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Belcher

May 14, 1981

Norwegian Caribbean Lines
1 Biscayne Tower
Miami, Florida 33132

Attention: Mr. Odd Olsen

This will serve to provide you with the results of various analyses of the boiler deposits from the S/S Norway.

Tests run in the laboratory here at Dodge Island indicated that the sulfur level was nil while vanadium measured 1244 ppm. The material was completely and immediately soluable in warm water with no apparent "grit". There were no indications of magnetic substances in the sample.

Since our facilities here for the type of analysis required are minimal, we chose to submit a sample to another, more complete laboratory for further analysis. Attached is the original of the laboratory report, expense of which was absorbed by us as a customer courtesy. The instrument is an emmission spectrophotomer and is "read" by comparison of the intensity of the emmision "line" an a photographic plate, thus accounting for the method of reporting the results. Complete quantitative analysis would require either a "wet" chemistry method or via the Atomic Absorbtion method, which is very expensive in the former case and not readily available in the south Florida area in the latter.

All of the above were reviewed by our Mr. Frank Stopinski. His additional comments indicated the vanadium level reported was not surprising nor unusual since it was a concentration of several possible compounds. Since the material was completely soluable in warm water his first suggestion would be the establishment of a routine maintenance practice of hot water washes. He would also like to know exactly from where the sample came.

We hope the above will be of assistance in your engine maintenance and fuel treatment porgrams. If we may be of any furthur service please let us know.

Respectfully,

Gene Gignac

Gene Gignac
Marine Product Supervisor

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Invoice#

QCM

Q C METALLURGICAL, INC

2870 STIRLING ROAD HOLLYWOOD, FLORIDA 33020
PHONES: 925-0499 949-3166 MIAMI

INSPECTION REPORT

DATE May 8, 1981

QCM JOB# 1EM-1152 CUSTOMER Belcher

DESCRIPTION (1) Sample

CUSTOMER ORDER# Verbal MATERIAL

INSPECTION SPECIFIED Chemical

APPLICABLE SPECIFICATIONS

RESULTS OF INSPECTION

Quantitative spectrographic analysis showed the following:

Lead	Trace
Chromium	Trace
Magnesium	Trace
Tin	Trace
Silicon	+++
Iron	++
Aluminum	+++
Copper	Trace
Gold	0
Titanium	Trace
Nickel	+++
Calcium	O
Sodium	O
Zinc	+++
Vanadium	+++
Carbon	.026

+++ Large Amount
++ Moderate Amount

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E-0113

BY Robert F. Smith

FORM #27

files.
Copy "Boiler Average 81"
8000

QC METALLURGICAL, INC.

HOME OFFICE
2870 STIRLING ROAD • HOLLYWOOD, FLORIDA 33021 • 305/925-0499
MIAMI TELEPHONE: 305/949-3166

TESTING June 19, 1981 CONSULTING

Norwegian Caribbean Lines QCM Job No. 1EM-1292

FAILURE ANALYSIS OF BOILER TUBES

Objective

Determine cause of failure of several boiler tubes received by Norwegian Caribbean Lines reportedly removed from the S/S Norway.

Method of Accomplishment

The failed tubing was examined using mechanical, scanning electron microscopy (SEM), energy dispersive analytical x-ray (EDAX), metallurgical and physical techniques.

Results

A photograph showing one of the main failures is in Figure 1. Noted is this sample failed in what would be called a typical thick wall rupture failure. Also submitted were several samples with lesser degrees of failure. As one of these samples was previously examined, it will be discussed first.

A SEM photograph showing the failed surface of the smaller fracture is in Figure 2. Noted is corrosion products on the surface. A photograph showing secondary cracking on the outside diameter surface is in Figure 3. Noted again is oxidation and multiple secondary cracking. EDAX analysis of this surface is in Table I as No. 3. A similar photograph showing the inside diameter is in Figure 4. Noted in this area is a pit with a crack initiating from it and several smaller cracks. A higher magnification view is in Figure 5. This shows the depth of the secondary crack in the pit. EDAX analysis of this area is in Table I as No. 5.

A photograph showing the fracture surface, near the OD, prior to cleaning is in Figure 6. This photograph suggests a high temperature failure similar to stress rupture. EDAX analysis of this region is in Table I as No. 6. It shows an extremely high Vanadium content with Copper also present. A photograph showing the fracture surface at the inside diameter region is in Figure 7. This also suggests corrosion or high temperature failure, but also indicates a very low cycle type fatigue propagation. The rate of which is 2×10^{-4} in/cycle which is in the low cycle (high stress) region. This is much like high temperature corrosion fatigue, meaning part of the mechanism is thermal in nature. EDAX analysis of this sample is in Table I as No. 7. A photograph showing the failed surface just slightly removed from that shown in Figure 7 is in Figure 8. This shows an intermediate type failure, suggesting corrosion or rupture propagation. EDAX analysis of that region is in Table I as No. 8. This particular area shows an elevated Copper and Nickel content.

A photograph showing the inside diameter of failed part after cleaning is in Figure 9. Noted is definite intergranular cracking mechanism. This failure is undoubtedly a combination of corrosion and rupture at the inner diameter. A photograph taken in a slightly different area is in Figure 10. This photograph again shows fatigue propagation. These striations are at a rate of approximately 6×10^{-5} in/cycle indicating vibrating and thermal fatigue stresses. A photomicrograph showing the fracture surface at the outer diameter is in Figure 11. This area is definitely all intergranular cracking and the direct result of stress rupture type failure. The sample was then examined using microstructural and EDAX techniques.

A SEM photograph showing a line profile analysis for Sulfur is in Figure 12. Noted is very high Sulfur content in secondary cracks. This definitely indicates that a sulfide bearing gas was involved in the corrosion aspect at the inner diameter. A photograph taken outside the area is in Figure 13. This again shows the secondary cracking. The photograph in Figure 14 reveals a line profile analysis for Sulfur across this crack. Again it is noted that a high Sulfur content occurs in the crack and adjacent surface at the inner diameter. Tensile and rupture specimens were also removed from this sample. The data for thicker and thinner areas is in Table II. Also to be determined is the stress rupture properties. This data will be supplied in a separate report. The remaining portion of this report was performed on the main failure samples.

A photograph showing intergranular cracking of the main failure is in Figure 15. This fracture is a result of high temperature exposure coupled with some corrosion. A higher magnification view is in Figure 16 and definitely indicates that corrosion is part of the failure mechanism within the inner diameter area. A higher magnification view is in Figure 17 and reveals the corrosion mechanism to be intergranular in nature. Also noted is edge of grain boundaries. The photograph showing intergranular fracture from rupture is in Figure 18. This photograph was taken midway between the inner diameter and outer diameter. The failure mechanism is definitely intergranular in nature.

A photograph showing intergranular cracking at the outside diameter section is in Figure 19. This indicates the fracture mechanism is rupture in nature. A second photograph taken in this area is again intergranular in nature. This indicates the primary fatigue mechanism is rupture in nature.

A macrograph showing etching for seamless tubing and indication of hydrogen embrittlement is in Figure 20. This photograph shows no signs of a weld or hydrogen embrittlement. The minimum outside diameter was found to be 2.422" near the thin area. This compares to the maximum of 2.862", 90° to the thin area. In terms of thickness the minimum was .177" wall and the normal .263". Samples of the main fracture and areas away from this area were then run suing metallurgical and physical techniques.

A photomicrograph showing the structure near the inner diameter of failed section is in Figure 21. Noted is this structure is martensitic. Hardness testing of this area revealed a microhardness of 355 DPH which converts to 36 Rc. A comparison with this to the outside diameter near the fracture is in Figure 22. This shows a decarburized region on the surface compared to just below it. The decarb region had a hardness of 155 DPH which converts to 80.5 Rb whereas the area just below it had a hardness of 400 DPH (41 Rc). For comparison properties, a section was made away from the failure in the thicker region.

A photomicrograph showing the inner diameter of an unaffected region is in Figure 23. This shows a typical normalized steel. The hardness of this region was found to be 148 DPH (78.5 Rb). A similar photograph taken at the outside diameter of the unaffected region is in Figure 24. This again shows a typical normalized structure. Hardness of this region was found to be 160 DPH (81.5 Rb) This definitely indicates carburization at the fracture surface. Carbon analysis of the material which was unaffected revealed a content of .129%. This coupled with the EDAX analysis indicates the material is similar to a Carbon Steel. Bending testing both the affected (thin) and unaffected (thick) regions revealed the material to be ductile. These tests were performed on the inner diameter and outside diameter in tension with little difference.

Conclusion

Based off this analysis it is evident that localized overheating was present. This resulted in a failure mechanism of primarily stress rupture with small amounts of corrosion and erossion fracture. EDAX study indicates that there was some Sulfur present in the inner diameter tubing suggesting the overheating was from bubbles formed in the water. As the leading areas are exceptionally thin I would definitely replace some of the tubing. A second structure examined at this time included residual stress rupture life. This data will be documented at a later date under separate cover.

The conclusions of this report were based on SEM analysis revealing intergranular failure and presence of Sulfur. This was backed up by localized overheating as shown by hardness and microstructure analysis. There were no signs of hydrogen embrittlement, hence, this can be eliminated. The intergranular failure found at the inner diameter is actually a stress corrosion type failure.

Frank E. Grate, P. E.
Q C Metallurgical, Inc.

Norwegian Caribbean Lines
Q C Metallurgical Job No. 1EM-1292

"Failure Analysis of Tubing"

T A B L E I

Sample	No. 3	No. 5	No. 6	No. 7	No. 8
Iron	Balance	Balance	Balance	Balance	Balance
Copper	.24	1.37	1.55	1.79	11.94
Nickel	.60	5.38	.27	1.74	3.85
Vanadium	4.85	0	14.52	0	1.4
Chlorine	.05	.22	.12	.18	.16
Sulfur	.64	1.01	.65	.95	1.77
Phosphorus	0	.91	.12	.98	1.6

T A B L E I I

Thickness	Width	T/KSI	Y/KSI	%Elongati
.190	.468	62.5	45.5	19.4
.248	.468	64.6	36.5	32.0

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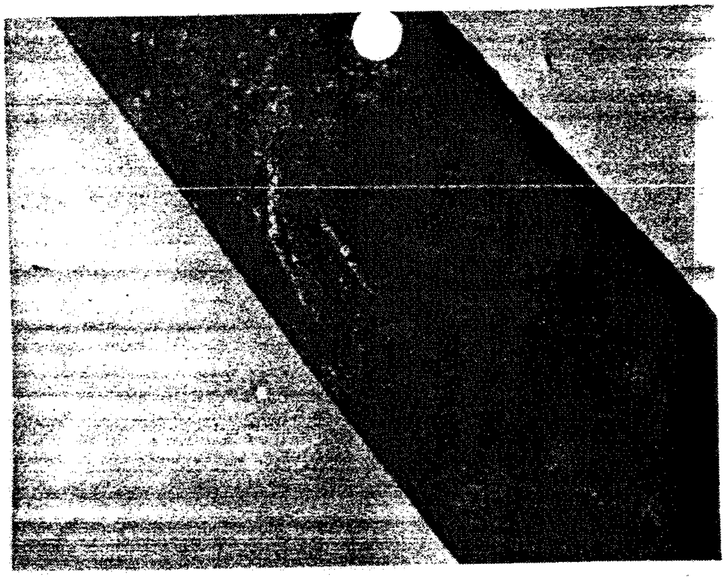
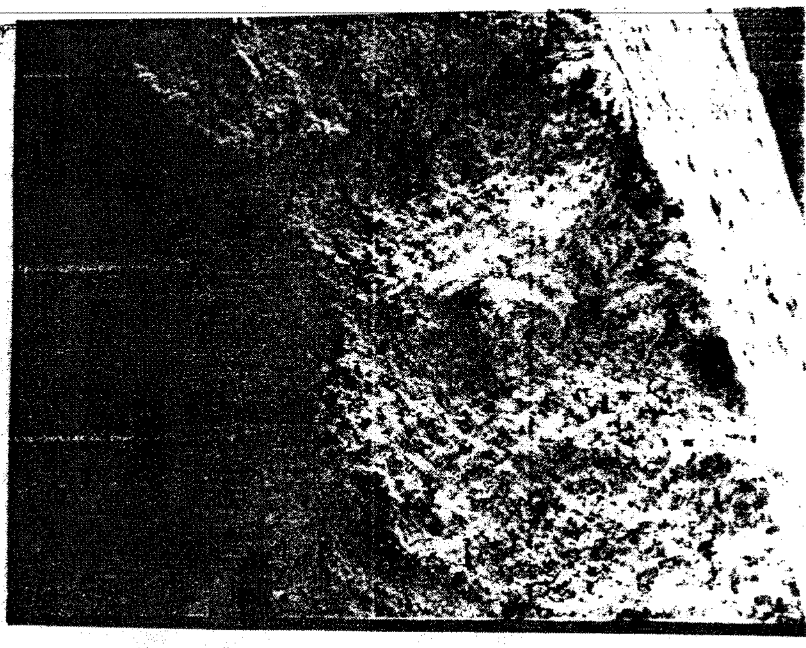
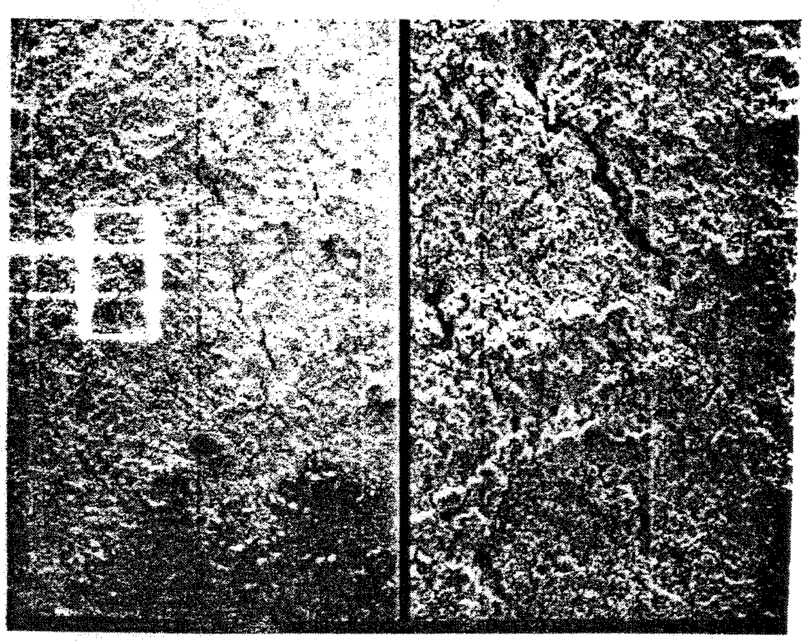


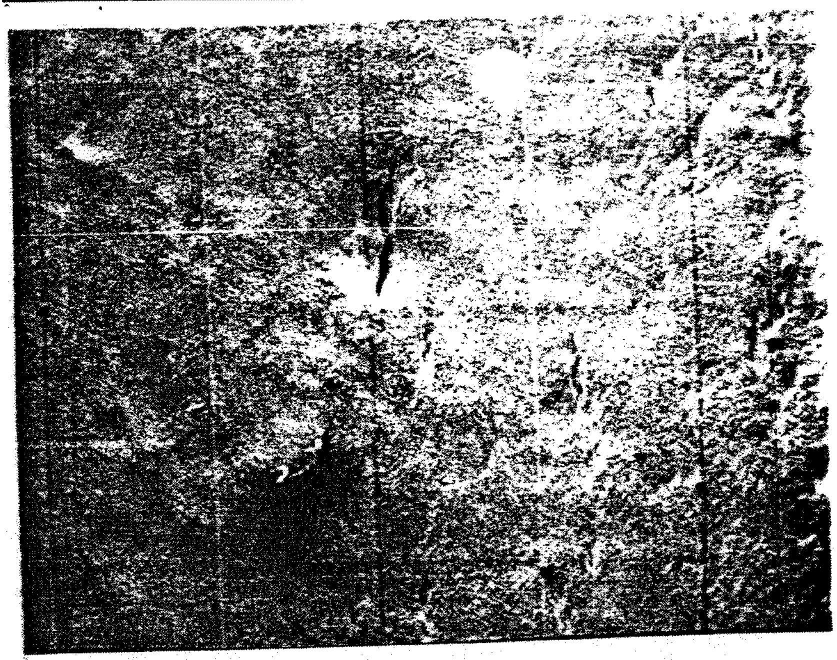
Photograph Figure 1
Showing main failure of tubing.



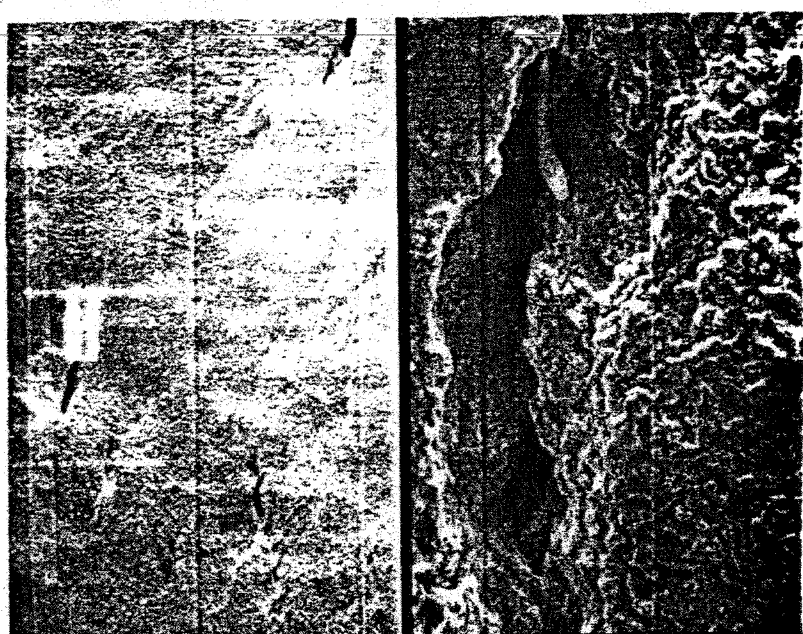
Photograph Figure 2
Magnification - 12X
Prior to cleaning. Showing fracture surface of smaller failed parts.



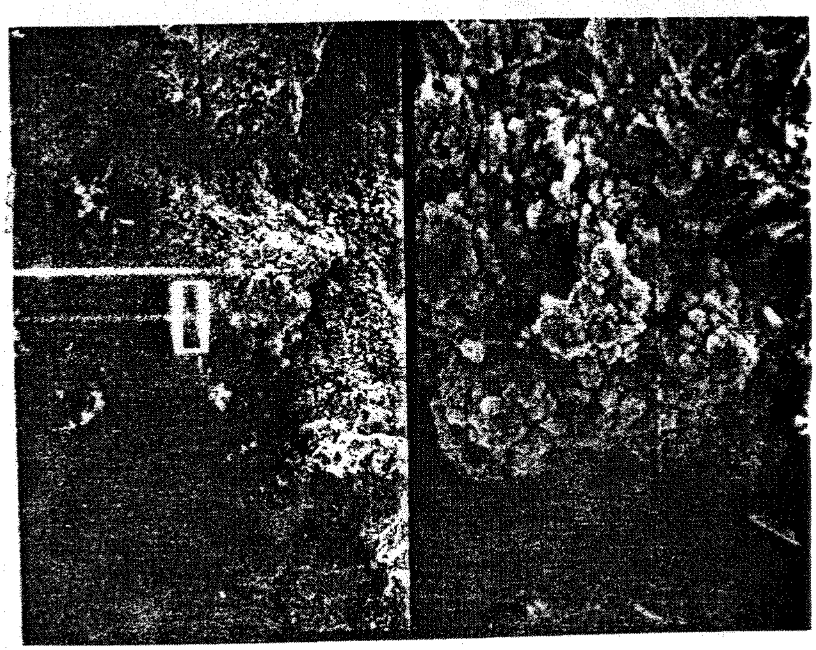
Photograph Figure 3
Magnification 15-75X
Showing secondary crack in the outside diameter surface. EDAX analysis results in Table I.



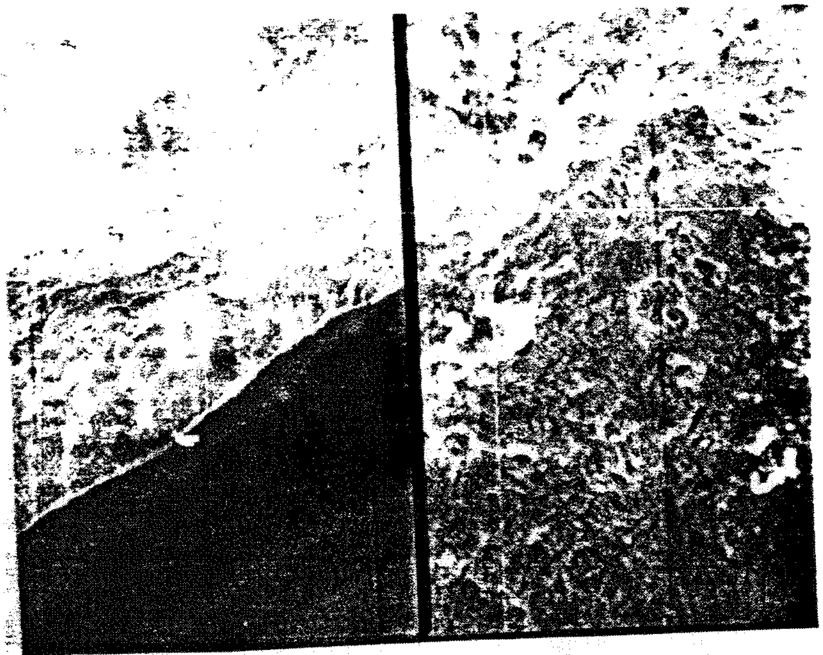
Photograph Figure 4
Magnification - 15X
Showing inside diameter surface
Note pitting and multiple
cracking.



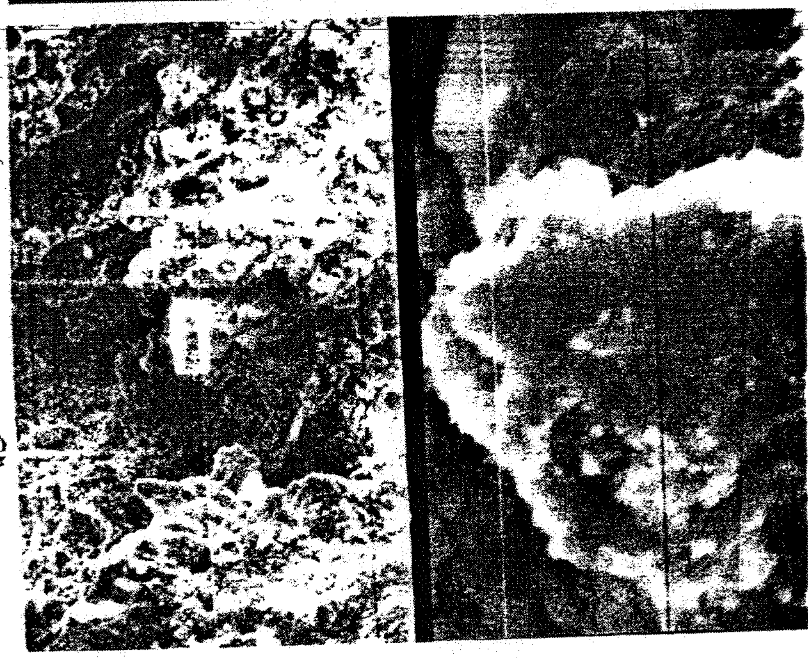
Photograph Figure 5
Magnification 15-75X
Showing pitting of inside tubing.
Noted is depth of secondary
crack. EDAX analysis in Table
I.



Photograph Figure 6
Magnification 50-500X
Showing fracture surface of
outer diameter prior to cleaning
Suggests an intergranular
fracture mechanism. EDAX
analysis in Table I.



Photograph Figure 7
Magnification 35-350X
Showing inside diameter surfac
prior to cleaning. This fractur
shows some fatigue which is
most probably thermal in natur
EDAX analysis in Table I.



Photograph Figure 8
Magnification 150-1500X
Showing intergranular type
failure of area near that shown
in Figure 7. EDAX analysis in
Table I.

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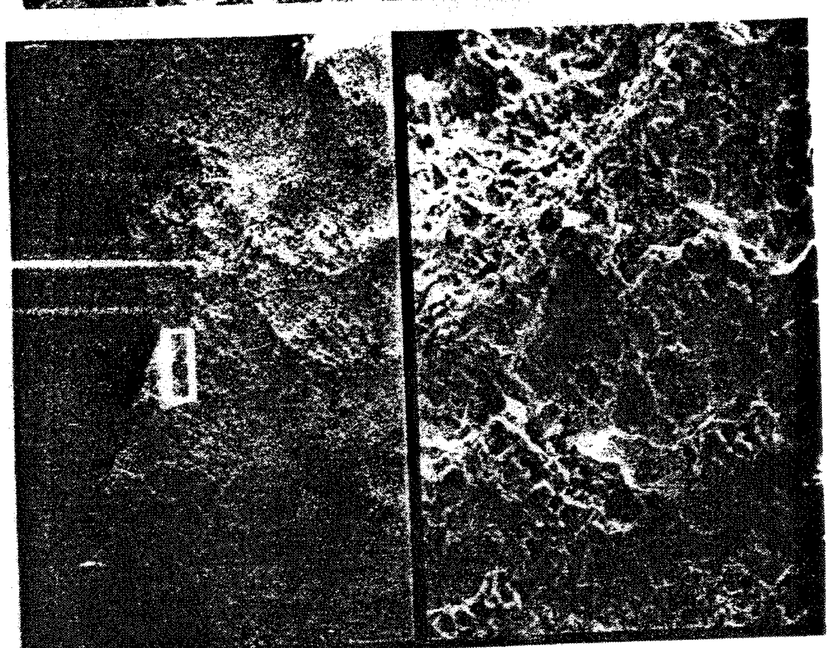
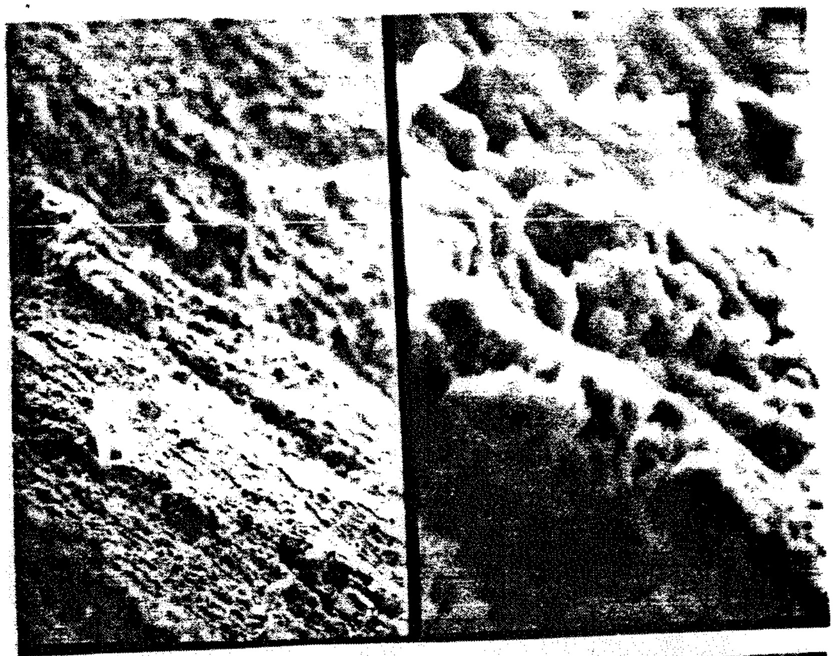
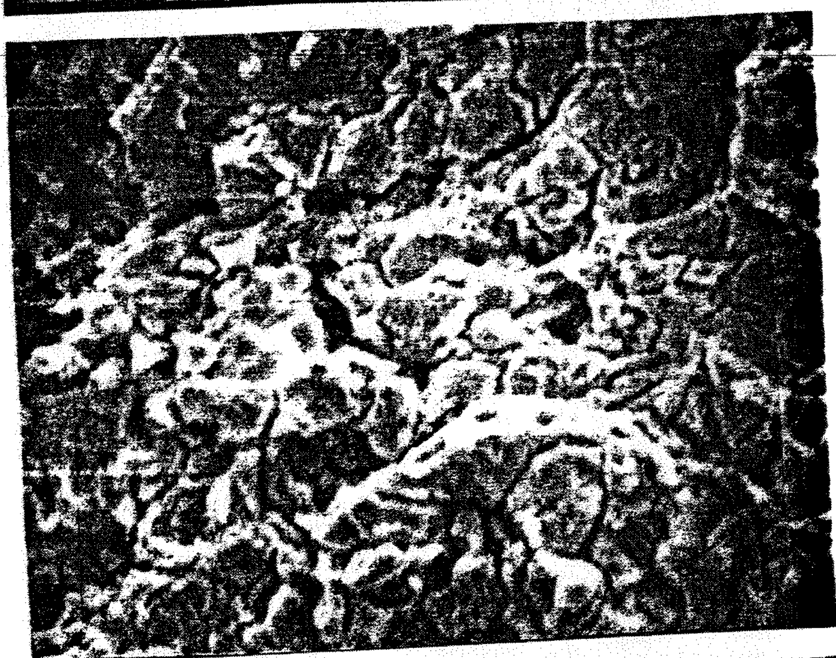


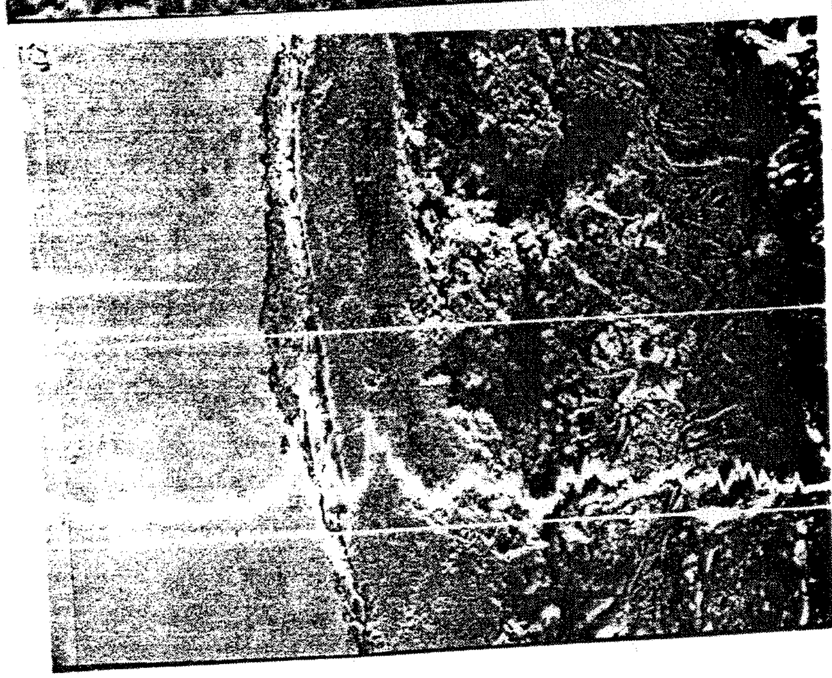
Photograph Figure 9
Magnification 35-350X
Showing intergranular cracking
of inside diameter area after
cleaning.



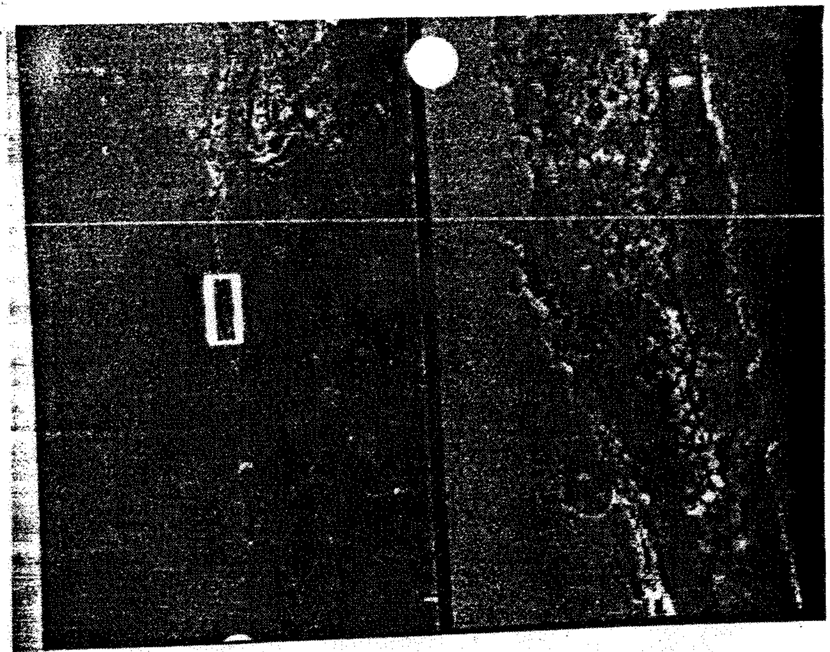
Photograph Figure 10
Magnification 150-1500X
Showing some fatigue striation: occurring at the inside diamete surface. These are most likely the result of thermal and fatigue striations.



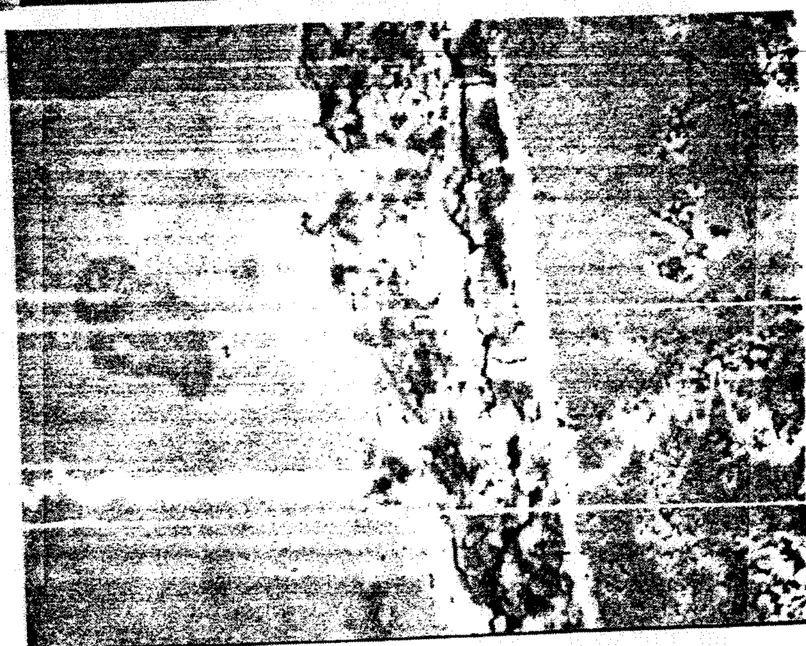
Photograph Figure 11
Magnification - 1000X
Showing intergranular crackin; at outside diameter surface. This is definitely the result of stress rupture failure.



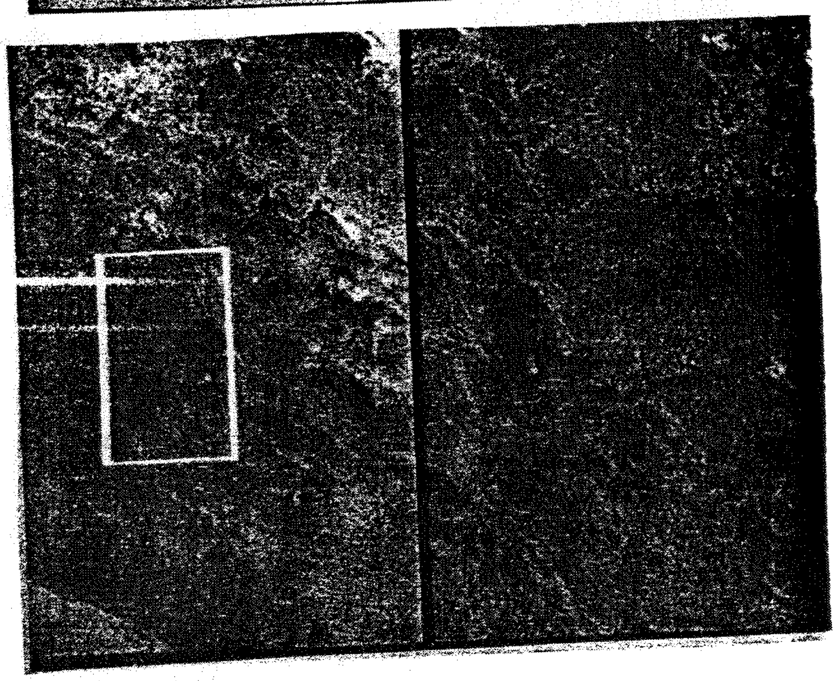
Photograph Figure 12
Magnification - 120X
Line profile for Sulfur. Showi high Sulfur content in seconda: cracking.



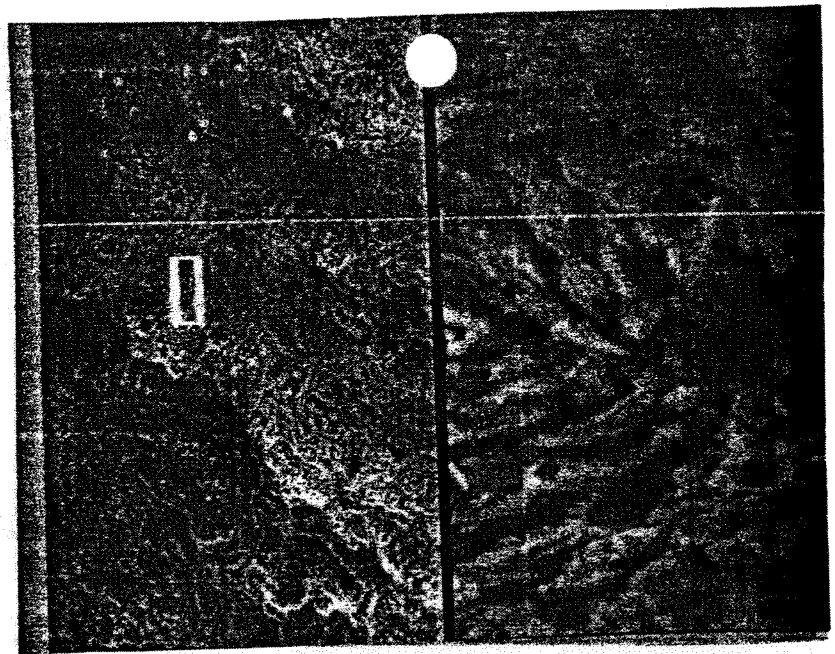
Photograph Figure 13
Magnification 40-400X
Showing separate area and a secondary crack at inner diameter.



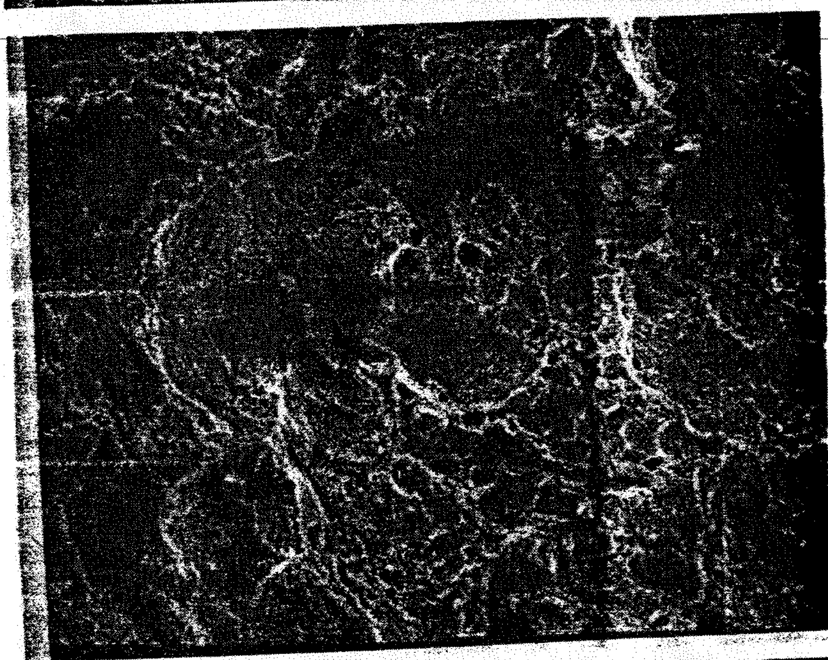
Photograph Figure 14
Magnification - 400X
Showing line profile analysis fo Sulfur. Noted is high Sulfur content in crack area.



Photograph Figure 15
Magnification 75-225X
Showing intergranular cracking at inner diameter surface.



Photograph Figure 16
Magnification 350-3500X
Showing intergranular fracture of inner diameter area.



Photograph Figure 17
Magnification - 350X
Showing intergranular rupture failure at mid section.

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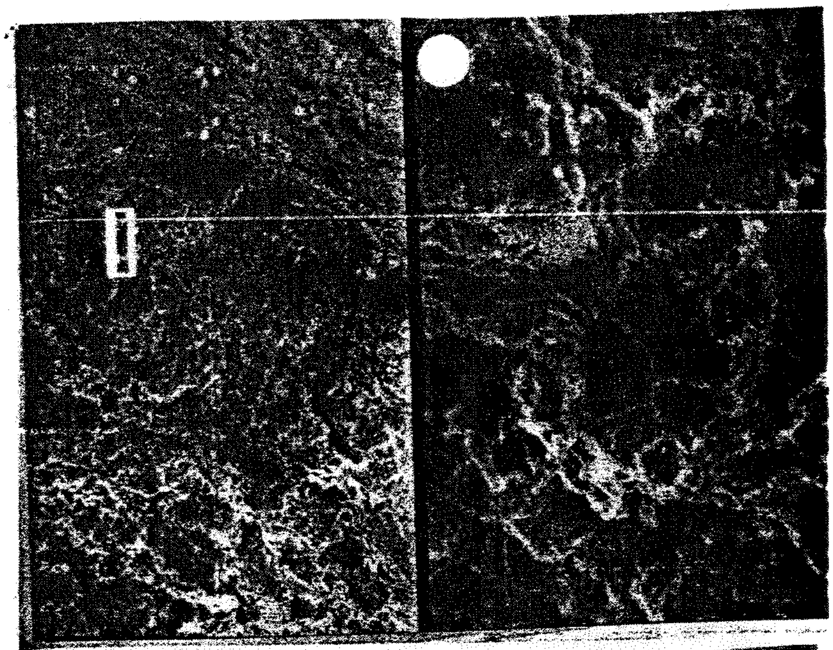
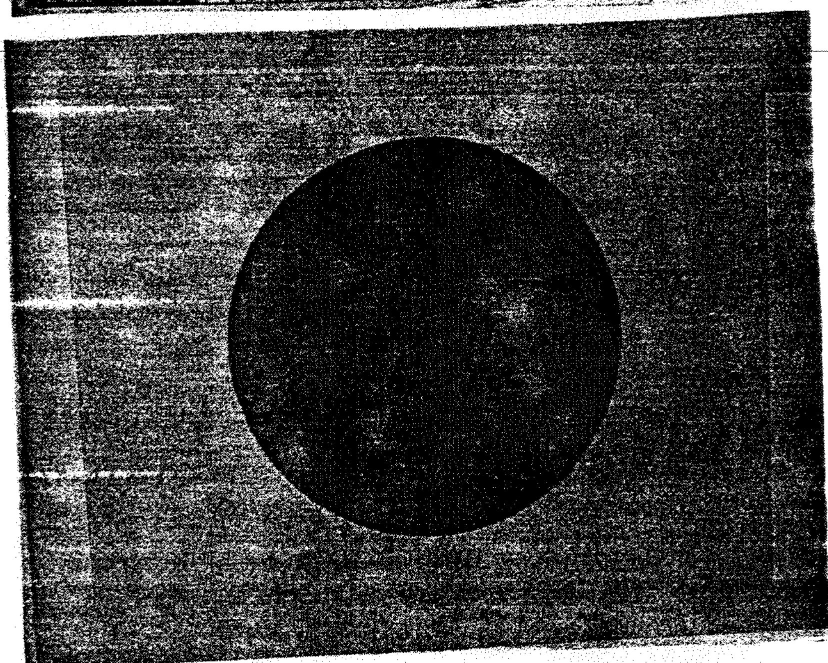
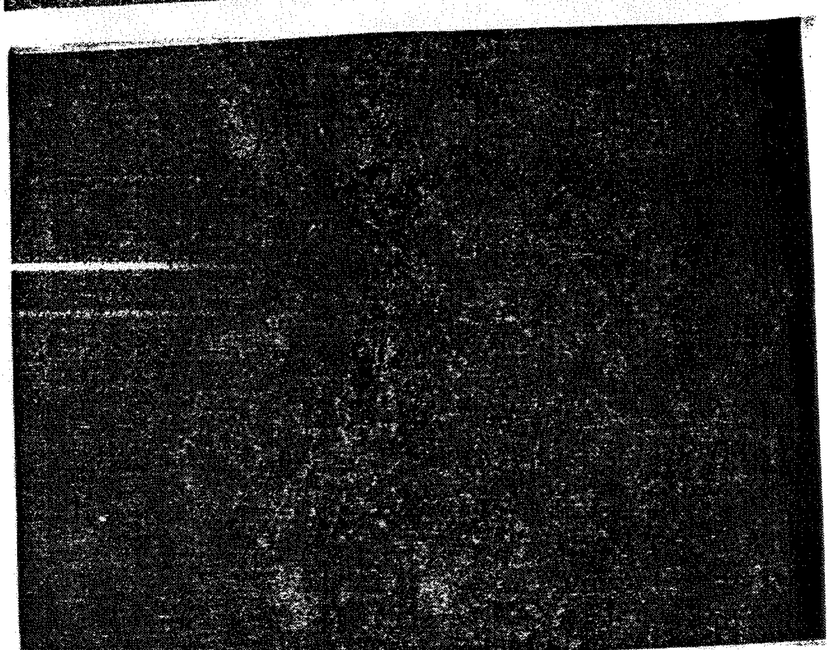
Photograph Figure 18
Magnification - 200X
Showing outside diameter failu[re]
to be intergranular in nature.



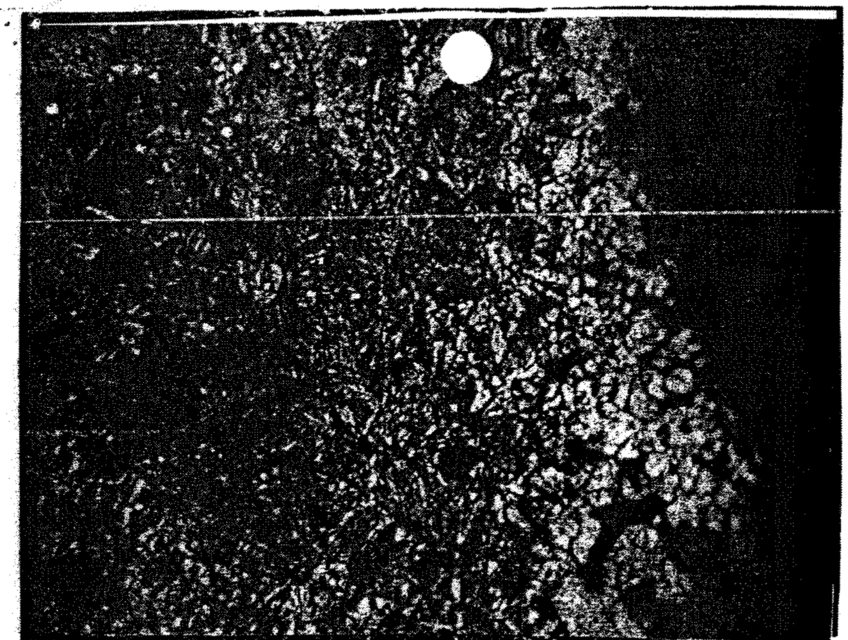
Photograph Figure 19
Magnification 100-1000X
Showing intergranular cracking at the outside diameter. This is rupture in nature.



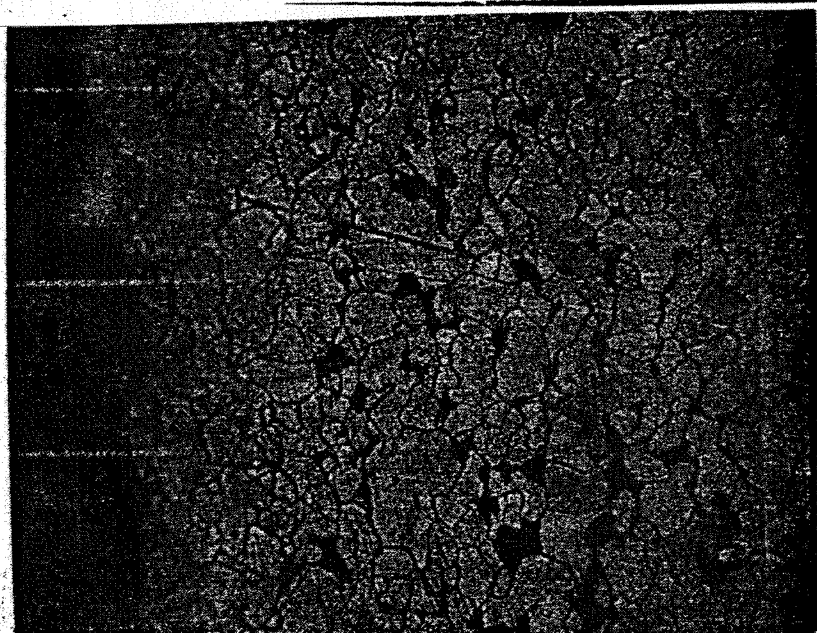
Photograph Figure 20
Macro showing tubing to be seamless and no signs of hydro gen embrittlement.



Photograph Figure 21
Magnification - 365X
Etched in 3% Nital. Showing inner diameter near failure to be tempered martensite. Hard ness is 355 DPH.



Photograph Figure 22
Magnification - 365X
Etched in 3% Nital. Showing structure at outer diameter of tubing to be decarb. Decarb area has hardness of 155 DPH compared to subsurface hardness of 400 DPH.



Photograph Figure 23
Magnification - 365X
Etched in 3% Nital. Showing inner diameter of unaffected region. Structure is normalized. Hardness is 148 DPH.

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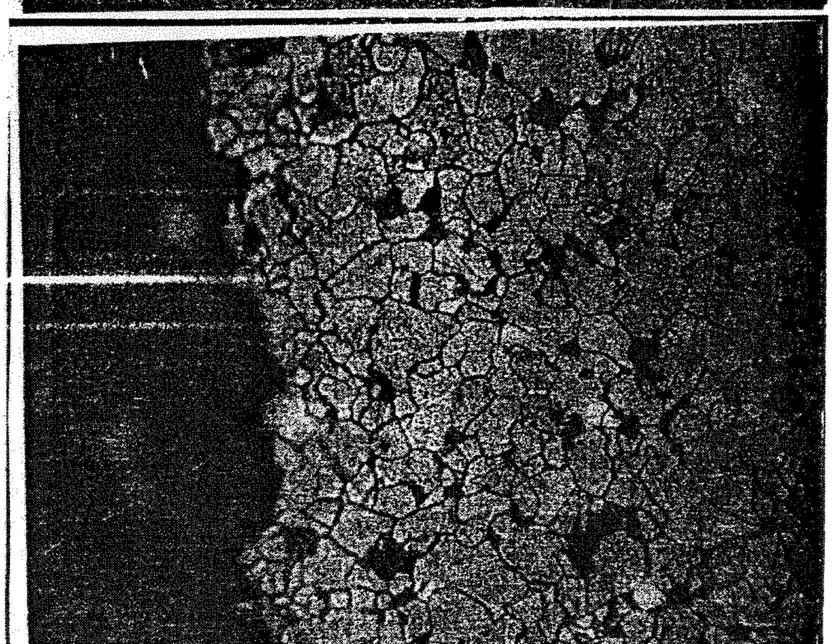

Photograph Figure 24
Magnification - 365X
Etched in 3% Nital. Showing outer diameter of unfailed area. Structure is normalized. Hardness is 160 DPH.