of 60 MW unit of one station of SEB's shown in photograph No.4. Water wall tube thinning from the water side. It has been observed as shown in the Figure-III and overheating of these tubes has been observed.

Steam blanketing can also result in tube failure for two reasons. Steam is a poor heat transfer media when compared to water or a mixture of water/steam. Accordingly high metal temperature results in high heat flux area. Also the porous oxide layer also increase the rate of steam blanketing. Blanketing can result from the separation of steam and water by gravity, centrifugal force or irregular flow. Boiler tube welds can often cause blanketing. Welds can upset the steam /water flow and result in the formation of deposit down steam of the weld which can lead to overheating, steam blanketing and severe corrosion. Effect of internal oxide thickness in water wall tube on the increase of tube metal temperature has been given in the Figure-IV at different heat flux.

CORROSION BY A ACIDIC SOLUTION

Solution of low pH may be generated in boiler into different ways.

1. pH of the entire water is reduced when contaminants which are acidic or which becomes acidic when heated enter the boiler.

2. The bulk boiler water remains alkaline but acidic solutions are generated within corrosion pits by the action of dissolved oxygen and chloride. The most common acid forming contaminants is sea water or a river water low in carbonate & sulphate. In the boiler, the acidity increased locally to corrosive concentrations by boiling. The acidic corrosion may occur almost anywhere, where boiling is taking place.

When a boiler is contaminated with dissolved oxygen and chloride in neutral or alkaline water, the protective oxide film may break down locally where oxygen is depleted and the metal becomes anodic to the surrounding surface. The dissolution of iron given ferrous chloride which hydrolyes to give an acidic solution as shown in Figure-V. An example of acidic corrosion has been seen in the 210 MW water wall tube as shown in photograph No.5. In this water wall, tube, the tube failed due to formation of localised acidic conditions and pit.

Hydrogen embrittlement mechanism is observed in some of the boiler of SEB's and 100 MW boiler of NTPC. Hydrogen embrittlement can takes place under high heat input conditions. Hydrogen gas formation often occurs under hard, dense deposits where high temp, and high chemical concentration condition exit.

Atomic hydrogen generates during the corrosion mechanism which enters the metal. It reacts with carbon in the steel to form methane gas. The decarburisation weakens the steel while trapped methane gas exerts pressure.

$3\ Fe + 4\ H_2O$ ----------- $Fe_3\ O_4 + 4\ H_2$

Concentrated caustic also generate hydrogen which enters the solution.

$4\ NaOH + Fe_3O_4$ --------- $2\ NaFeO_2 + Na_2FeO_2 + 2\ H_2O$

with the protective magenetite removed the caustic than reacts with iron as follows :-

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

Hydrogen embrittlement of boiler tubes is oftgen characterised by a detachment of portion of the tube. This type of fracture is often called a "Window" fracture which has been observed in 200 MW boiler as shown in photograph No.6. Microstructure of 100 MW, water wall failed tube shows the presence of cracks inside the metals as seen in Photograph No.7.

3. CORROSION BY ALKALINE SOLUTION

Boiler water may contain dilute alkali because of alkaline nature of boiler water or because of inleakage of untreated water which is, or becomes, alkaline when heated as shown in Fig. VI. A high degree of local concentration is necessary to lead to alkaline corrosion, for example, if the bulk water contains 2 ppm of NaOH, a very high concentrating factor is needed to form dangerously high concentration of 20% NaOH. This requirement restricts corrosion due to concentrated alkaline solution to specific location in a boiler where concentration can occur to a high degree, for example, at a steam blanket. Since the corrosion product formed in alkaline solutions in poorly adherent.

The typical example of caustic corrosion is shown in Photograph No.8 observed in 60 MW boiler. The most common type of caustic corrosion is caustic gouging which is generally found in high pressure boilers. A buildup of black iron oxide is found beneath the deposit in the vicinity of caustic attack when exposed to the atmosphere, it turns into white substance of sodium carbonate due to conversion of sodium hydroxide with the reaction of atmospheric carbon dioxide. This phenomenon has been observed in 60 MW station where the heavy condenser leakage was responsible for caustic gouging. This phenomenon is also found in high heat transfer area where the poor circulation aggravate the condition.

One type of shallow gouging occurs under the departure from nucleate boiling (DNB). During nucleate boiling; steam bubbles form a distinct points on the metal surface. As the steam bubbles leave the surface, additional water washes the surface clean. However, as the steaming rate is further increased, the bubbles form faster than the surface can be washed. As a result, the concentration of salts at that particular surface increases and caustic corrosion can results in. As the steaming rate further increases, a stable steam blanket develops and gouging gives optical shape along the edges of the blanket.

STRESS CORROSION CRACKING

Several cases of superheater & reheater tube failures by caustic & chloride stress corrosion cracking (SCC) in 210 MW & 500 MW Unit boilers in NTPC Stations have been received. These tubes 304H & 347H grade austinitic stainless steels failed mainly at bends. The metallographic & SEM examinations revealed the characteristic features of SCC (Photograph No.11 & 12)

Transgranular & intragranular with bracking. These were caused by ingrace of chlorde & hardness in cooling water through condenser tube corrosion.

At one power station, several cases of trangranular SCC were found in a particular zone. Spool pieces of final superheater coils. That boiler gave problems just after commissioning of the unit. After detailed investigation it was established that tube was not cleaned before welding the spool pieces. Another source of chloride where failure occured after several years of operation was condenser tube leakages.

SCC of steam turbine blades in 110 MW & end retaining ring of 210 MW generator rotor were also investigated. Several cases of low pressure heater & condenser tubes have suffered due to SCC. (Photograph No. 12 & 13).

CORROSION FATIGUE

Corrosion fatigue, cases of boiler Tubes are received mainly from water wall regions and a few cases of LP turbine blades & lacing wires have also been analysed at the R&D Centre.

Metallographic examinations show the cracks to be transgranular, usually filled with oxide and relatively wide and blunt. They always initiate on the waterside surfaces and propagate outwards.

It is strongly influenced by number of Unit starts & operating hours & chemical cleanliness. Water chemistry and oxygen play a major factor: a two-orders-of-magnitude increase in dissolved oxygen, which is typical during boiler start-up, can lead to an order of magnitude reduction in the number of thermal (strain) cycles required to initiate corrosion fatigue cracks(Figure 7)

CONCLUSIONS

Failure investigation study of different capacity boiler indicated that the main reason of tube failures are :-

1. over heating due to oxide growth on the internal surface of tube.

2. Localized formation of alkaline/acidic condition due to ingress of cooling water into the feed water.

3. Use of less corrosion resistant materials in heaters -
   Steam Super heater & feed water heater -
   & Condenser tubes.

REMEDIAL MEASURES

1. To reduce the tube failure because of above said reasons, it is suggested to control the ingress of raw water from the condenser tube leakage which leads to salt concentration on to surface of tubes & turbine blades.

2. If the Internal Oxide growth increases from the limit as per the Indian standards IS-10391-82 as shown in the figure-VII, Post operational chemical cleaning of boilers should be recommended which would remove the existing porous oxide layer and form a new adherent magnetite layer and reduce the possibilities of on-load corrosion & overheating.

3. Use of better materials & Stress relieving reduces the SCC problems in tubes.

RELATIONSHIP OF ANALYSED DEPOSIT QUANTITY TO UNIT CLEANLINESS

Boiler type	Clean Surface mg/cm/um	Moderately Dirty Surface	Very Dirty Surface mg/cm/um
Super Critical Units > 220 kg/cm2	< 15 < 30	15-25/30-50	> 25/>50
Sub Critical Units	<15/<30	15-30/30-60	> 40/>80
< 100-150 150 Kg/cm2			

Remarks : The values are measured on the Furnace side of the tube samples and include soft and hard deposit.

ACKNOWLEDGEMENTS

The authors is thankful to Dr.P.Jain and Shri A.K.Sinha, Sr.Manager(R&D) for their technical supports and help provided during investigation. We wish to thank to Mr.I.Gaurishankar, Sr.Manager(R&D) Metallurtgy Group for the help rendered by his group in metallographic examination, Mr.Nagrajan for determination of average internal oxide thickness as per ASTM standard and Mr.Lalit Kumar Alreja for typing of this paper. The contributions of our colleagues who helped directly or indirectly to this work are greatfully acknowledged.

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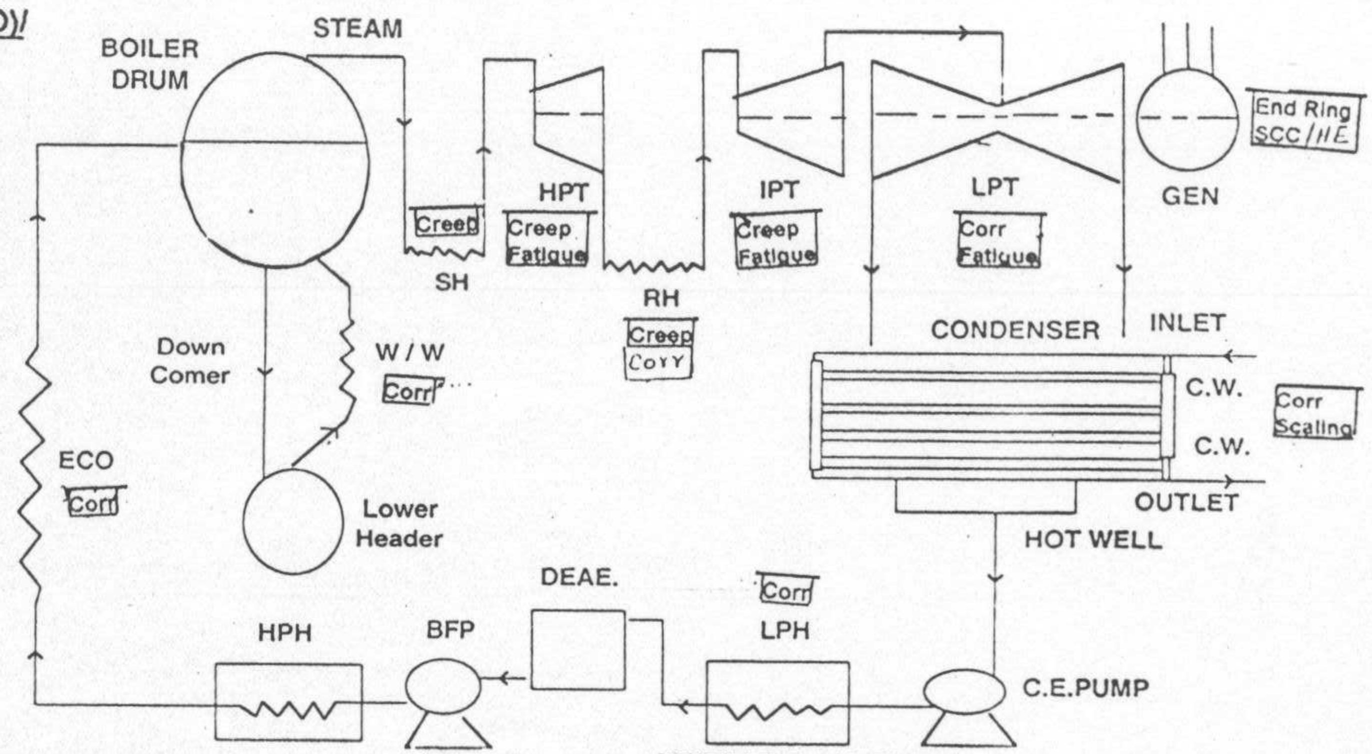

SUPERHEATERS	–	(Cr/Mo. AND AUSTENITIC ALLOYS) NaOH AND NaCl STRESS CORROSION
REHEATERS	–	(MILD STEEL, Cr/Mo AND AUSTENITIC ALLOYS) SALT DEPOSITION, CO_2 INGRESS STRESS CORROSION. OFF-LOAD PITTING CORROSION (Na SO_4 + O_2)
TURBINES	–	(Cr/Mo/V ALLOYS) NaOH/NaCl/Na_2 SO_4/ORGANIC ACIDS/CO_2 SHAFT/DISC STRESS CORROSION CRACKING AND BLADE SHIELD CREVICE CORROSION, SiO_2/Fe/Cu/PO_4 BLADE DEPOSITION
CONDENSER	–	(MAINLY CU-NI) NH_3 ATTACK AIR EXTENSION ZONE
	-	**AUSTINITIC ALLOYS, PITTING & CREVICE CORR**

Fig. 1. MATERIALS & FAILURE MECHANISMS OF VARIOUS COMPONENTS IN A POWER PLANT.

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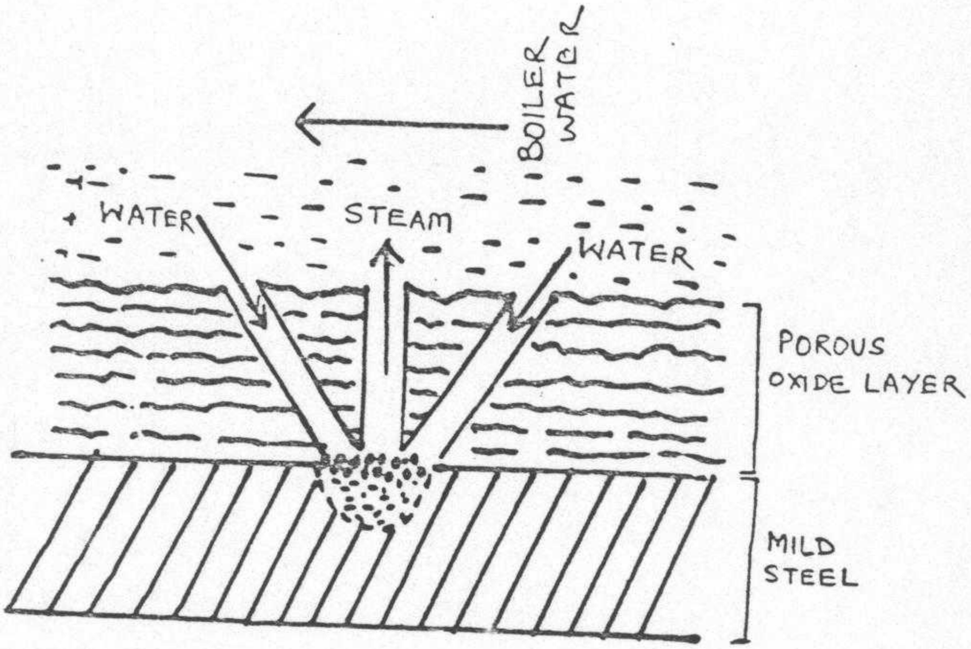


Figure-I Mechanism of Salt Concentration by Wick Boiling Phenomenon Inside the Internal Deposit
1(a)

OVERHEATING OF WATERWALL TUBE DUE TO INTERNAL OXIDE DEPOSITION

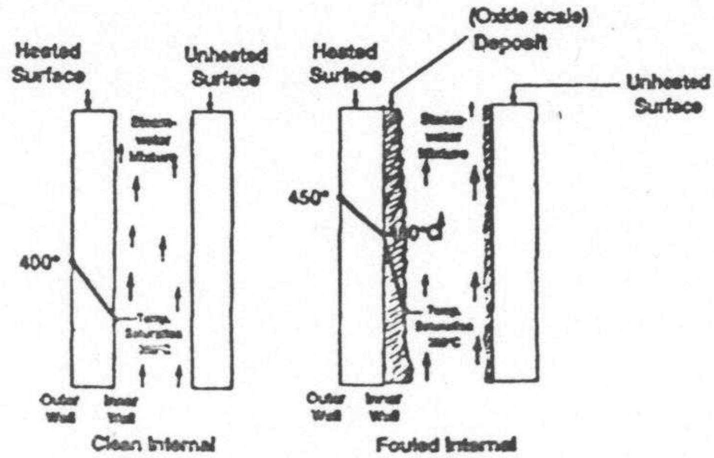


Figure-II: Overheating of Waterwall tube Due to Increase of the Internal Oxide layer

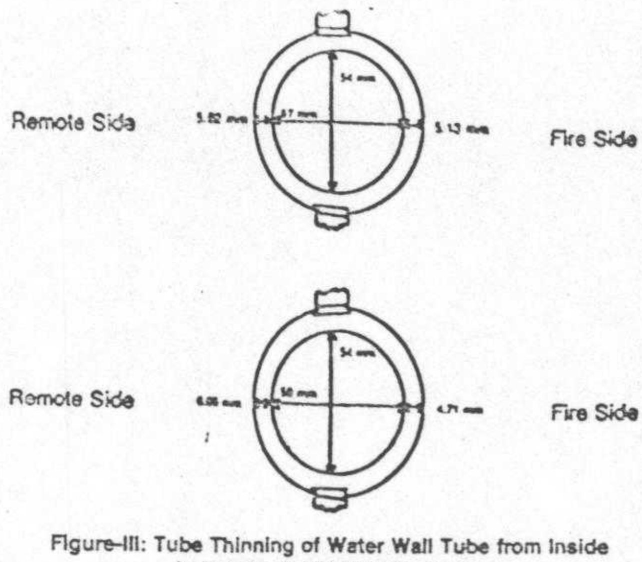


Figure-III: Tube Thinning of Water Wall Tube from Inside
In Unit No.4, 210 MW, Badarpur

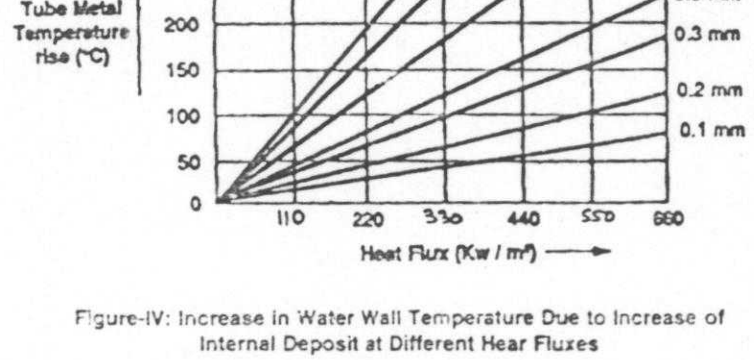
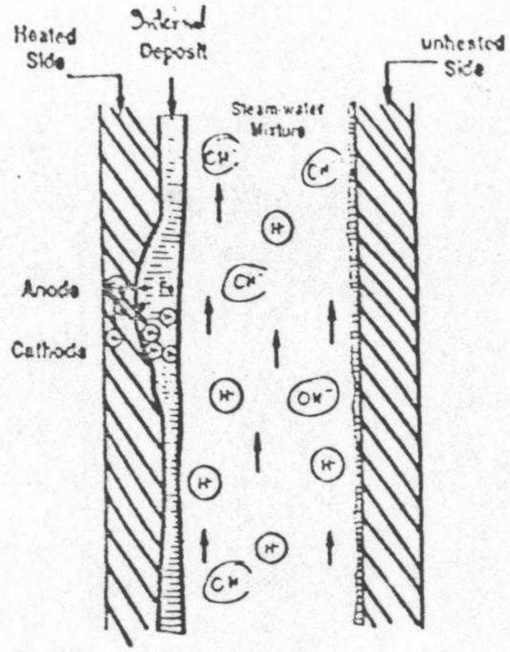


Figure-IV: Increase in Water Wall Temperature Due to Increase of
Internal Deposit at Different Hear Fluxes



Anode — $Fe^{0} \longrightarrow Fe^{++} + 2e^{-}$

Cathode — $2H^{+} + 2e^{-} \longrightarrow 2H^{0} \longrightarrow H_2$

Figure-V: Mechanism of Formation of Acidic Condition Inside the Internal Deposit in Water Wall Tube

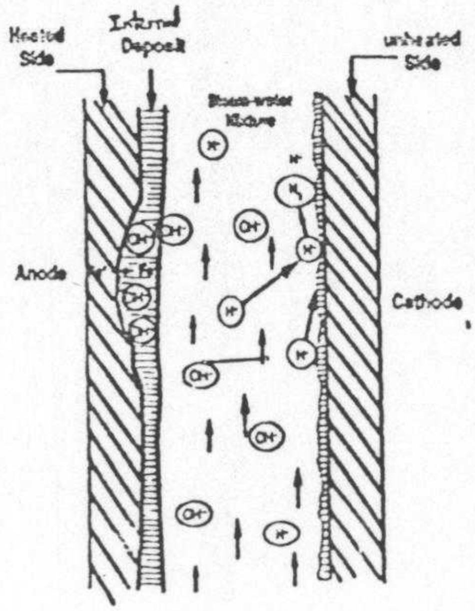


Figure-VI: Mechanism of Formation of Alkaline Condition Inside the Internal Deposit in Water Wall Tube

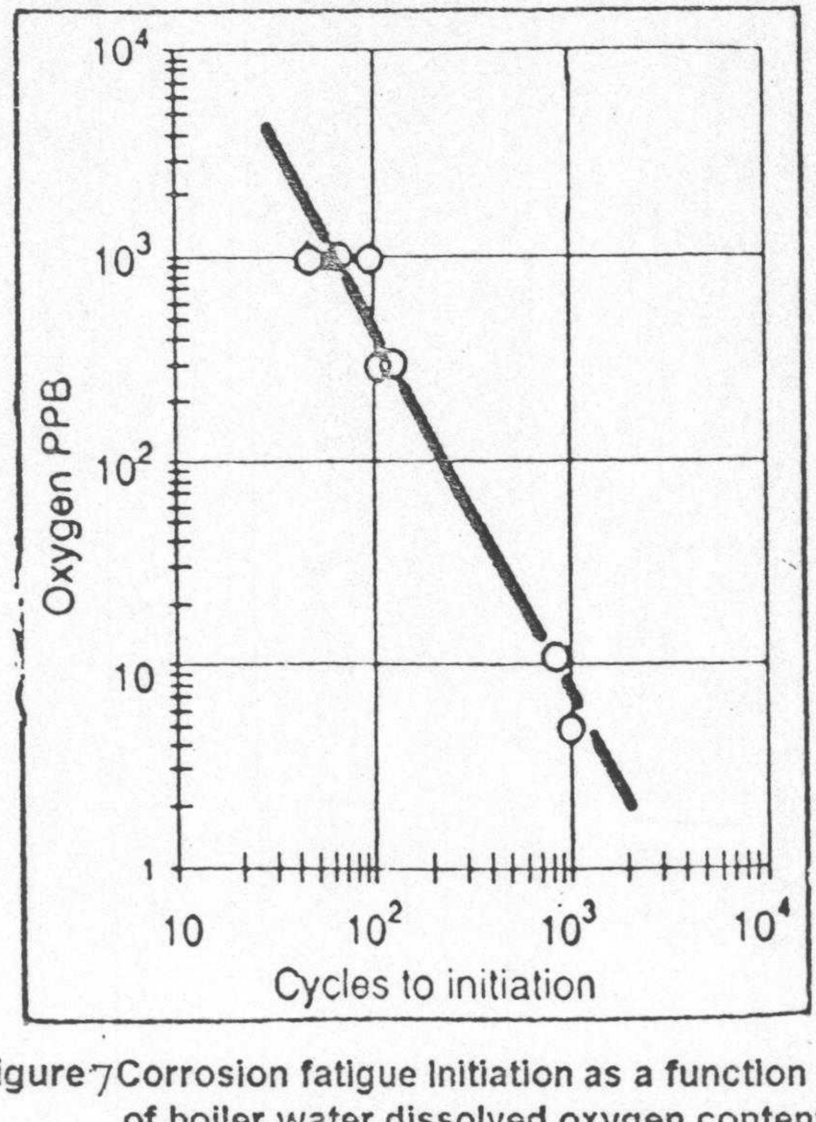
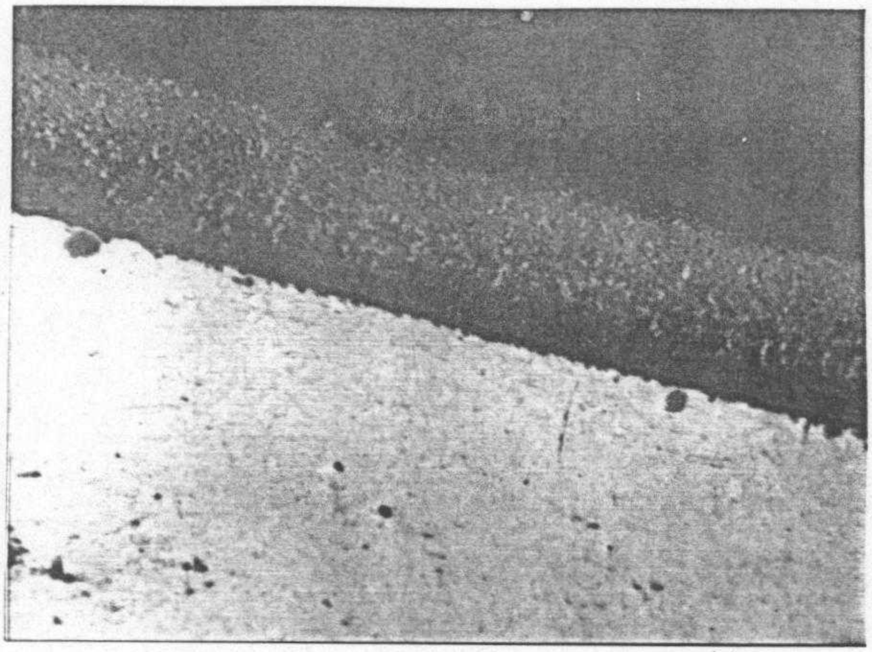
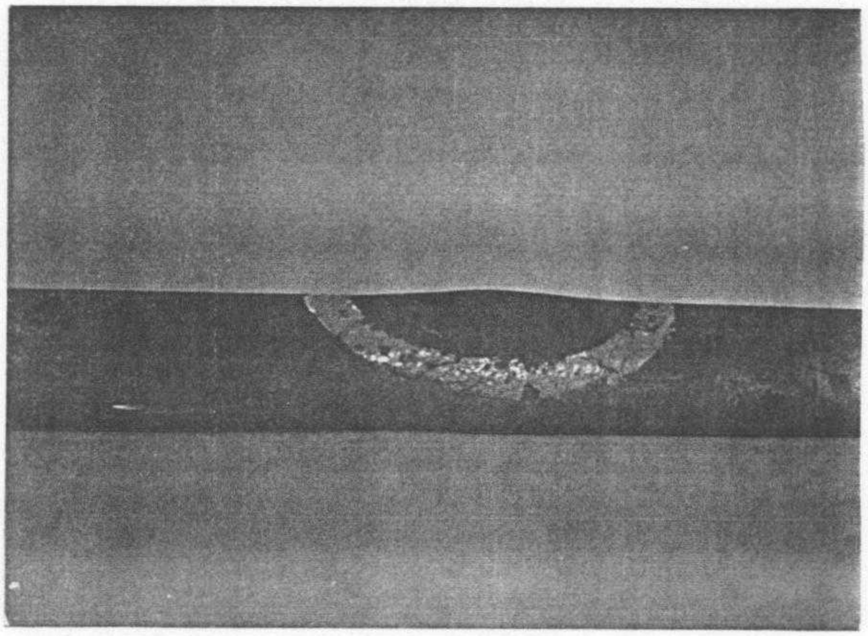


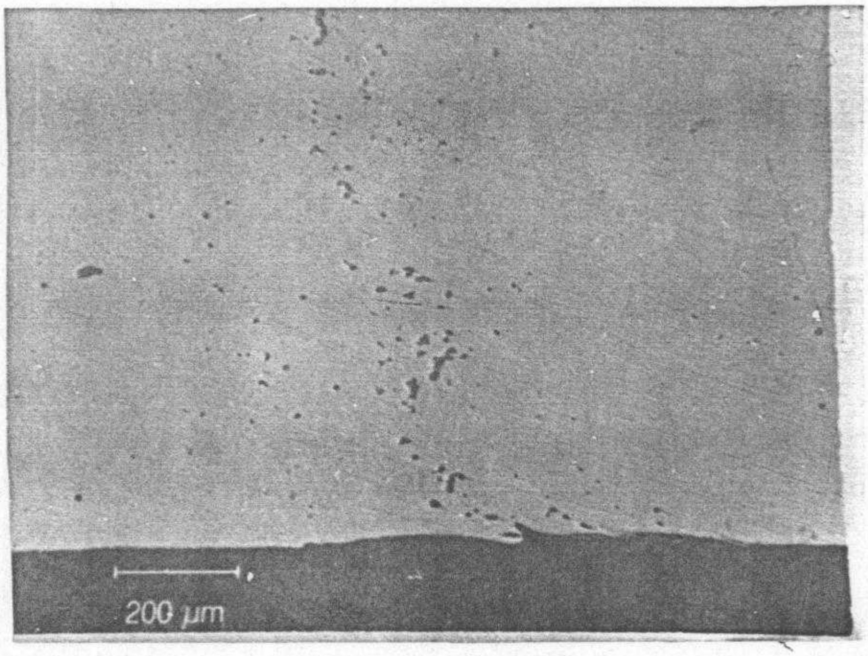
Figure 7 Corrosion fatigue Initiation as a function of boiler water dissolved oxygen content.



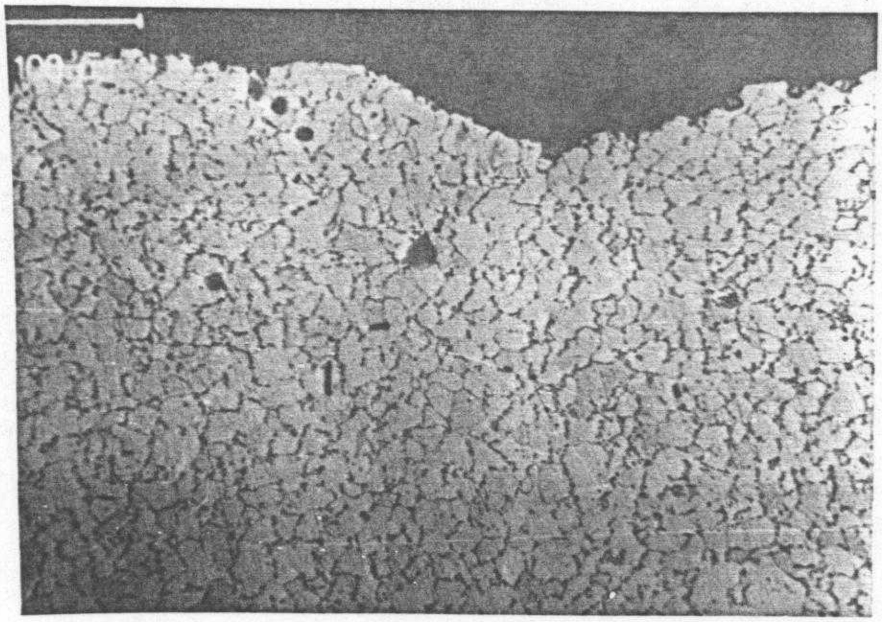
Photograph No.1: Porous, Cracked Internal Oxide Layer having Copper Deposition in Water Wall Tube, 210 MW,



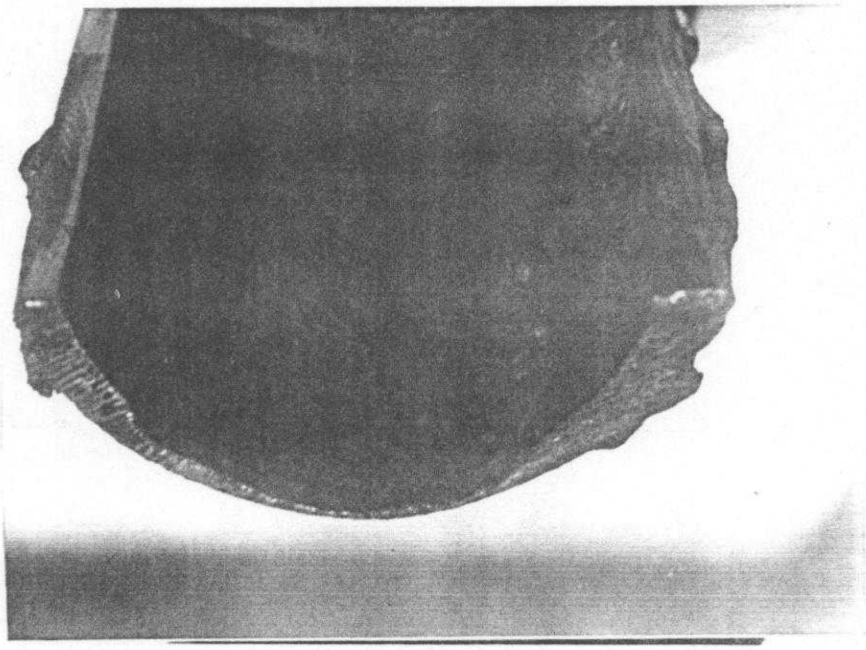
Photograph No.2a: Swelling of Water Wall Tube Due to Overheating Due to Presence of Internal thick Oxide,



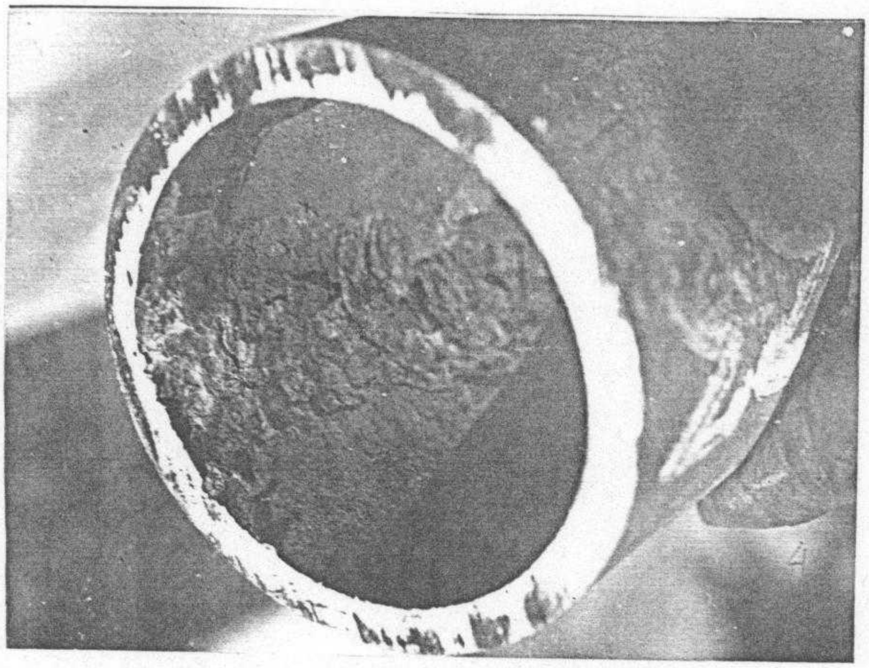
Photograph No.2b: Graphatisation in Water Wall Tube Due to Overheating
Unit No.3, 60[redacted] MW



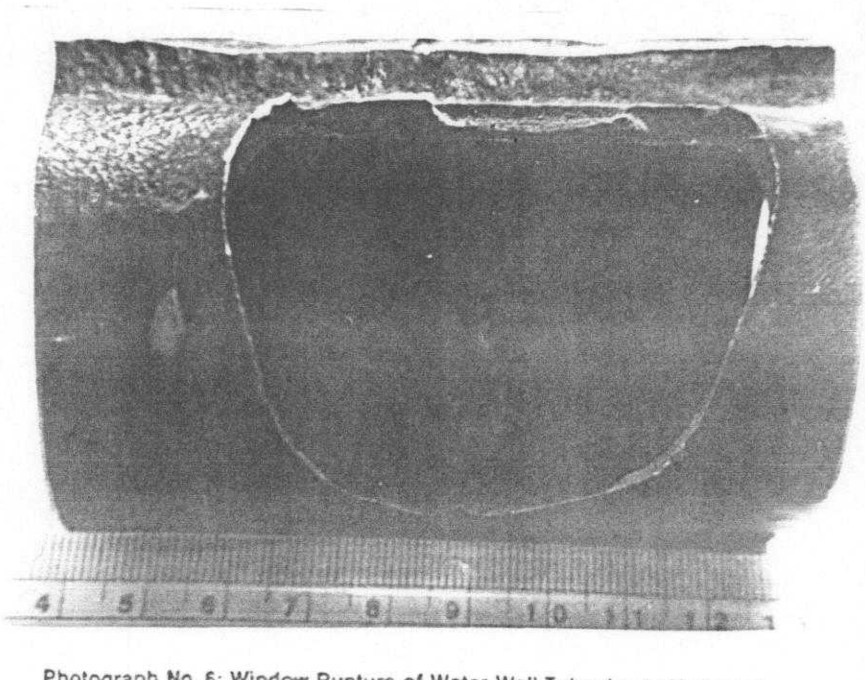
Photohgraph No.3: Microstructure Showing the Spherodisation in Water Wall Tube, Unit No.4, 60 MW.



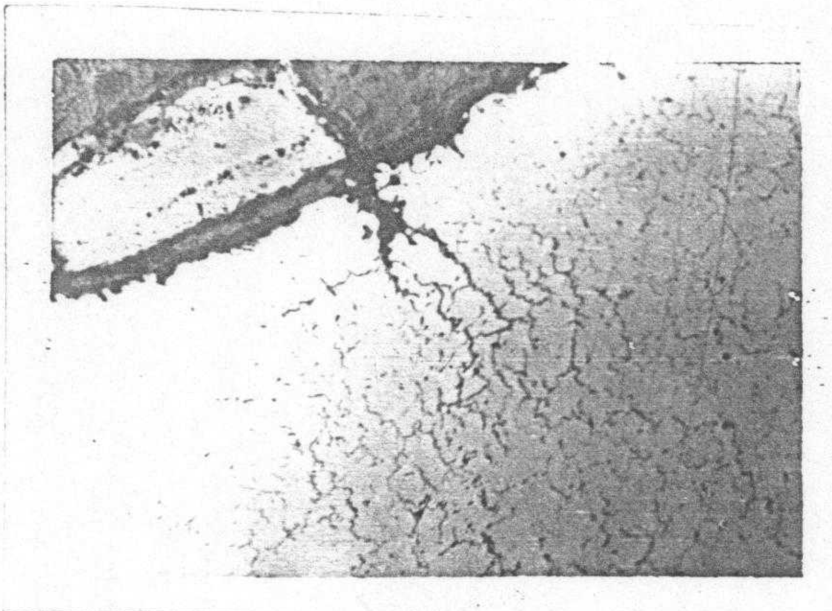
Photograph No.4: Internal Corrosion & deposition on the surface of Water Wall Tube facing flame, Unit-3, 60 MW.



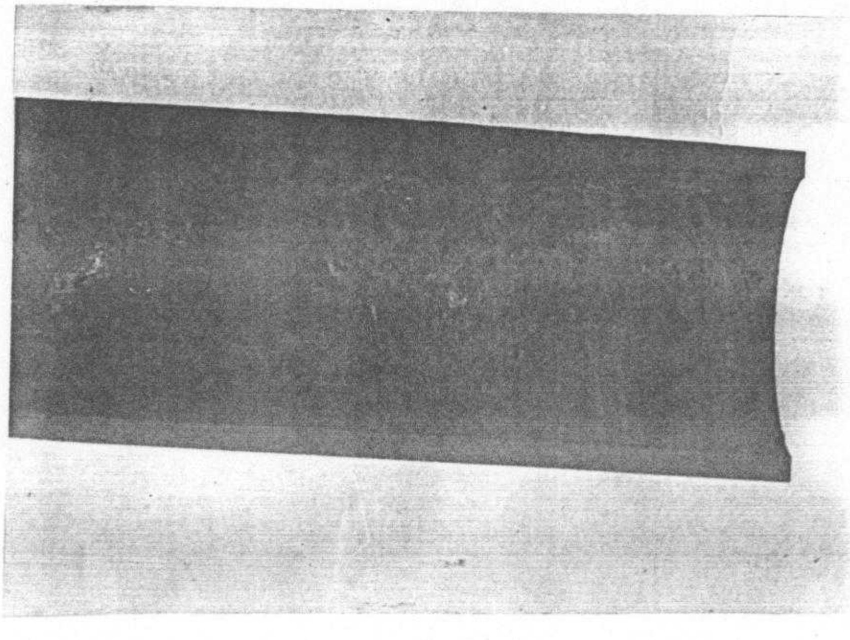
Photograph No.5: Acidic Corrosion Having Hard Adherent Deposit with Puncture, ~~Unit-4,~~ 210 MW,



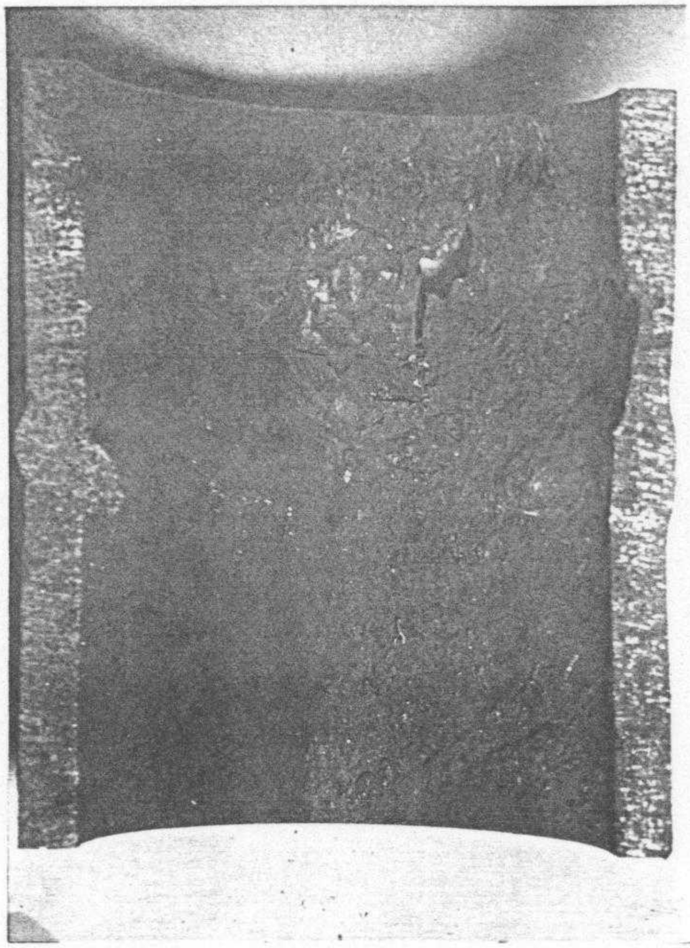
Photograph No. 6: Window Rupture of Water Wall Tube due to Hydrogen Embrittlement, 200 MW, Unit No.



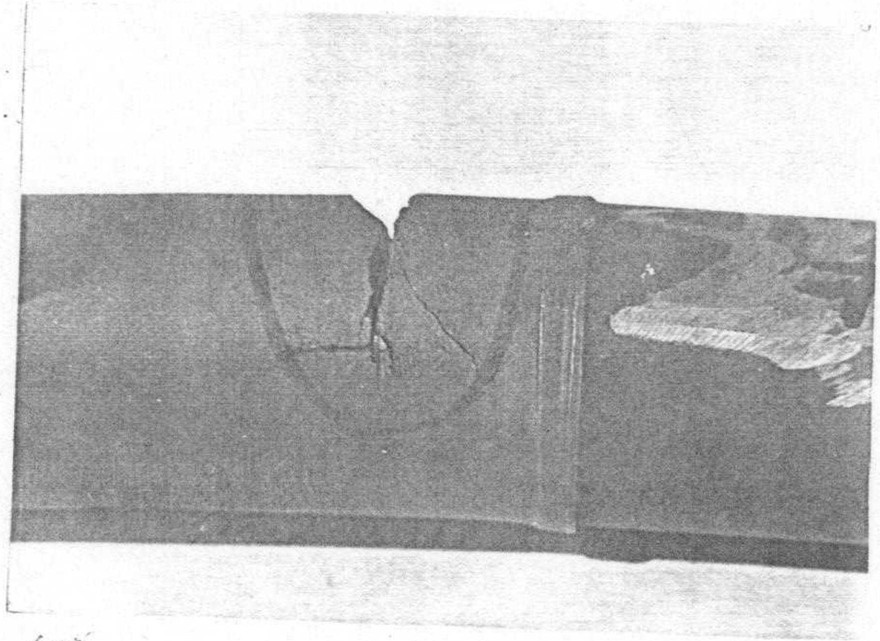
Photograph No. 7: Crack Developed in Side the Water Wall Tube, Failed due to Hydrogen Embrittlement. (100 MW, Unit) ~~No. 1,~~



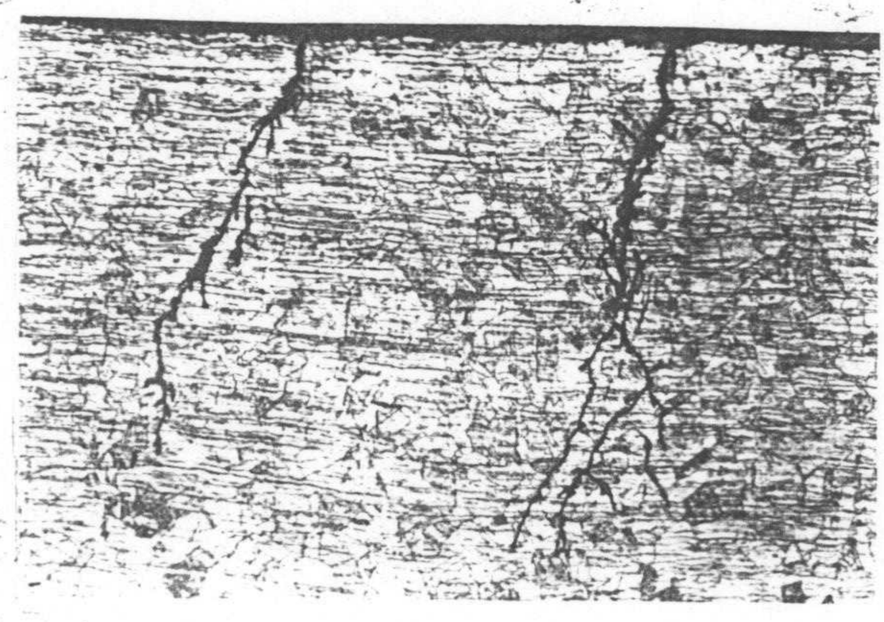
Photograph No. 8: Presence of Caustic Gouging In Water Wall Tube, Unit-2, 60 MW,



Photograph No. 9 : Goughing due to steam Blanketing Near the Welding Zone in Water Wall Tube, Unit-2, 60 MW.



(a)



Phot 10 (b) Transgranular Stress Corrosion Cracking of Stainless Steel Super Heater. 210 MW.

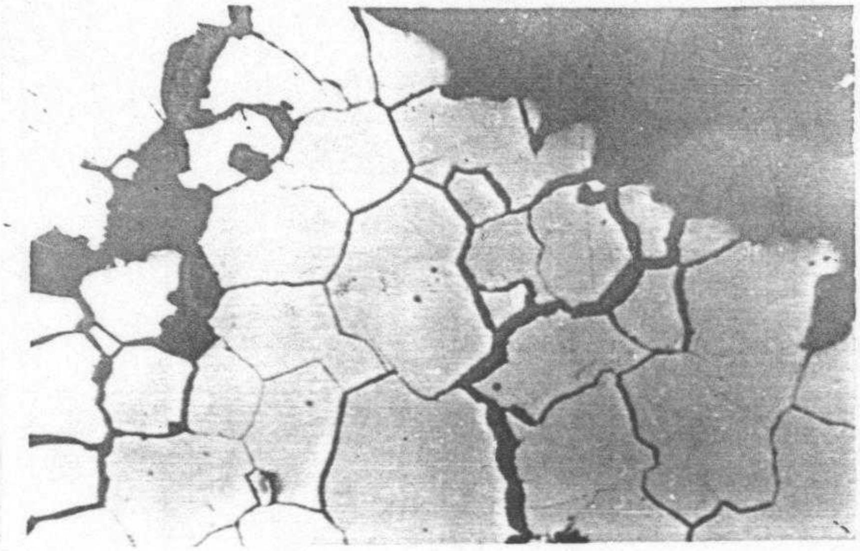
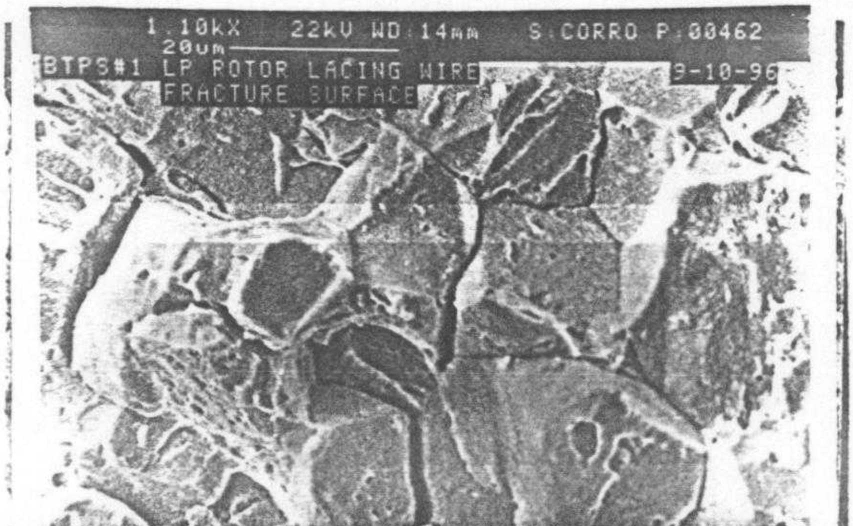


Photo. 11. Intergranular Stress Corrosion Cracking of Reheater Stainless Steel Tubes. 500 MW.



Phot. 12 Stress Corrosion Cracking (Intergranular SCEM) of lacing wire L.P. turbine blades. 110 MW.

Photo.13 Intergranular Stress Corrosion cracking of brass condenser tubes. (210 MW)

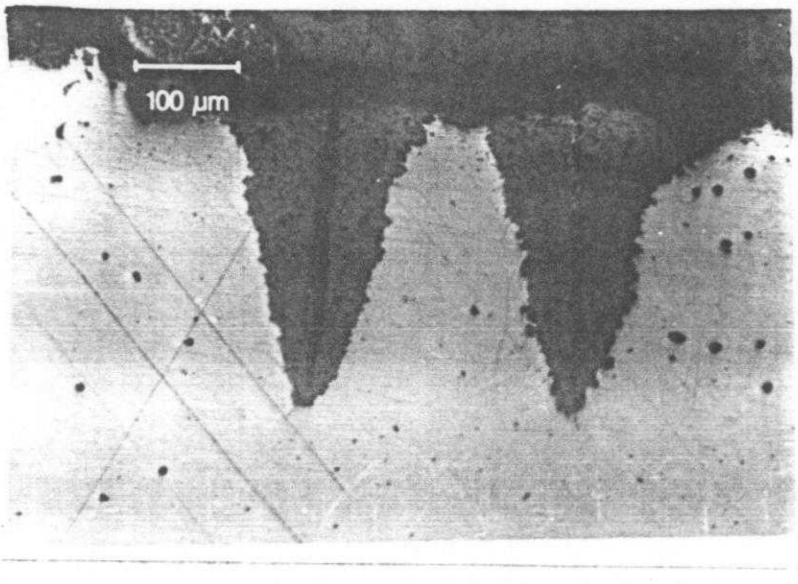


Photo.14. Corrosion fatigue of Water Wall tubes. 210 MW.