TECHNICAL REPORT NO. 7154

CIRCUMFERENTIAL WELD BOAT SAMPLE FROM STEAM GENERATOR 32, INDIAN POINT 3 NUCLEAR POWER PLANT

POWER AUTHORITY OF THE STATE OF NEW YORK

Lucius Pitkin
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TECHNICAL REPORT

June 24, 1982
T. R. No. 7154
L. P. No. M-6785
Your P. O. NYO 82-105
Ref. No. OEAR 234767

Power Authority of the State of New York
123 Main Street
White Plains, New York

Attention: Mr. W. Spataro

Subject: CIRCUMFERENTIAL WELD BOAT SAMPLE FROM STEAM GENERATOR 32, INDIAN POINT 3 NUCLEAR POWER PLANT

INTRODUCTION:

A boat sample removed from the upper shell-to-cone girth weld of Steam Generator 32 at the Indian Point 3 nuclear power plant was submitted to Lucius Pitkin, Inc. for metallurgical examination.

The 4-in. long by 1-in. wide, elliptically shaped boat sample had been removed from the inner surface of the girth or circumferential weld in an area exhibiting circumferentially oriented cracks which had been identified as UT indication 75. The 4-in. axis of the boat sample was oriented circumferentially with respect to the vertical axis of the steam generator.

The location of the girth weld from where the boat sample was taken is shown in Fig. 1. Taking of the sample was witnessed by an LPI engineer.

OBJECT:

The purpose of this examination is to determine the nature and, if possible, the probable cause of the cracking exhibited by the submitted boat sample.

PROCEDURE AND OBSERVATIONS:

A. Visual Examination

As received, the submitted boat sample exhibited two cracks on the inner surface. The longer of the two cracks was oriented parallel to the long axis of the boat sample; that is, circumferentially with respect to the vertical axis of the steam generator. A second, shorter crack was oriented at approximately 45 degrees to the first crack.

The inner surface was free of any significant general corrosion, merely exhibiting a normal thin, black oxide. However, several fine pits were present, one of which was associated with the longer crack. There were also fine, randomly oriented grind marks. Fig. 2 is a photograph of the inner surface side of the boat sample showing the cracks, pitting and grind marks. Fig. 3 is a photograph showing a side surface of the boat sample in which the depth of penetration of the circumferentially oriented crack can be seen.

B. <u>Fractographic Examination</u>

The boat sample was cut transverse to the long axis so as to intercept the circumferentially oriented crack and the smaller, 45-degree crack. Separation of the crack revealed the fracture surface to be generally smooth in appearance and to contain a dark, thumb-nail size zone with radially oriented ridges originating from a relatively large pit at the inner surface. It was also observed that there were faint beach-like markings characteristic of progressive cracking also centered about and emanating from the inner surface pit at the fracture surface.

Fig. 4 is a close-up photograph showing the fracture surface at the origin site of the circumferential crack.

Scanning electron microscopy of the inner surface at the origin site of the fracture surface confirmed the presence of corrosion attack at the origin site. Fig. 5 is a scanning electron micrograph showing the fracture origin pit as seen on the inner surface; Fig. 6 is a scanning electron micrograph showing the pit penetration as seen on the fracture surface.

Scanning electron microscopy of the fracture surface below the pit origin revealed the fracture to be smooth and to contain a thin, oxide preventing the observance of any discernible striation lines as shown in Fig. 7.

At higher magnification,the presence of discrete crystals of what probably was iron oxide were observed on the fracture surface. These crystals are shown in Fig. 8.

Scanning electron microscopy of the inner side surface of other specimens cut from the boat sample revealed the presence of additional pits, one of which contained a very fine, tight crack. The pits present on the inner surface of the boat sample and the pit with the fine crack are shown in Fig. 9.

C. Fracture Surface Analysis

Energy dispersive X-ray (EDAX) and Auger analyses was performed on areas of as-exposed fracture surface. The EDAX spectrum obtained showed energy peaks for molybdenum and/or/sulfur, iron, nickel, copper and zinc. The presence of molybdenum, iron and nickel is attributable to the base metal. The presence of copper and zinc is most probably attributable to carry-over from copper alloy tubes in the condensers. The sulfur peak is coincident with the molybdenum peak but subsequent Auger analyses confirmed the presence of sulfur.

Fig. 10 is a photograph showing the EDAX spectrum of the as-exposed fracture surface.

Auger analysis of the as-exposed fracture surface revealed the elements, silicon, sulfur, chlorine, carbon, nitrogen, oxygen, iron, copper and sodium. The Auger spectrum obtained is shown in Fig. 11. The as-exposed fracture surface was ion beam sputtered to remove corrosion product to depths of 50 and 500 angstroms. The Auger spectra obtained after each sputtering interval are shown in Figs. 12 and 13 respectively. Ion beam sputtering removed the initially present elements of silicon, chlorine, carbon and nitrogen. The sulfur and copper, however, were still present at a depth of 500 angstroms.

D. Shell and Weld Metal Composition

Qualitative spectrographic analysis on drillings taken from weld and base metal of the submitted boat sample revealed the weld deposit and base metal to be similar in composition corresponding to ASME SA 302 Grade B material. (Previously, Lucius Pitkin, Inc. had analyzed 14 samples removed from the steam generator shell and it was seen from the analyses that the boat sample and the 14 samples were similar in composition).

Complete results of the analyses performed on the weld and base metal from the boat sample are appended. In addition, the analyses on the 14 previously submitted steam generator shell samples are also appended.

E. Macro-Examination

Two transverse cross-sections were cut perpendicular to the long axis of the boat sample, ground flat and deep-etched in hot, mixed acids for macrostructural examination.

Examination of the deep-etched specimens confirmed the cracks to have initiated from the inner surface in weld metal and to have propagated into the shell base metal. In addition to the primary cracks observed visually, there were several finer cracks present in the weld metal at the inner surface.

Examination of the deep-etched sections did not reveal the presence of any weld, heat-affected zone or base metal cracks which could be attributed to the original welding. A small, insignificant slag inclusion was observed at the weld base metal fusion line in one of the sections. The general microstructure of the weld deposit and base metal appeared to be satisfactory.

Fig. 14 is a photomacrograph showing the deep-etched cross-sections.

F. Hardness

A hardness survey performed on the deep-etched cross-sections showed the weld deposit to exhibit a more-or-less uniform hardness of Rockwell B 90 to 96.5 and the base metal to exhibit a hardness of Rockwell B 94 to 96.

Based on standard conversion charts for steel, the weld metal hardness is equivalent to an approximate tensile strength of 88,000 to 100,000 psi. The base metal hardness is equivalent to an approximate tensile strength of 100,000 psi. Thus, at least from a strength point of view, the weld and base metals were suitably matched.

G. Metallographic Examination

Several cross-section specimens were cut from the boat sample so as to intersect the primary and secondary cracks. These specimens were prepared for metallographic examination.

In the as-polished, unetched condition, the weld deposit and shell base metal exhibited a normal quantity of non-metallic inclusions. Several fine, secondary cracks were observed emanating from pits at the inner surface. The cracks were generally corrosion filled and relatively straight as is characteristic of corrosion fatigue cracks. Figs. 15 and 16 are photomicrographs in the as-polished condition showing two, fine oxide-filled cracks penetrating from pits at the inner surface of the weld metal.

Etching the specimens confirmed the cracks and pits to have initiated in weld metal and to have propagated through the weld metal toward the base metal. The primary cracks revealed the fracture profile to be smooth, straight and transgranular in both the weld metal and base metal. Figs. 17 and 18 are photomicrographs showing the same cracks in Figs. 15 and 16 but after etching.

The general microstructure of the weld metal was found to consist of ferrite and pearlite and is illustrated in Fig. 19. The general microstructure of the base metal consisted of uniformly tempered bainite and is illustrated in Fig. 20.

DISCUSSION AND CONCLUSIONS:

Metallurgical evaluation of the boat sample removed from the inner surface of the shell-to-cone girth weld of Steam Generator 32 identified the mode of cracking to be transgranular and characteristic of low-cycle corrosion fatigue.

All of the cracks examined in the submitted boat sample initiated from pits on the inner surface and had propagated transgranularly through the weld and base metal. The cracks observed were totally or partially filled with corrosion product.

Qualitative analysis of deposits on as-exposed fracture surfaces indicated the deposits to consist essentially of base metal oxides. The existence of discrete crystals of iron oxides was considered evidence of rapid anodic reaction typical of corrosion attack in high temperature water containing oxygen.

In addition to the oxygen, some sulfur and chlorine was also present on the fracture surface in trace amounts. Ions of these elements may also have contributed to the observed cracking.

It would appear that cyclic stresses necessary to produce the fatigue cracking were thermally induced. The stresses present in the upper shell-to-cone girth weld were of sufficient magnitude so that combined with mild pitting corrosivity of the water environment, corrosion fatigue cracks initiated and propagated.

The effect of corrosion on fatigue is more pronounced when the frequency of cyclic stress loadings is low, as would be experienced by the steam generator shell in service, as the shell side water would have longer time to aggravate crack propagation.

Although the metallurgical evaluation of the submitted boat sample revealed cracking to have initiated in weld metal, additional cracks in the areas adjacent to but outside of the girth weld may be present in the shell.

The prior analyses of filings from the steam generator indicated the base metal to meet the compositional requirements SA 302 Grade B material with the weld similar. The boat sample appeared comparable.

Hardness (and strength, based on conversion charts) of weld and base metal was considered satisfactory for SA 302, Grade B.

Respectfully submitted,

LUCIUS PITKIN, INC.

A. J. Vecchio
Vice President &
Asst. Chief Metallurgist

AJV/mm

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SPECTROGRAPHIC ESTIMATES

Report No. M-6785 · Date June 23, 1982

The following is our analysis of 2 sample(s) of drillings from boat sample

	Weld Metal	Base Metal
Iron	Major	Major
Manganese	0.X	Minor low
Silicon	0.X	0.X high
Molybdenum	0.X low	0.X
Nickel	0.X	0.X low
Aluminum	0.0X low	0.0X high
Copper	0.0X low	0.0X
Chromium	0.0X low	0.0X
Vanadium	0.0X low	0.00X
Magnesium	0.00X low	0.00X low

Other elements looked for, but not found:

titanium, zirconium, zinc, bismuth, lead, tin, antimony, gallium, germanium, phosphorous, boron, beryllium, cobalt, columbium, tungsten.

Power Authority of the State of New York
10 Columbus Circle
New York, N.Y. 10019
Attn.: Mr. W. Spataro

Respectfully submitted,
LUCIUS PITKIN, INC.

By A. J. Vecchio
Vice President &
Asst. Chief Metallurgist

AJV/mm/

NOTE: Major = above 5% estimated. Minor = 1.5% estimated. .X, .OX, .OOX, etc. = concentration of the elements estimated to the nearest decimal place – e.g. .OX = .01-.09% estimated. *= less than. NF = not found. The numbers in parenthesis indicate the estimated relative concentration of the element among the various samples. Detectability varies considerably among the elements and also depends upon the amount and nature of the sample, therefore, "Not Found" or NF means not detected in the particular sample by the technique employed.

FORM 104-7/81

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SPECTROGRAPHIC ESTIMATES

Report No. M-6785 Date June 23, 1982
The following is our analysis of 14 sample(s) of filings from Steam Generator No. 32
Indian Point No. 3

BY QUANTITATIVE CHEMICAL AND QUALITATIVE SPECTROGRAPHIC ANALYSES

	1	2	3	4	5
Carbon, %	0.13	0.11	0.15	0.14	0.10
Manganese	1.40	1.42	1.35	1.43	1.43
Phosphorous	0.014	0.013	0.014	0.012	0.012
Sulfur	0.015	0.015	0.014	0.011	0.013
Silicon	0.24	0.24	0.26	0.23	0.31
Molybdenum	0.48	0.47	0.47	0.50	0.50
Nickel	0.50	0.48	0.12	0.094	0.093
Chromium	0.092	0.098	0.094	0.090	0.079
Iron	Major	Major	Major	Major	Major
Copper	0.0X	0.0X	0.0X	0.0X	0.0X
Aluminum	0.0X	0.0X	0.0X	0.0X	0.0X
Vanadium	0.00X	0.00X	0.00X	0.00X	0.00X
Magnesium	0.00X low	0.00X low	0.00X low	0.00X low	0.00X low

Other elements looked for, but not found:

titanium, zirconium, zinc, bismuth, lead, tin, antimony, gallium, germanium, boron, beryllium, cobalt, columbium, tungsten.

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Continued ....

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AJV/mm/4

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BY QUANTITATIVE CHEMICAL AND QUALITATIVE SPECTROGRAPHIC ANALYSES

	6	7	8	9	10
Carbon, %	0.18	0.11	0.16	0.18	0.13
Manganese	1.33	1.43	1.42	1.41	1.40
Phosphorous	0.017	0.011	0.012	0.014	0.010
Sulfur	0.009	0.010	0.015	0.016	0.010
Silicon	0.26	0.23	0.24	0.24	0.22
Molybdenum	0.44	0.51	0.49	0.50	0.50
Nickel	0.50	0.11	0.50	0.50	0.10
Chromium	0.073	0.098	0.14	0.13	0.098
Iron	Major	Major	Major	Major	Major
Copper	0.0X	0.0X	0.0X	0.0X	0.0X
Aluminum	0.0X	0.0X	0.0X	0.0X	0.0X
Vanadium	0.00X	0.00X	0.00X	0.00X	0.00X
Magnesium	0.00X low	0.00X low	0.00X low	0.00X low	0.00X low

Other elements looked for, but not found:

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	I1	I2	I3	I8
Carbon, %	0.13	0.16	0.16	0.15
Manganese	1.27	1.45	1.35	1.45
Phosphorous	0.014	0.014	0.011	0.014
Sulfur	0.016	0.015	0.014	0.015
Silicon	0.29	0.25	0.25	0.26
Molybdenum	0.39	0.49	0.48	0.48
Nickel	0.67	0.49	0.11	0.49
Chromium	0.079	0.11	0.098	0.098
Iron	Major	Major	Major	Major
Copper	0.0X	0.0X	0.0X	0.0X
Aluminum	0.0X	0.0X	0.0X	0.0X
Vanadium	0.00X	0.00X	0.00X	0.00X
Magnesium	0.00X low	0.00X low	0.00X low	0.00X low

Other elements looked for, but not found:

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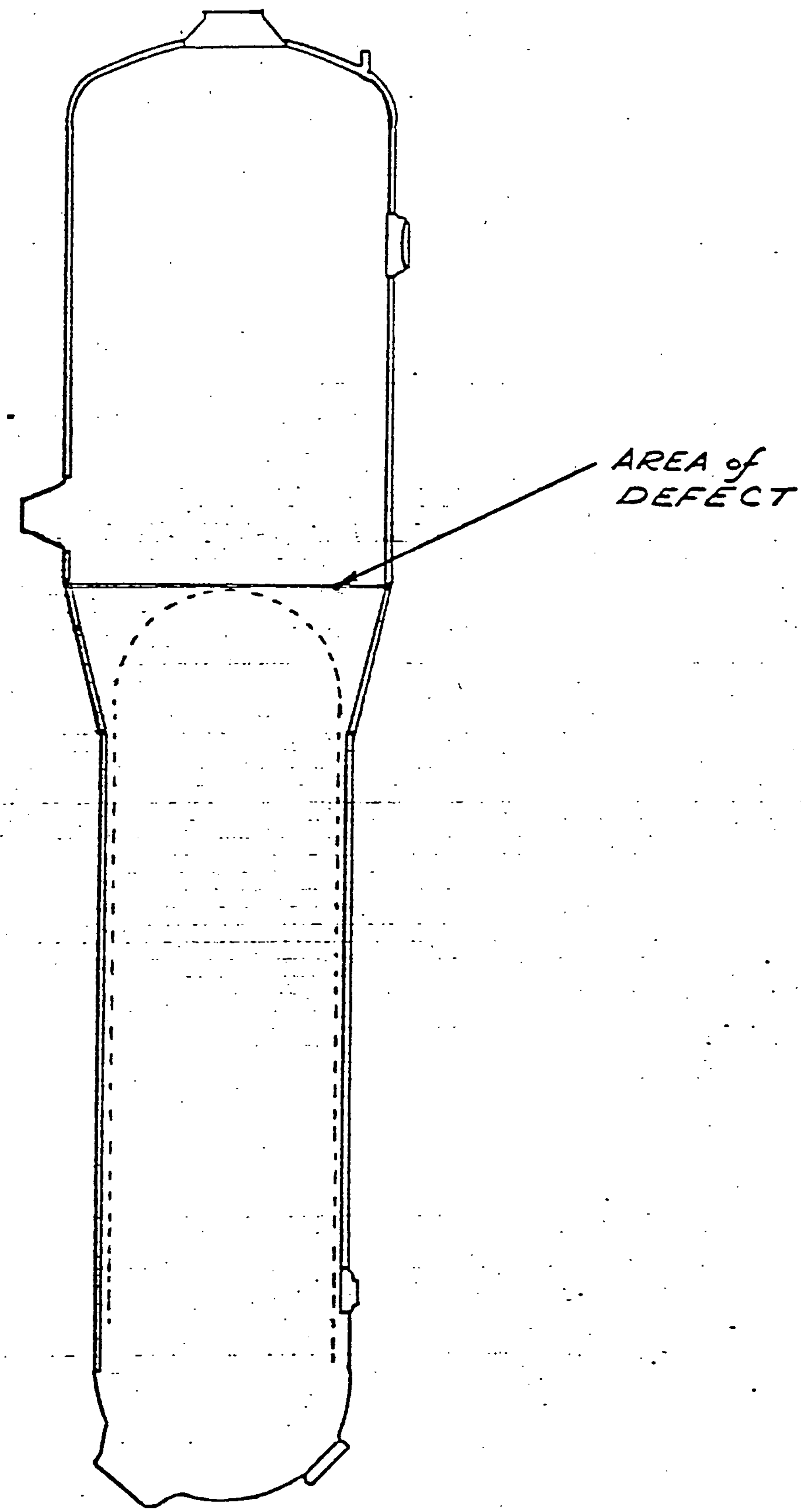

Fig. 1 GIRTH WELD BOAT SAMPLE LOCATION

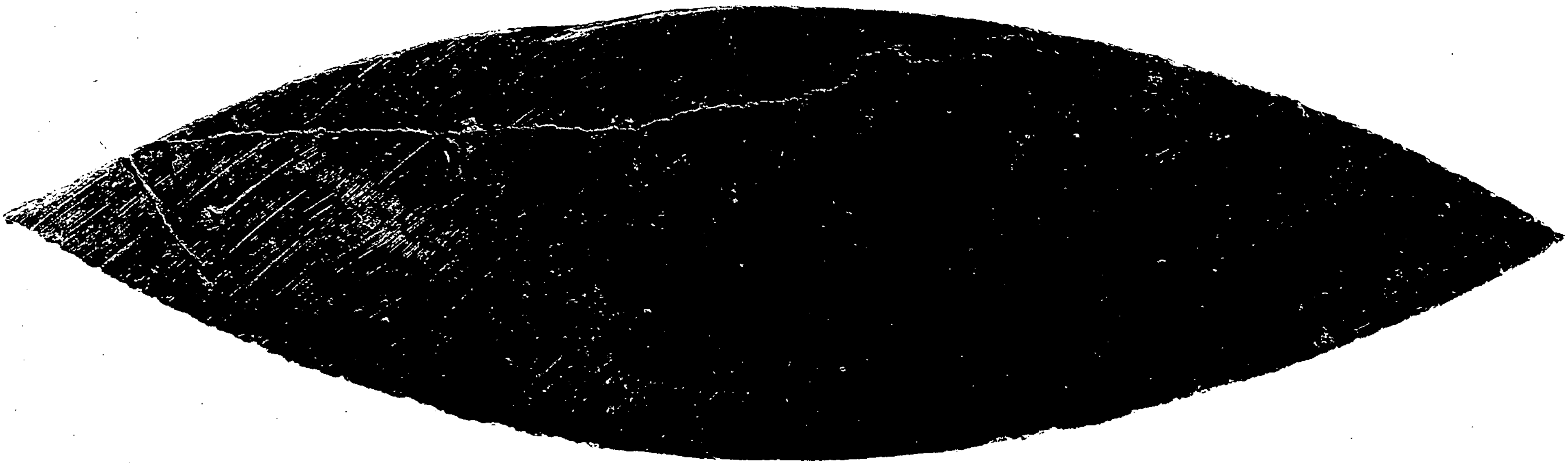

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Fig. 2 SUBMITTED BOAT SAMPLE, AS RECEIVED

Photograph showing the submitted boat sample in the as-received condition.

The surface shown is the inner surface of the steam generator in the area of the upper shell-to-cone girth weld.

It can be seen that the inner surface of the boat sample exhibits two, well-defined cracks. The longer of the cracks is circumferentially oriented whereas the shorter is oriented at approximately 45 degrees.

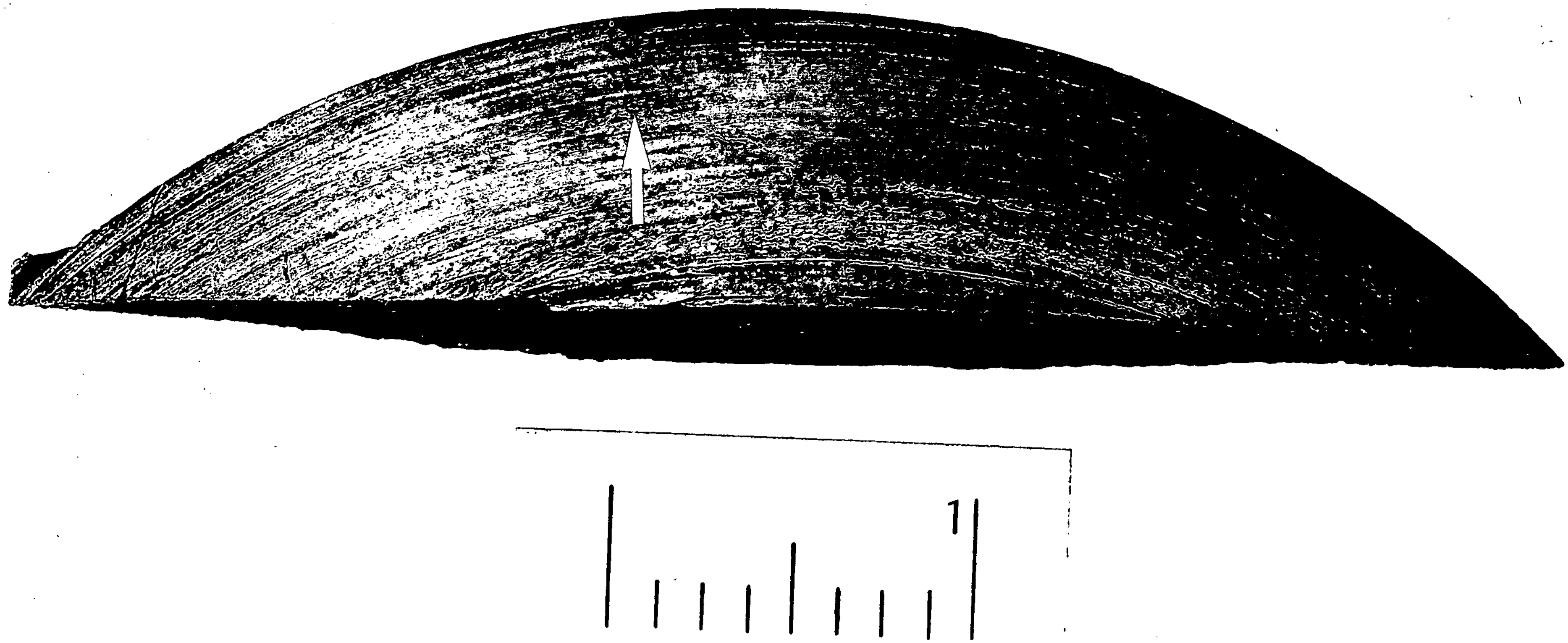

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Fig. 3 SIDE VIEW OF BOAT SAMPLE

Photograph showing the circumferential crack penetration as seen in the side of the boat sample.

Fig. 4 FRACTURE SURFACE 20 X

Close-up photograph showing the fracture surface of the circumferential crack exposed after cutting through the crack at one end. The fracture origin (dark zone) is associated with a corrosion pit in the inner surface. Faint beach-like marks and radiating ridges characteristic of progressive or fatigue cracking emanate from the pit origin site.

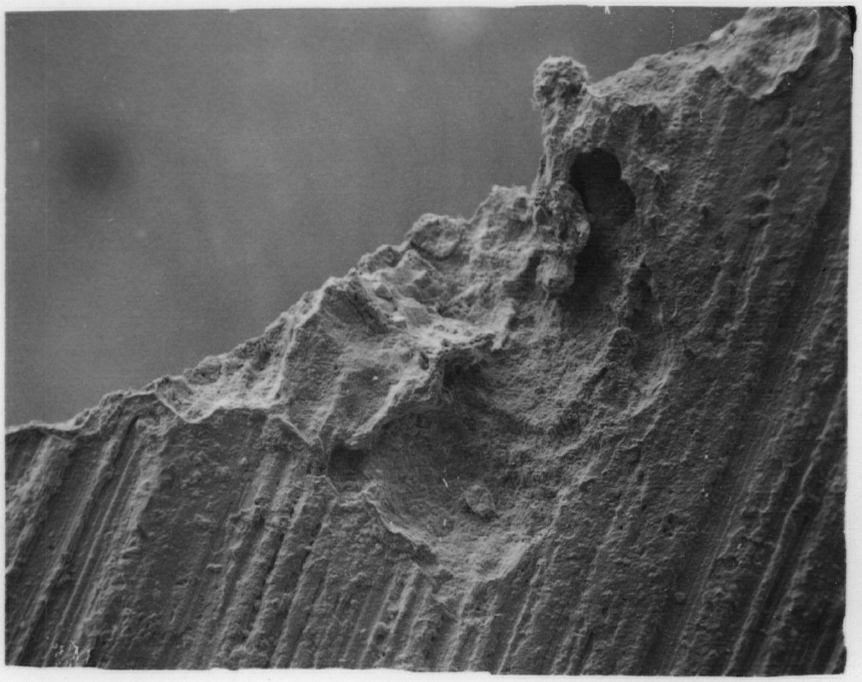

Fig. 5 CORROSION PIT - INNER SURFACE 40 X

Scanning electron micrograph showing corrosion pit as viewed from the inner surface. The fracture passes through the corrosion pit (lower left to upper right).The inner surface exhibits numerous fine, parallel score marks, the result of original grinding performed on the girth weld.

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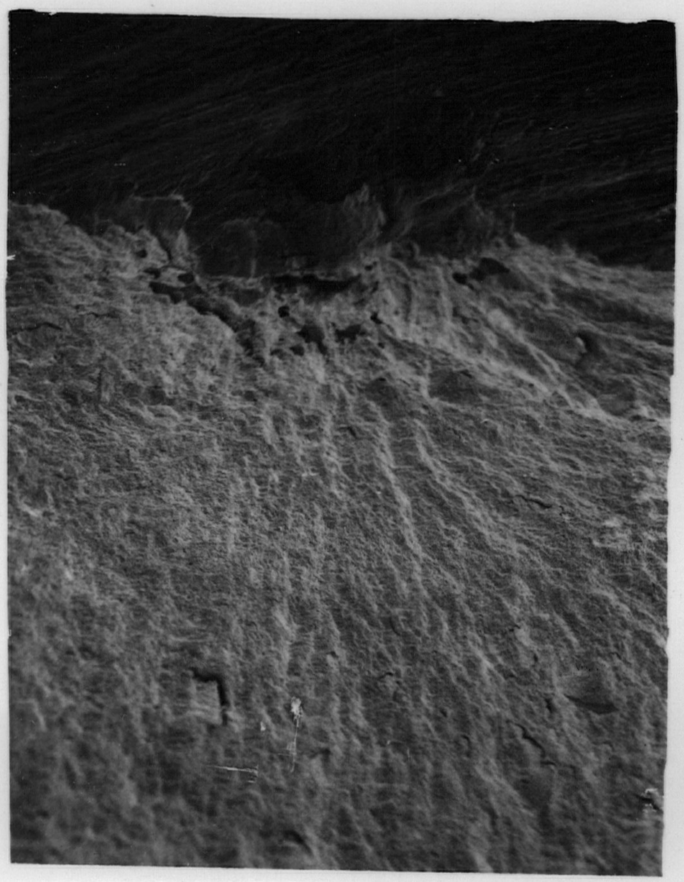

Fig. 6 CORROSION PIT - FRACTURE SURFACE 20 X

Scanning electron micrograph showing the corrosion pit at the fracture origin.

Fig. 7 FRACTURE SURFACE 200 X

Scanning electron micrograph of the as-exposed circumferential crack fracture surface. Although the fracture surface is covered with an oxide corrosion product, the surface is generally smooth as is characteristic of corrosion fatigue cracking.

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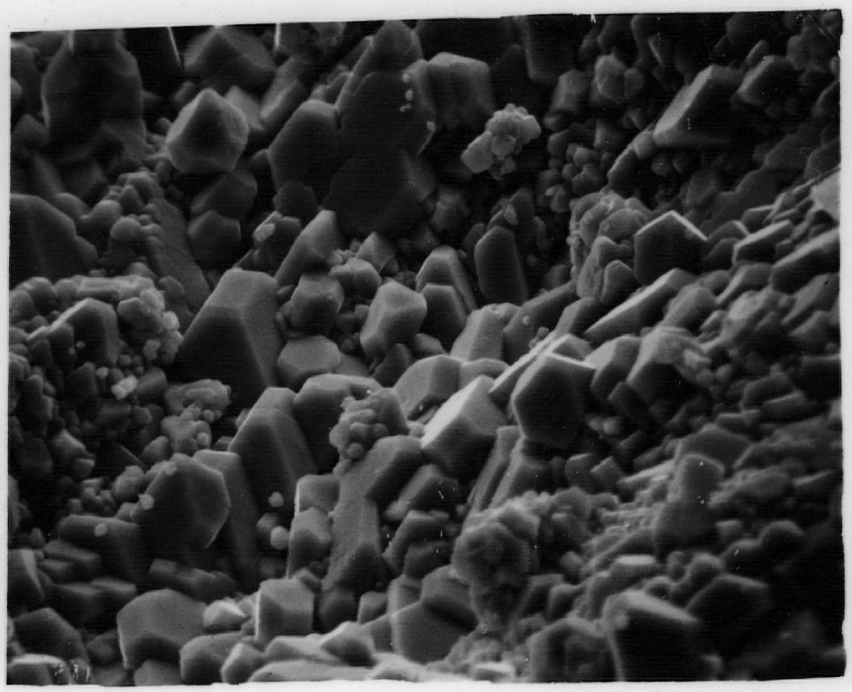

Fig. 8 FRACTURE SURFACE CORROSION PRODUCT 2000 X

Scanning electron micrograph of area shown in Fig. 7 but at higher magnification showing discrete crystals (probably iron oxide) on the as-exposed fracture surface which is evidence of corrosion attack in high temperature water containing oxygen.