Saline Water Conversion Corporation
Saline Water Desalination Research Institute (SWDRI)

MATERIAL SELECTION AND STRESS-INDUCED CORROSION IN DESALINATION AND POWER PLANTS

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INTRODUCTION

Metallic materials such as carbon steels, stainless steels, copper-based alloys and titanium and non-metallics such as polymers, composites and ceramics form the bulk of conventional constructional materials of present day seawater thermal and reverse osmosis desalination plants. Proper materials selection plays a most important role in restricting the physical and chemical deterioration of plant constructional materials, thus prolonging the service life of the high efficiency of the plant as envisaged by the users.

Continued

Stress induced failures in the components occurred as a result of the presence of internal stresses/residual stresses culminating in the so-called stress corrosion cracking (SCC). The stresses generated in dynamic components bring about fatigue failures. The study of stress induced failures forms an integral part of the realm of corrosion investigations on materials. Material selection, operational parameters, environmental conditions and design are some of the important factors that influence the stress induced failures.

Continued

In desalination plants, components like shaft, column and elbows of seawater pumps, valves, gear and other parts are affected by SCC or corrosion fatigue. In power plants, boiler tubes and turbine components show failure either due to SCC or corrosion fatigue or simply failed by mechanical fatigue.

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The stress-induced failure has been quite a familiar phenomenon in desalination and power plants, a considerable number of cases related to stress related failures are reported from various SWCC plants every year.

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In this presentation, five typical cases related to stress failures are discussed in detail. These cases represent typical stress-induced corrosion failures in different SWCC desalination and power plants. An account of the background of the failure, investigation outlines, results, discussions, conclusions and recommendations are included for each case.

SOME CASE STUDIES

CASE - 1

Failure of a Shaft of a Brine Recirculation Pump in MSF Plant

Figure 1. Cracks on the shaft of a brine recircu-lation pump

A case of failure of a shaft of a brine recirculation pump was reported.

Physical Examination

An examination of the damaged shaft revealed two major circumferential cracks passing through the almost entire shaft cross-section, but did not separate into several pieces (Fig. 1).

SHAFT FAILURE

Figure 2. Section of the Shaft showing the cracks. Corrosion is seen on the key slot surface and on the corners

The cracks had occurred near the end of the shaft where it is coupled to the electric motor. Some of the cracks had also passed through the two keys that had been used to assemble the joint between the shaft and coupling (Figure 2).

SHAFT FAILURE

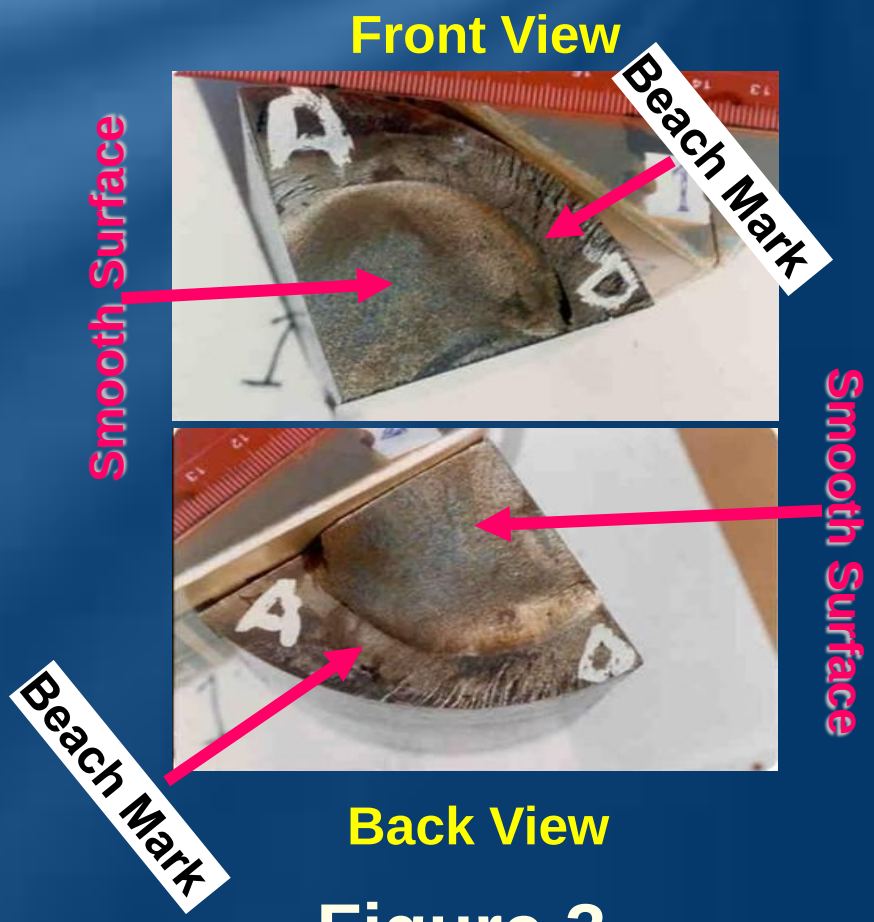


Figure 3

A piece of the damaged shaft was vertically cut into several sections and examined through a stereomicroscope. The fracture surface showed beach marks (Fig.3).

SHAFT FAILURE

Microstructural studies

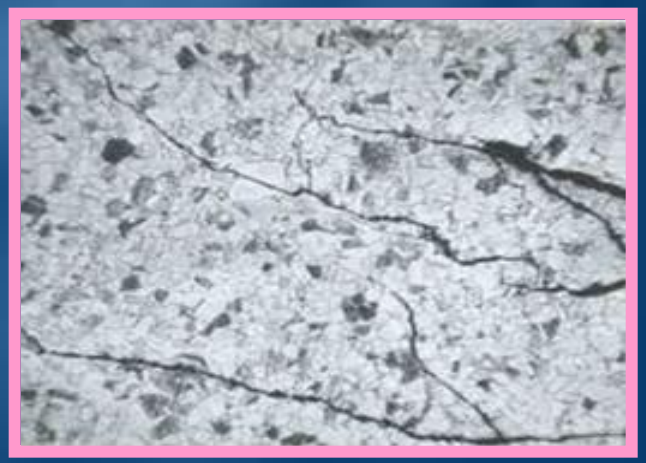


Figure 4. Photomicrograph of the shaft specimen transgra-nular nature of the cracks is evident 50X

Figure 5. Photomicrograph taken from near the edge of specimen showing the emanation of fine, branching cracks from the corroded edge

RESULTS AND DISCUSSION

SHAFT FAILURE

The results of investigation indicate that the failure of the shaft basically occurred due to corrosion fatigue cracking in chloride containing environment. The occurrence of corrosion fatigue is evidenced by two observations: (1) typical branching cracks, emanating from corroded metal edge, and (2) the typical beach mark observed on the fracture surface. However, the possibility that some of the cracks being occurred due to mechanical fatigue alone cannot be ruled out.

RESULTS AND DISCUSSION

SHAFT FAILURE

The ingress of the chloride ions at the locations such as key slots where crack initiation occurred appeared to play a significant role. The keys are used to make the joint assembly between the shaft and the coupling on the driving motor. The ingress of chlorides into the crevice of the key slot recess caused intense localized corrosion in this area giving rise to stress concentration sites for attack initiation.

SHAFT FAILURE

CONCLUSIONS

1. Failure of the shaft has occurred mainly due to corrosion fatigue cracking.
2. Ingress of chloride containing fluids into the key-slot recess through the coupling provided the aggressive medium for corrosion fatigue to occur.

PREVENTION

The remedial action to prevent such failure in future would require to eliminate any chances of chloride ingress inside the key slot recess. This may require slight modification of the assembly between the shaft and the coupling.

Failure of Main Seawater Cooling Pump in MSF Plant

CASE - 2

The occurrence of failure of a column pipe belonged to one of the six pumps of main cooling water intake system was reported. It was found that the column pipe of the pump was damaged. A large portion of the pipe measuring approximately 1.5 meters length, 0.7 meter width had come off from the main body leaving a big hole in the pipe (Fig. 6).

Figure 6. Photograph showing damaged pipe

Pump Specification:

Type	:	Vertical mixed flow pull out. Type [Model KVP-180P]
Discharge Capacity	:	26,300 m^3/Hours
Total Head	:	28.5 meters
Dimension of the Column pipe	:	1.6m dia 2.8m long 25 mm thick
Column pipe Material	:	Ni-Resist D2 W

Figure 7. Close view of the damaged column pipe showing crack extending up to the end of the flange

PHYSICAL INSPECTION

The failed column pipe was an intermediate pipe between impeller casing and L bend pipe leading to common header. It had diverged end flanges for coupling. The fracture consisted of dull and bright regions suggesting mixed mode namely, ductile and brittle fracture.

MICROSTRUCTURAL EXAMINATION

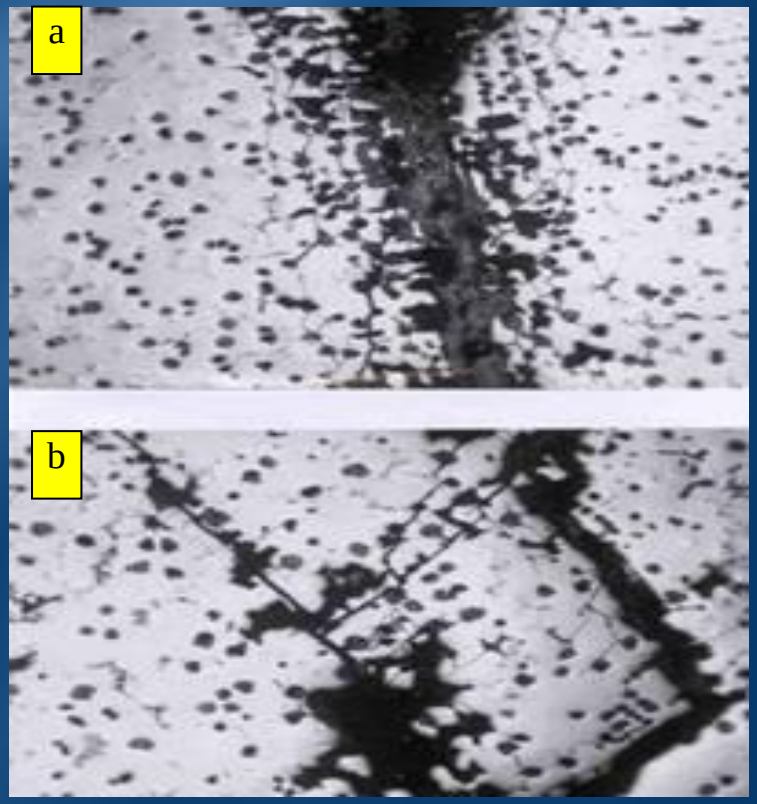


Figure 8.

(a) Crack propagation along graphite modules

(b) Transgranual branching of crack intersecting graphite

SEM STUDIES

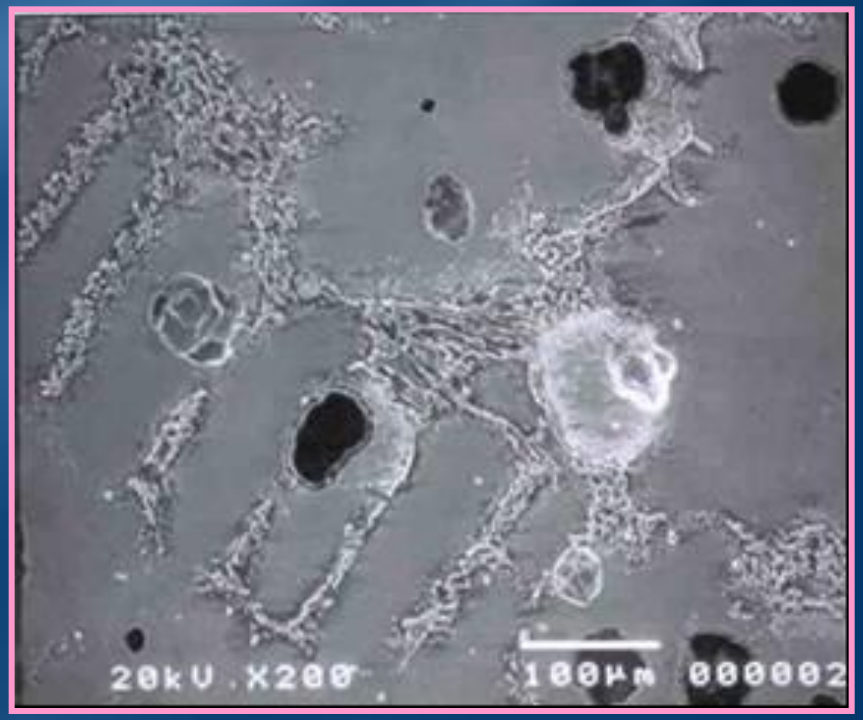


Figure 9.
SEM photomicrograph of a cross-section of failed pipe showing graphite nodules, lamellar carbides in austenite matrix

EDX STUDIES

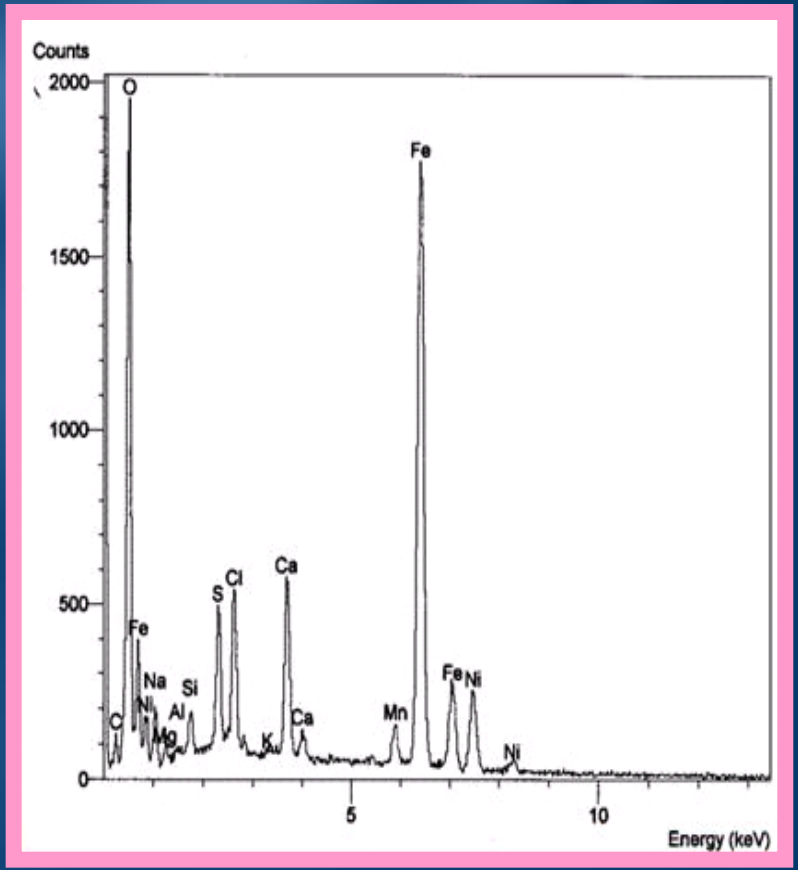


Figure 10.

EDAX spectrum of corrosion deposits collected from the inner surface of cracked regions of the pipe. Deposits are rich in chloride.

MECHANISM OF FAILURE

The failure mechanism is consisted of two steps:

1. **Initiation of pits due to presence of chloride and internal stresses in Ni-Resist alloy.**

2. **The pits act as stress raisers and subsequently cracks initiate and progressively propagate from inner surface to the outer surface of column. The corrosion products collected from crack show considerable concentration of chloride.**

CONCLUSIONS

1. The column pipe of main cooling pump had failed due to SCC as a result of synergic action of internal stresses and corrosive species (mainly chloride) in seawater.
2. The internal stresses had been induced in the body due to shortcoming in the manufacturing process which in consequence resulted in the development of pits.
3. The internal stresses might have also developed due to “hammer effect”.

RECOMMENDATIONS

It was recommended to consider cast duplex steels like 2205, 2507, DP3W or similar alloys as column material, which have much better SCC resistance than austenitic Ni-Resist cast iron.

Leakage in a Control Oil Piping Steam Turbine System

CASE - 3

The AISI 304L pipe had been in service for five years and it was used to carry oil from the control oil unit to the steam turbine control valves servomotor. The control oil Pump delivered 23 liters of oil per minute at 120 bars to distribution lines. The failure of one of the line pipes occurred in the form of oil leakage. Oil operating temperature was 75ºC, the outside environment around the pipe was atmosphere.

PHYSICAL EXAMINATIONS

Figure 11.

Closer view showing nucleation of pits after dye penetration test

Figure 12.

Crack propagation horizontally along the tube (after removal of dye penetrant)

Figure 13. Splitted tube showing oil deposits inside

The piece of the splitted pipe latitudely shows oil contamination deposits at the inner side of the tube (Figure 13).

OPTICAL MICROSCOPIC STUDIES

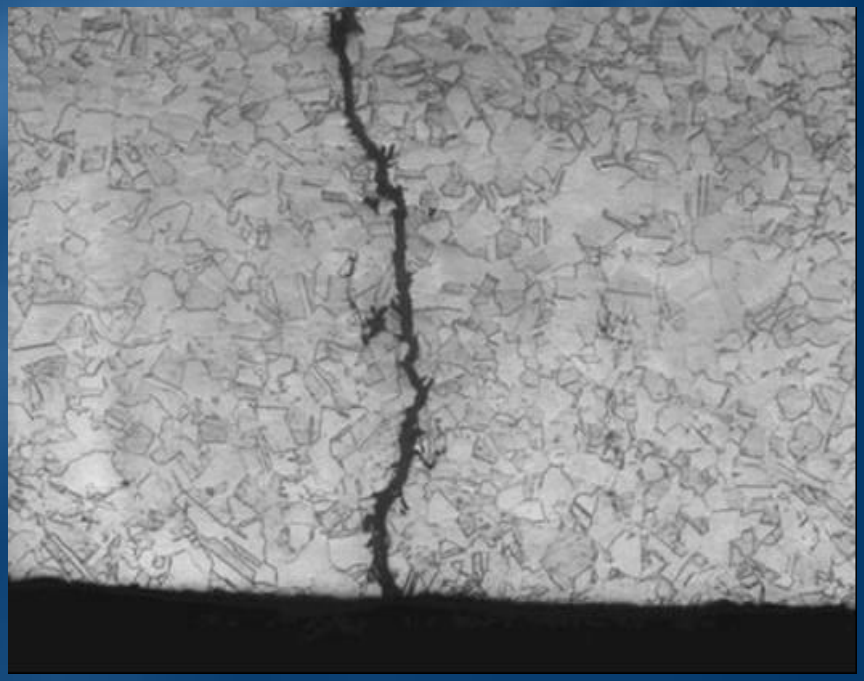


Figure 14. Crack 1 started from outside pipe X100

The Microstructural studies of the cross-section of the pipe shows crack propagation inside the pipe with normal austenitic structure (Fig.14). It appears that the crack was initiated from outside the surface of the pipe and propagated to inner surface.

SEM STUDIES

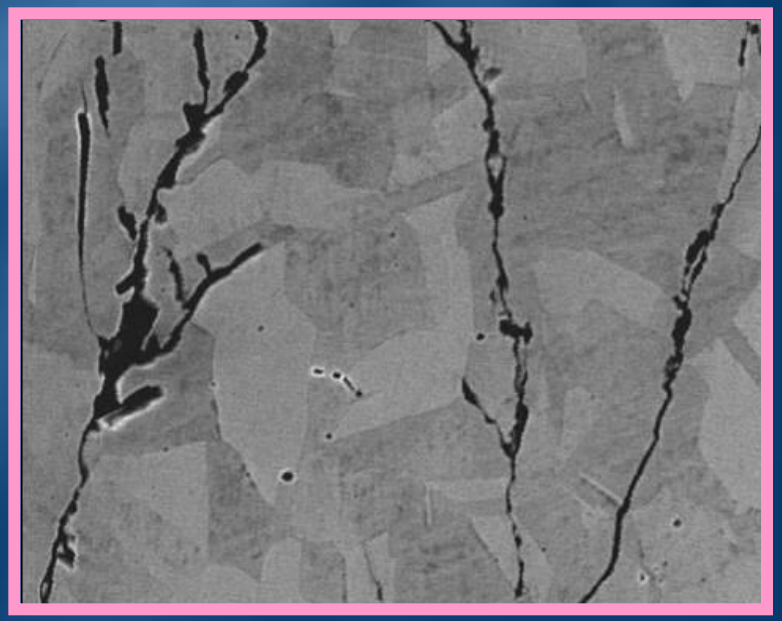


Figure 15.

SEM Image showing branching cracks at the matrix 750

DISCUSSION

The reason of crack propagation horizontally along the pipe surface (Fig. 4) was due to the high pressure (120 bar) exerted by the tube internal. The outer environment in contact with pipe was atmosphere which was enriched in chloride ions due to proximity to seashore. Therefore, Cl ions appeared to be responsible for pitting and SCC of the pipe.

CONCLUSIONS

1. Failure was due to SCC to which austenitic stainless steel 304L is susceptible.

2. Outer environment contaminated with chloride ions supported with stresses developed due to high internal operating pressure in the tube appear to be the main cause of SCC.

RECOMMENDATIONS

- In order to prevent the pipe from SCC failure it is recommended to use a suitable coating which can act as a barrier against chloride ions attack on the pipe surface.

- Upgrading the material to high stainless steels is another alternative to reduce the attack of atmosphere contaminated with chloride ions.

Failure of Main Seawater Pump Intermediate Bearing support

CASE - 4

During overhauling it was found that cracks have developed in the intermediate bearing support block near the arm and the rim joint and thus made it unsuitable for future service. The bearing support has normally lasts for full life time of the pump which was estimated to be 25 years.

PHYSICAL EXAMINATION

The cracked intermediate bearing support block was examined. The central support hub was supported by rim through equally spaced 5 numbers of tapered arms of 60 mm thickness. Out of the 5 arms, 2 arms had developed several cracks at the rim and interface (Fig. 16). Other arms and rim joints were visually inspected and no cracks were apparently observed.

Figure 16. Photograph of main seawater pump intermediate bearing support. Arrows indicate the area where cracks have developed during service.

Figure 17. Photograph of cut up portions of intermediate bearing support block shows the cracks at arms and rim interface.

Chemical Composition of the Bearing Support Material (Weight %)

C	Si	Ni	Cr	Fe
1.8	0.2	27.8	1.7	Balance

The composition corresponds to Ni-Resist cast-iron grade ASTM A439 type D-2

MICROSTRUCTURAL STUDIES

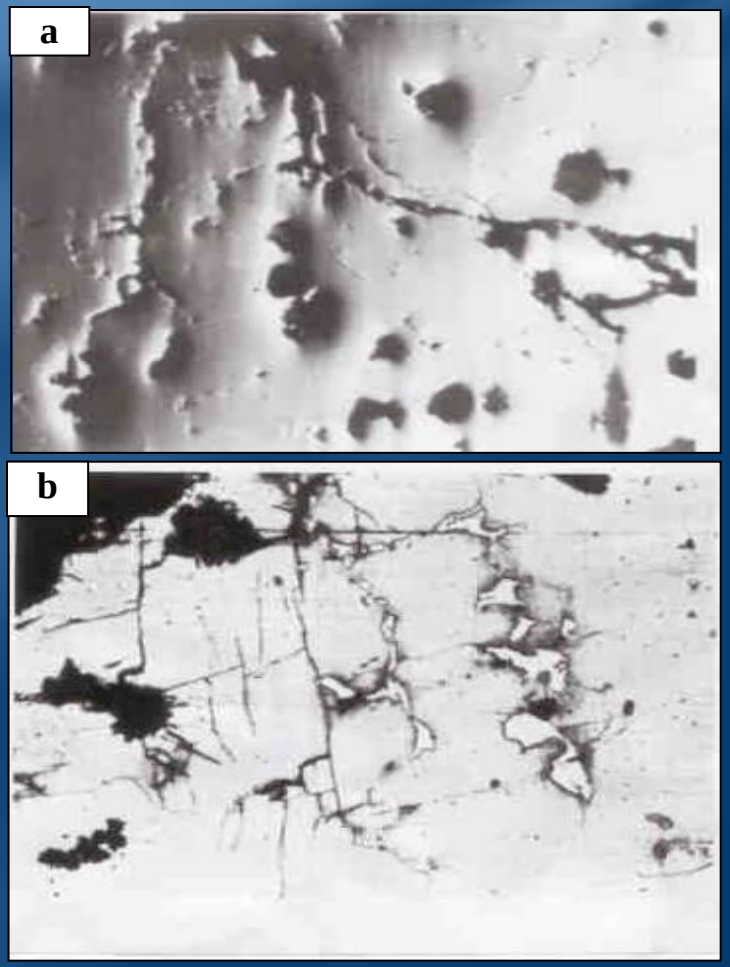
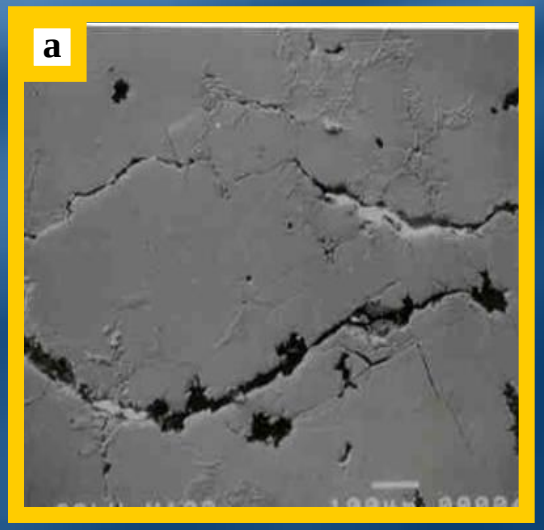


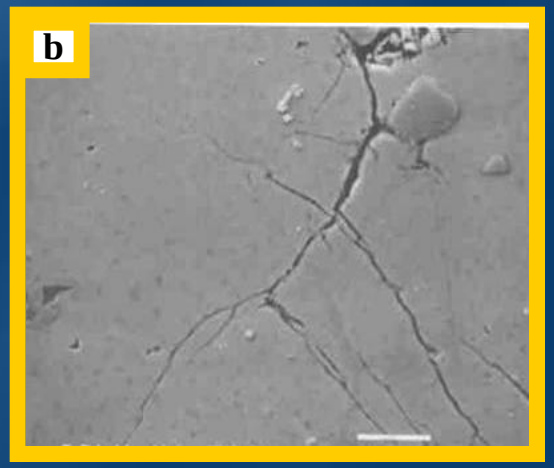
Figure 18. Photomicrograph shows main crack and branching of cracks:

(a) Spheroids of graphite and even distribution of chromium carbide in austenitic matrix

(b) Transgranular cracking emanating from the carbides & graphite nodules.

SEM STUDIES





The typical branching of the cracks from the main cracks associated with corrosion suggests typical material failure due to stress corrosion.

Figure 19. SEM picture showing:

(a) cracking along the grain boundaries and

(b) transgranular cracking

DISCUSSION

The branching of sub-cracks from the graphite nodules in transgranular mode and the presence of macrocracks connecting the graphite strongly suggest that the local residual internal stresses accumulated at those regions where cracks were initiated. Therefore, the observed cracks could be due to internal stresses developed during the casting process and the material has not been sufficiently stress relieved by heat treatment.

CONCLUSIONS

1. The developments of cracks in the component are predominantly due to the combined effect of stress and corrosion leading to stress corrosion cracking (SCC).
2. The reason of SCC may be due to the presence of residual stresses at the regions where there is large variation in section size of the component.

RECOMMENDATION

It is suggested to make use of duplex stainless steel as an alternative material for the component. These steels have good strength and better corrosion resistance to seawater particularly to SCC.

Failure of Blades in Turbine

CASE - 5

During routine shut down maintenance of turbine # 81 from C-8 power plant, the turbine blades were cleaned by means of alumina blasting. However, after the cleaning, cracks were noticed on some blades of the 9th stage. The 9th stage turbine, manufactured by Mitsubishi Heavy Industries (MHI) has a configuration in which 6 blades have a common shroud (Fig. 20).

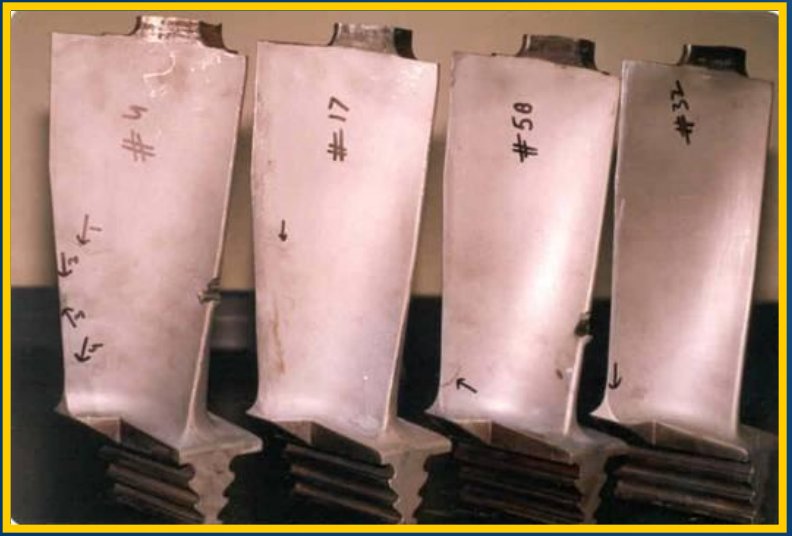
Figure 20. Overall view of stage 9 of turbine # 81, C-8 Power Plant

PHYSICAL EXAMINATION

The blades were examined by dye penetration test and 6 blades of stage # 9 were found to have cracks. In all the cases, the cracks had started at the trailing edge of the blade and progress up to about 1/3 to ½ of blade width (Fig.21). No blade was completely broken and no pitting was observed on any blade.

Figure 21. Photograph of blade No. 4, stage 9, three cracks are visible

Figure 22. Four cracked blades from 9th Stage of turbine #81



CHEMICAL COMPOSION

Description	Fe	Cr	Ni	Mn	Cu
Blade Material	78.4	13.8	4.4	0.29	3.1
Deposits	58	1.5	2.5	<1.0	10.3
	Cl^- 0.058				

The blade material has the composition corresponding to 17-4 pH and deposits are predominantly consisted of iron compounds (oxides). XRD of the deposits indicate the presence of Fe_2O_3.

MICROSTRUCTURAL STUDIES

Figure 23. Photomicrograph of the cross-section of crack # 2 of blade # 4 showing a large single crack, transgranular X 570

Figure 24. Photomicrograph of crack # 3 of blade# 4 multiple branched cracks are visible, which are both transgranular & intergranular 280X

SEM STUDIES

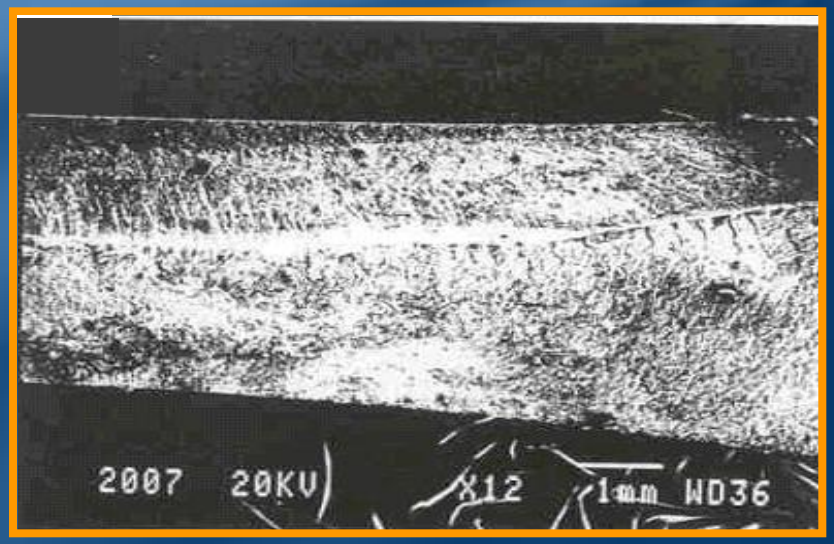


Figure 25. SEM pictures of the crack surface of a specimen from blade #17, showing beach marks

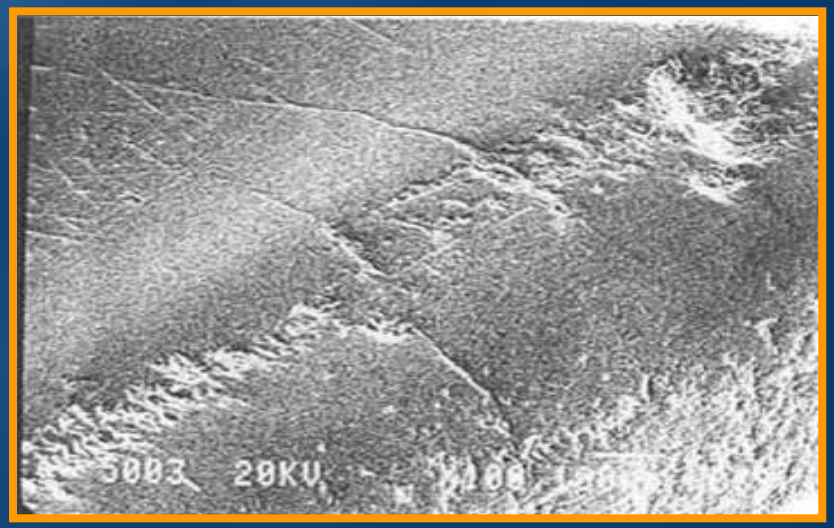


Figure 26. SEM of trailing edge of the blade # 19, showing the initiation of some more cracks from pits 100 X

DISCUSSION

The investigation reveals the following information regarding the nature of cracks:

1. Some blades contain large cracks very clearly visible by naked eye, these cracks are penetrated deep and could be seen on both sides (convex or concave) of the blades.

2. Microstructural studies (Optical and SEM) reveal the presence of different types of cracks, large, straight or curved cracks with few or no branching which are normally associated with fatigue failure. In some other cases, fine cracks in the form of branches emanating from large cracks which are characteristic of stress corrosion cracking were also found.

3. Visual examination and stereomicroscophic views of the cracked surfaces showed the presence of beach marks characteristic of fatigue failure.

4. From microstructural studies there is overwhelming evidence that transgranular is the predominant mode of crack propagation.

CONCLUSIONS

1. There is an overwhelming experimental evidence to support the view that the mechanical fatigue is the predominant cause of some blades in the 9th stage # 81 steam turbine.
2. SCC or corrosion fatigue might have played a secondary role in initiating cracks which would have acted as stress raiser.
3. The cracks invariably initiated at the trailing edge because the latter is the thinnest section where maximum stress concentration occurred.

GENERAL CONCLUSIONS

The role of stresses in initiating the cracking or breaking process in static and dynamic structures has been overemphasized. The results of 5 cases representing typical stress related failures have illustrated the importance of this subject. Material selection, stress level of the material, design, environment and operational parameters appear to play their role(s) on the performance of the unit.

Thank You