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EXAMINATION OF CRACKED BOILER SAMPLES FROM T.S.S. 'PRINCESS HELENE.'

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Examination of a cracked section of steel plate and a tube taken from one of the boilers of T.S.S. "Princess Helene" showed that the plate conformed to the chemical requirements of AISI 1020. The tube composition resembled AISI 1006.

No material defect was detected, in the plate or tube, which appeared to contribute to the formation of ligament cracks. Random shallow pits were observed on the water side of the plate but no evidence of inter-crystalline stress corrosion (caustic cracking) was observed.

The hardness, chemical composition, micro-structure and tensile properties appeared normal for the plate and tube material. Nothing was observed which would be expected to cause difficulty during welding.

Cracking was attributed to the cyclic action of thermal stress producing fatigue cracks at a change in section. These cracks propagated slowly, finally resulting in the severance of two tube-hole ligaments. Traces of corrosion product were observed on the crack surface, showing that this surface had been exposed to boiler water for some period of time.

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INTRODUCTION

On April 1, 1960, Mr. R.C. Blyth submitted a cracked section of steel plate which had been cut from the water drum tube plate of the Johnson boiler in the C.P.R. ship T.S.S. "Princess Helene." It was requested that metallurgical examination of this specimen be carried out to determine if intercrystalline corrosion or defective material had contributed to formation of the crack. Also submitted for examination was a 6-in. length of boiler tubing which had been removed at the time the ligament cracks were repaired.

The ship is a C.P.R. ferry in regular service between Saint John, N.B. and Digby, N.S. and hence, the boilers are subjected to cyclic heating and cooling. Prior to detection of these cracks, this boiler gave satisfactory service for 27 years.

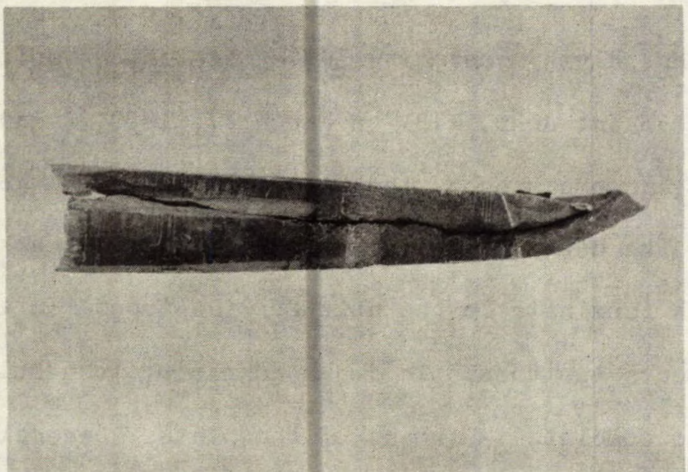
Mr. Blyth's covering letter stated, "During a visit to the ship at Saint John, N.B. on March 27, 1960, I made a survey of the boiler, accompanied by the Steamship Inspector and Lloyds' surveyor. The defects consist of several short cracks in the tube plate which terminate in the hole for the tube. In two cases the crack connects one tube hole to an adjoining tube hole, and extends through the complete thickness of the plate. Several of the cracks were cut out to ascertain their depth. The metal in way of the crack showed no unusual condition; there was no indication of brittleness.

Boiler repairs are now in progress, consisting of cutting out all cracks in the plate, building up same by electric welding, and fitting plugs in the tube holes. This method of repair has been approved by the Steamship Inspector and by Lloyds' Surveyor.

In order to ascertain the cause of the defects, I have requested the Chief Engineer of the ship to forward to your office a specimen of the split tube and two sections of the water drum plate between the tube holes containing the cracks."

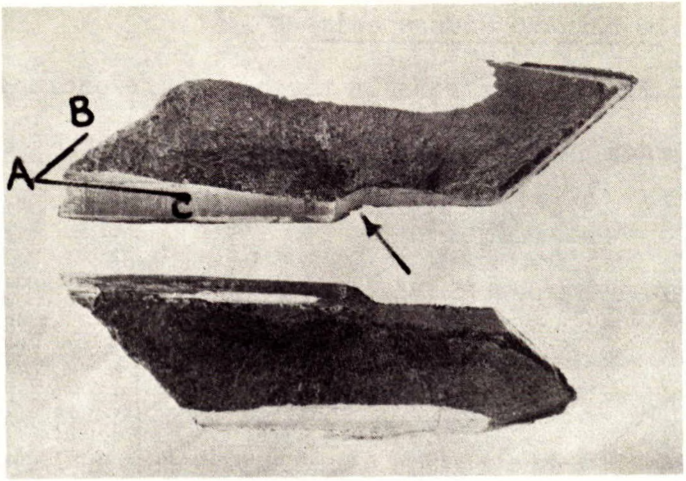
SCOPE

The results of this examination are limited to examination of one of the cracked ligament sections, Figures 1-3, and to examination of a 6-in. length of boiler tube removed at the same time as the split tube. The split tube was not available for examination.



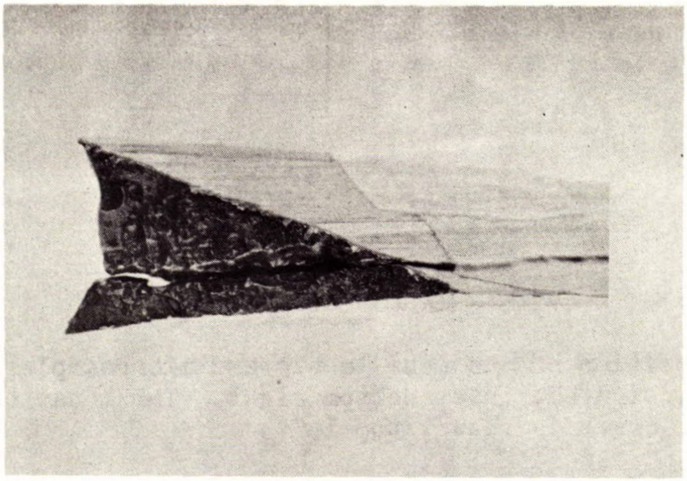
Actual size

Figure 1. Tube hole surface (left), water side (right), and ligament crack. This metal, containing a crack, was cut from the water drum plate between two tube holes.



Actual Size

Figure 2. Crack surfaces, water side (right).
The appearance of the fracture suggests that the crack started on the water side at the change in section where the tube hole surface opened into the water drum (arrow).

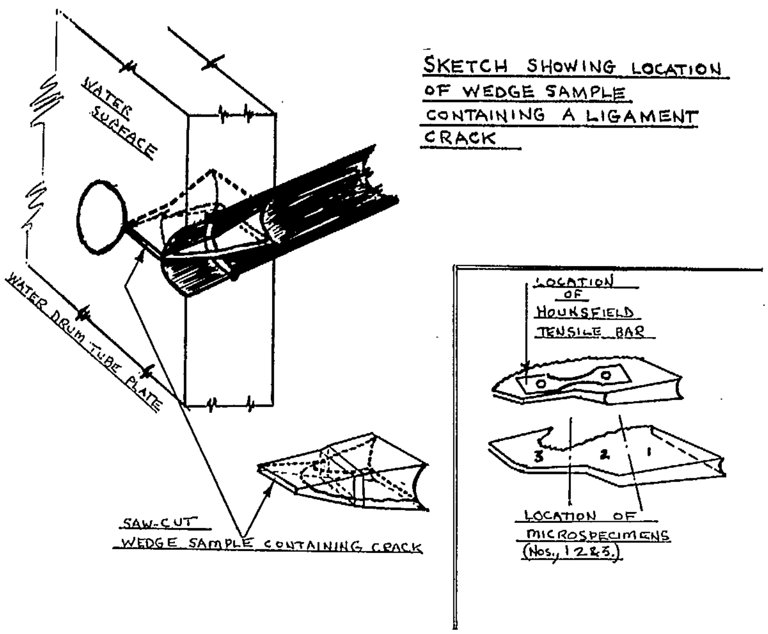


Actual Size

Figure 3. Fire side, water drum plate.
The fire side surface is slightly pitted, as illustrated left foreground.

Location of Tensile Bar and Microspecimens

The location of the tensile bar and microspecimens in relation to the crack is shown in the sketch, Figure 4.



X1/3

Figure 4. The position of the tensile bar and microsamples is illustrated, inset bottom right. The location of the crack is shown, top left.

EXAMINATION

Metallurgical examination of the cracked plate and of the tube section were carried out as follows:-

Visual examination - (plate and tube)

Metallographic examination - (plate and tube)

Hounsfield tensile test - (plate adjacent to crack).

Hardness tests (plate and tube).

Chemical analysis.

Visual Examination

The appearance of the crack surface, illustrated in Figure 2, suggests that the crack originated on the water side, where the tube hole surface met the water surface of the drum plate. The crack later changed direction and propagated, leaving a radial fracture pattern.

The fire side of the plate, Figure 3, appeared to be clean and was covered with an adherent black scale and was mildly pitted. The water surface of the plate, Figure 1, appeared to be clean and did not seem to be excessively coated with oxide or boiler deposit.

Metallographic Examination

Water Drum Tube Plate Section:

The portion of the fractured plate, illustrated at the top of Figure 2, was cut into three sections and was examined metallographically. No indication of unusual corrosion or of intercrystalline cracking was observed although, as expected after

27 years of service, numerous shallow pits were present on the water side of the plate. These pits were filled with corrosion product. The path of the crack was transcrystalline and contained traces of corrosion product on the fracture surface, indicating that the crack had been exposed to the boiler water for a period of time prior to examination.

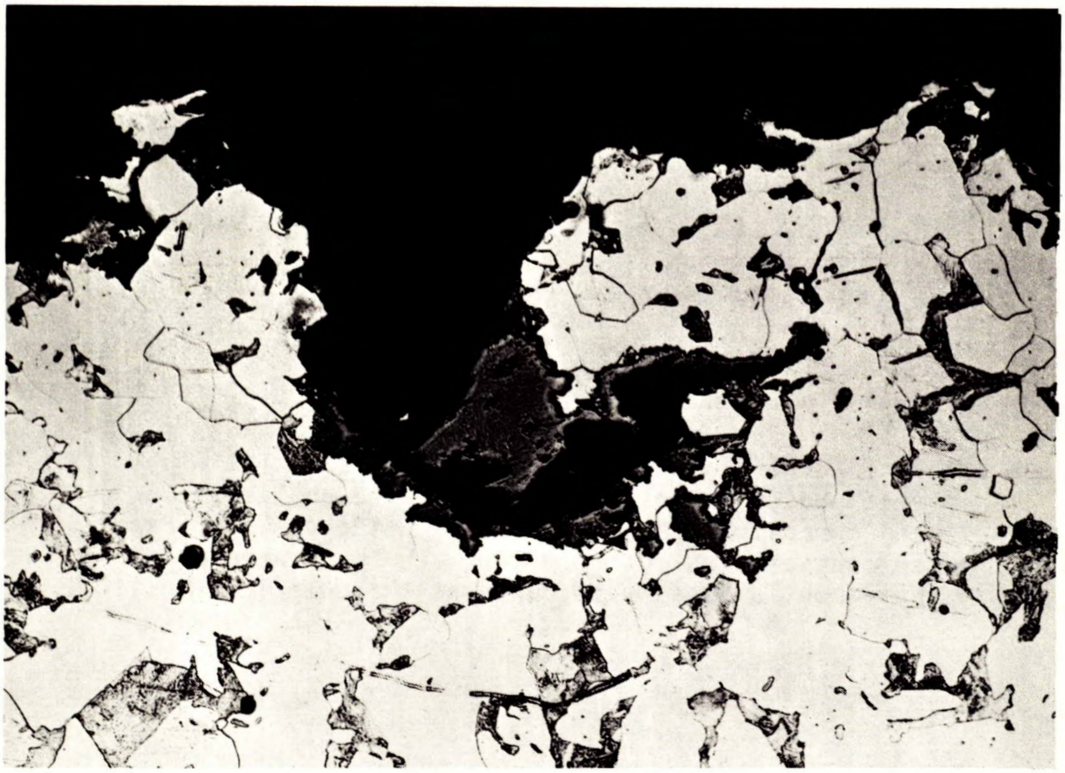
The plate microstructure of ferrite and pearlite was consistent with a carbon content of 0.21%. The steel appeared normal with respect to cleanness.

A shallow zone of heat-affected metal, where the pearlite was partially spheroidized, was observed on the tube hole surface in the position marked by the solid line in Figure 2. The affected zone was about 0.16 in. deep at position A, Figure 2. This metal should not have any adverse effect on mechanical properties and is not significant unless it indicates the presence of an adjacent weld or some condition of local overheating during operation of the boiler. The spheroidization observed could have been produced by heating in the temperature range 1000 to 1300°F for a short time or by heating for a longer period of time at lower temperature.

Figure 5 shows the absence of intercrystalline attack on the fracture surface and illustrates typical traces of corrosion product observed on this surface.

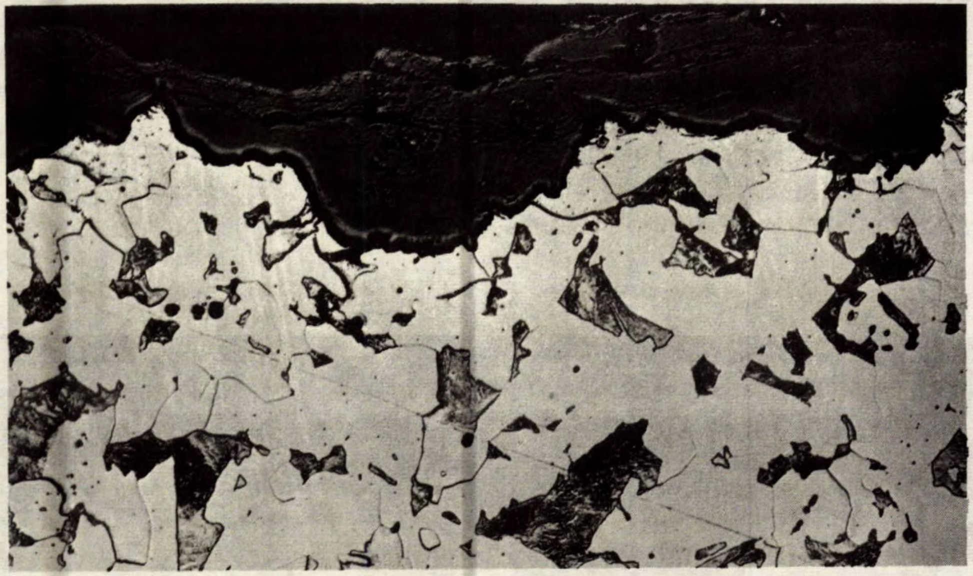
The plate microstructure, containing numerous random but shallow pits, for the surface in contact with the boiler water (water side) is illustrated in Figure 6.

The heat-affected microstructure of the metal in the location corresponding to position A, Figure 2, is shown in Figure 7.



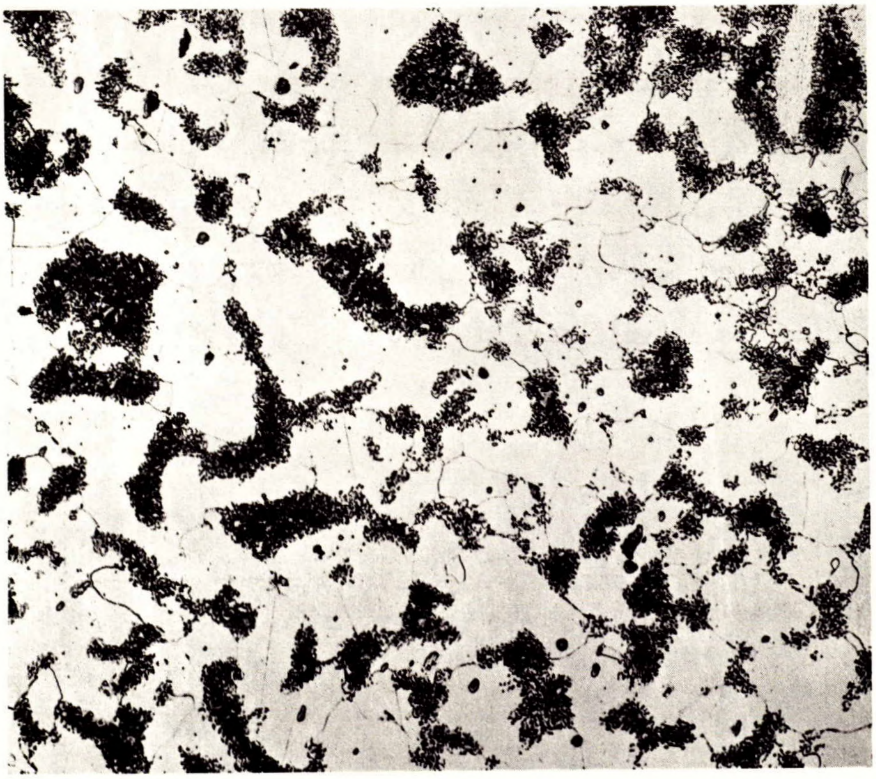
X150

Figure 5. Crack surface showing corrosion product and trans-crystalline fracture path.
No evidence of intercrystalline (caustic) attack was observed.



X150

Figure 6. Water drum plate - water side $\frac{1}{2}$ in. from fillet. This photomicrograph illustrates the shallow pits and corrosion product observed on the plate surface in contact with boiler water. The pits were similar but about 3 times this depth at the change in section.



X150

Figure 7. Water drum plate - spheroidized microstructure at the location corresponding to position A, Figure 2.

Boiler Tube Sample:

Metallographic examination of transverse sections cut through the sample of boiler tube supplied for examination showed that the carbon content of the steel was very low and appeared similar to that of seamless steel boiler tubing supplied to ASTM A-83-55T, having a maximum carbon content of 0.08%. The metal was clean and had a ferritic microstructure with traces of coarse carbide, as illustrated in Figure 8.

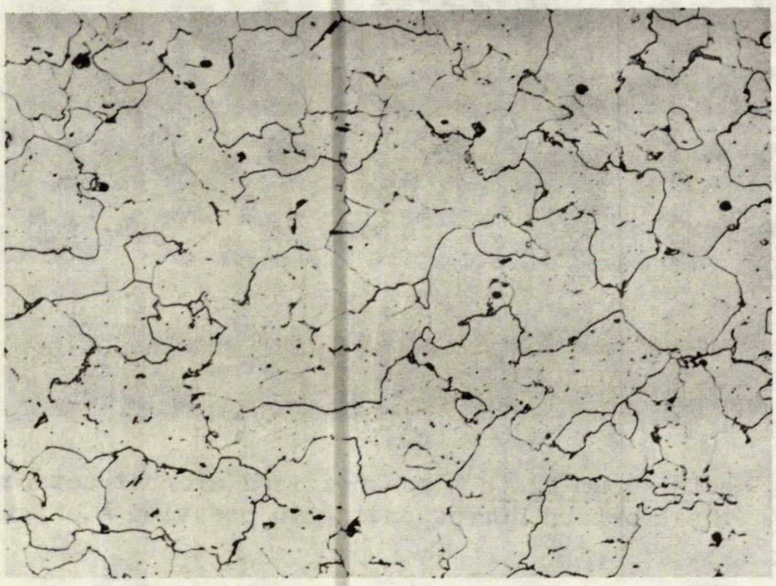


Figure 8. Typical microstructure of boiler tube taken from T.S.S. "Princess Helene," Johnson boiler.

Hounsfield Tensile Test

A flat Hounsfield tensile test bar was cut from the plate metal, as shown in Figure 4, and was broken in tension. The results are shown in Table 1.

TABLE 1.

Hounsfield Tensile Test

Sample	Ultimate Tensile Strength		Yield Strength		Elongation % 1/2 In.* % 2 In.**	Hardness Rockwell 'B'
	psi	long tons	psi	long tons		
Hounsfield Bar	62,700	28.0	46,300	20.7	30*	73-76
AISI-1020 Cold-Drawn	61,000	27.2	51,000	22.8	15**	75

The mechanical properties are approximately comparable to cold-drawn AISI-1020 steel.

Hardness Tests

The hardness of the water drum tube plate was Rockwell B 73-76, measured on the flat surface of the Hounsfield tensile bar. The hardness of the boiler tube, measured at the centre of the cross section, was Rockwell B 45-46.

Chemical and Spectrographic Analyses

The results of chemical and spectrographic analyses made on the water drum plate and on the boiler tube are shown in Table 2.

TABLE 2

Chemical and Spectrographic Analyses (Per Cent)

Element	Water Drum Plate	AISI-1020	Boiler Tube	AISI-1006
Carbon	0.21	0.18/0.23	0.07	0.08 max.
Manganese	0.51	0.30/0.60	0.30	0.25/0.40
* Silicon	0.26			
Sulphur		0.050 max.		0.050 max.
Phosphorus		0.040 max.		0.040 max.
* Chromium	0.35			
* Molybdenum	< 0.01			
* Nickel	< 0.10			
* Copper	0.08			
* Tin	0.005			
* Aluminum	0.01			

* Quantitative spectrographic analysis.

The chemical composition of the water drum plate appears to conform to AISI-1020; the composition of the boiler tube appears similar to that required by AISI-1006.

The residual content of the plate should not affect its weldability.

DISCUSSION

No intercrystalline attack along grain boundaries or preferential attack of carbide was observed. A normal quantity of shallow random pits were observed on plate surfaces in contact with the boiler water. These pits were filled with corrosion product. Traces of similar corrosion product were observed on the fracture surface, showing that this surface had been exposed to boiler water. The presence of corrosion product on the fracture surfaces, the record of 27 years' service without leakage, the location of the cracks at a change in section of the tube plate, and the history of cyclic boiler operation suggest that the cracks have propagated as a result of cyclic stresses.

Nothing was observed to indicate defective material in the water drum plate or in the boiler tube specimen. The chemical composition of the water drum plate (insofar as the quantity of material allowed analysis) corresponded to AISI-1020. The chemical composition of the tube corresponded to AISI-1006.

The tensile strength, yield strength and elongation of the steel, measured adjacent to the crack, appeared normal for mild steel boiler plate. The hardness of Rockwell B 73-76 was consistent with the tensile strength. Nothing in the mechanical properties or hardness indicated embrittlement of the steel, or suggested difficulty in making repairs by welding.

A shallow zone of spheroidized pearlite was present on the tube hole adjacent to the fire surface. This structural damage was limited to a shallow zone and should not affect the steel's properties, but its presence shows that the metal in this region has been heated, probably in the range 1000 to 1300°F.

The appearance of the fracture suggested a slowly propagating crack typical of fatigue cracking rather than a sudden tensile failure. This opinion is supported by the presence of corrosion product on the crack surface and by the appearance of the fracture.

SUMMARY

1. The appearance of the fracture, the fact that the crack had propagated slowly and the presence of corrosion product on the crack surface suggest fatigue failure possibly as a result of cyclic thermal stresses in the presence of a change of section.

2. A shallow zone of metal in the water drum plate, adjacent to the tube at the fire surface, had been heated to a temperature sufficient to cause spheroidization of the pearlite. (This zone is marked by the solid line A-B-C, Figure 2).

3. The steel composition, tensile strength, ductility and hardness appear normal for AISI 1020, cold-finished, carbon steel plate. The boiler tube material was a soft, low-carbon steel, resembling seamless boiler tubing supplied to ASTM A-83-55T having the

approximate analysis of an AISI-1006 grade of steel.

4. No evidence of intercrystalline stress corrosion (caustic cracking) was observed in the water drum plate or boiler tube specimens.

5. The content of residual elements was low and should present no unusual hazard during welding.

DEP:ac