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EXAMINATION OF SAMPLES CUT FROM CCGS JOHN A. MacDONALD SPARE PROPELLER BLADES

by

D. E. PARSONS

PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Inspection of six spare cast steel propeller stub blades from CCGS John A. MacDonald, after approximately thirteen months of marine service, revealed the presence of crevice defects on the working surfaces of five blades. The crevices were most numerous on the aft face of two of the starboard blades.

Metallurgical examination showed that crevice defects resulted from selective corrosion following chain sulphides situated in primary grain boundaries. The presence of grain boundary sulphides was attributed to low recovery of aluminum and titanium-zirconium deoxidizing additions and to segregation of sulphur in the affected heavy section of the casting.

It was recommended that, pending the results of metallurgical examination of two broken blades, the possibility of electrolytic action, due to the presence of stray currents or dissimilar metals, be reviewed. Modifications already undertaken by the propeller manufacturer, in design, casting procedures and deoxidation are expected to avoid the presence of primary grain boundary films in integral propeller blades.

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INTRODUCTION

On September 24, 1962, samples cut from the CCGS John A. MacDonald spare propellers were submitted, by Mr. S.P. Morrison, Supervisor of Construction, Department of Transport, Lauzon, Quebec, to the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, for metallurgical examination.

The decision to examine samples cut from these spare propellers, prior to weld repair, was a consequence of a conference between Department of Transport, Davie Shipbuilding Company, Wm. Kennedy and Sons Limited, Canadian Steel Foundry and Department of Mines and Technical Surveys personnel, held in Ottawa on September 12, 1962. Subsequent to this meeting, Wm. Kennedy and Sons Limited, and Department of Mines and Technical Surveys officers inspected the spare propellers at Davie Shipbuilding Limited, on September 18, 1962.

The affected blades were spares for the CCGS John A. MacDonald and after service showed a surface condition that caused concern and led to a decision to carry out weld repair of the affected blades. After weld repair the blades were to be retained for future use, hence sectioning and destructive metallurgical examination were not possible. However, two boat samples, four triangular metal samples and chip samples were obtained for metallurgical examination, while the blades were undergoing weld repair.

The spare blades for the starboard, build-up propeller were identified as Nos. 1, 2, 3 and 4, R.H. and for the port, built-up propeller were identified as Nos. 1, 2, 3 and 4, L.H., respectively.

The appearance of the surfaces of six of the cast nickel-vanadium steel propeller blades is illustrated in Figures 1 to 8, inclusive. The locations of the two surface "boat" samples are shown in Figures 1 and 4, respectively. Two blades were not examined at this time.

X1/6 Approx.

Figure 1. No. 2. R.H. Blade Surface. Working Side. Aft Surface. Contains numerous intergranular crevices having depths up to 3/8 in. The location of a boat sample is illustrated. This boat sample intersected one typical crevice.

X1/6 Approx.

Figure 2. No. 3 R.H. Blade Surface. Working Side. Aft Surface. Numerous branching crevices are shown. The surface of the casting has a pitted and etched appearance caused by service in salt water.

X1/6 Approx.

Figure 3. No. 3 R.H. Blade Surface. Forward Surface. Opposite to that shown in Figure 2. "Weld deposits" have not been attacked during service. Minor quantities of crevice defects are present on this surface.

X1/6 Approx.

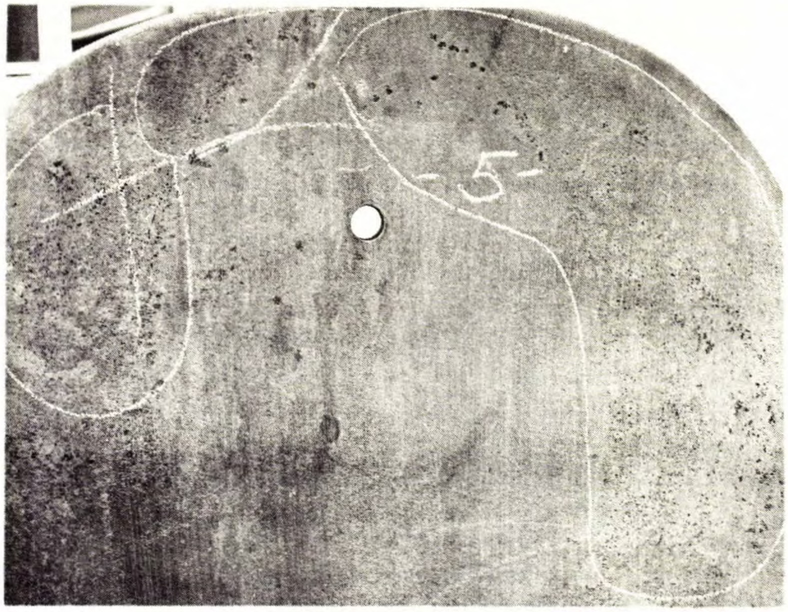
Figure 4. No. 1 R.H. Blade Surface. Working Side. Aft Surface. Except for one central area crevices were absent on this surface. Similarly, the forward surface (Fig. 5) contained only a few regions where chipping and weld repair were necessary. The location of a "boat" sample is illustrated. The surface of this boat sample contained pits but did not intersect any crevice cracks.

X1/6 Approx.

Figure 5. No. 1. R.H. Blade Surface. Forward Side. This surface contained a few crevices in one local area. The deep etched appearance of the steel surface is illustrated. The areas that have resisted pitting may be weld deposits.

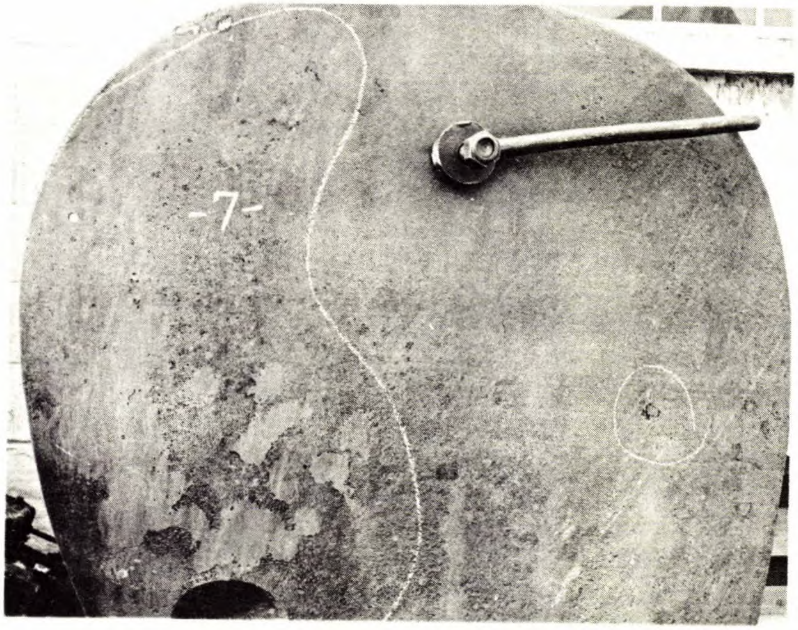
X1/6 Approx.

Figure 6. No. 2. L.H. Blade Surface. Working Side. Forward Surface. Relatively small crevices are randomly distributed on the face of this blade.



X1/6 Approx.

Figure 7. No. 3 L.H. Blade Surface. Non Working Side. Aft Surface. Cavitation is visible at the edge surfaces, but only minor pitting is present on the central surface.



X1/6 Approx.

Figure 8. No. 4 L.H. Blade Surface. Non Working Side. Aft Surface. A minimum of pitting was observed in this blade.

MATERIAL SUBMITTED FOR METALLURGICAL EXAMINATION

Samples obtained for metallurgical examination while the propellers were being chipped, prior to weld repair (October 1962 at Davie Shipbuilding Limited) are listed in Table 1.

TABLE 1

Materials Submitted

Sample	Description
Blade No. 1, R.H.	(A) Boat Sample (no crevice but has pitted surface)
" " "	(B) Two Corners (ahead and astern sides)
" " "	(C) Chip Samples
Blade No. 2, R.H.	(A) Boat Sample (contains crevice and pits)
" " "	(B) Two Corners (ahead and astern sides)
" " "	(C) Chip Samples
Blade No. 4, R.H.	(A) Chip Samples
" " "	(B) " " (old weld)
Blade No. 2, L.H.	(A) Chip Sample
Blade No. 3, L.H.	(A) Chip Sample

VISUAL INSPECTION OF BLADE SURFACES

The results of visual inspection made to assess the severity of the crevice defects, of cavitation and of pitting on the forward and aft surfaces of stub blades from the port and starboard propellers, are shown in Table 2. This inspection indicated that the blades most affected by the presence of crevices after service were No. 2, R.H., No. 3, R.H. and No. 1, R.H., respectively. The aft surfaces of three of the starboard blades were most affected. The No. 4 L.H. blade was least affected. (Blades Nos. 4 R.H. and 1 L.H. were not inspected).

TABLE 2

Visual Inspection of Blade Surfaces and Observations

Starboard Blades

No. 1 R.H. Fwd	Minor quantity of crevice defects.
No. 1 R.H. Aft	(Stamp Side) Moderately affected, crevices having dendritic pattern.
No. 2 R.H. Fwd	Moderately affected by presence of crevices.
No. 2 R.H. Aft	(Stamp Side) Most severely affected by branching crevices, 4 longitudinal zones.
No. 3 R.H. Fwd	Good condition, except for minor attack and pitting adjacent to root.
No. 3 R.H. Aft	(Stamp Side) Numerous branching crevice defects, fairly deep pits.
No. 4 R.H. Fwd	Not inspected - (previously repaired).
No. 4 R.H. Aft	" " " "

Port Blades

No. 1 L.H. Aft	Not inspected - (previously repaired).
No. 1 L.H. Fwd	" " " "
*No. 2 L.H. Aft	"Normal pitting" only - some cavitation at trailing edge.
No. 2 L.H. Fwd	(Stamp Side) Shows random short crevices, fairly deep and numerous pits.
No. 3 L.H. Aft	Nick at edge of blade, minor pitting, cavitation observed at edge of blade.
No. 3 L.H. Fwd	General pitting - small central area contains some crevices, 3/4 in. length.
No. 4 L.H. Aft	Best blade.
No. 4 L.H. Fwd	Best blade

R.H. - Right Hand
L.H. - Left Hand

* "Normal pitting" was not defined; however, after some period of salt water service all blades had an etched and pitted appearance, similar to that obtained by laboratory deep-etching procedures.

METALLURGICAL EXAMINATION OF SAMPLES FROM BLADES NOS. 1 AND 2 R.H.

Examination was made as follows:

(1) Chemical Analyses - by wet methods using millings obtained from one of each of the triangular blocks No. 1 R.H. and No. 2 R.H.

(2) Metallographic Examination of Boat Samples. No. 1 R.H. (pitted) and No. 2 R.H. (pitted and intersecting a crevice).

(3) Impact Tests Four Charpy V-notch bars were broken. One bar was cut from each of the triangular samples. Two bars were broken at room temperature and two were broken at 0°C (32°F). These bars were taken from a chilled portion of the casting and were not affected by crevices or grain boundary sulphides.

Chemical Analyses

The results obtained by chemical analysis are shown in Table 3(a)

TABLE 3(a)

Chemical Composition (Per Cent)

Sample	C	Mn	Si	P	S	Ni	V	N	Zr	Al
No. 1 R.H.	0.14	0.80	0.55	0.012	0.022	2.10	0.13	0.009	0.01	0.05
No. 2 R.H.	0.12	0.73	0.33	0.016	0.019	1.98	0.13	0.009	0.01	0.02

Nitrogen was determined by the Kjeldahl wet method.

The aluminum recoveries were approximately 40% and 16% for a 2-1/2 lb/ton addition. The residual zirconium content is less than is stated to be necessary for the avoidance of Type II eutectic sulphides (1).

Quantitative spectrographic analyses confirmed the zirconium and aluminum contents. The results of quantitative spectrographic analyses are shown in Table 3(b).

TABLE 3(b)

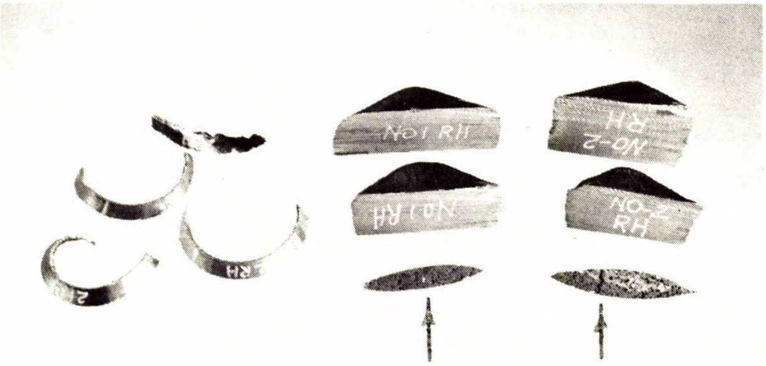
Quantitative Spectrographic Analyses (Per Cent)

Sample	Cu	Sn	V	Mn	Si	Cr	Zr	Mo	Al	Ni	Ti*
No. 2 R.H.	0.12	0.02	0.11	0.68	0.31	0.28	<0.002	<0.01	<0.1	>2.0	0.024

* The residual titanium content is higher than that of the zirconium.

Metallographic Examination

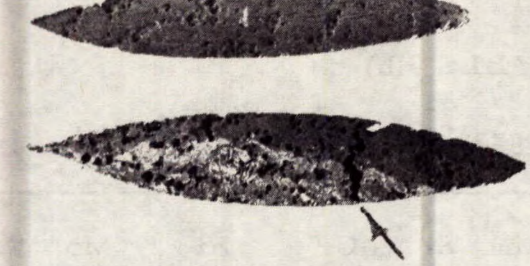
The appearance of the four triangular metal samples, two boat samples and representative chips are illustrated in Figure 9.



X1/4

Figure 9. Samples from Blades No. 1 R.H. and No. 2 R.H. Metallographic examination was made on sections cut along the centre axis of the two boat samples, illustrated (arrows). One of the sections intersected the crevice visible in the boat sample at the right of the picture.

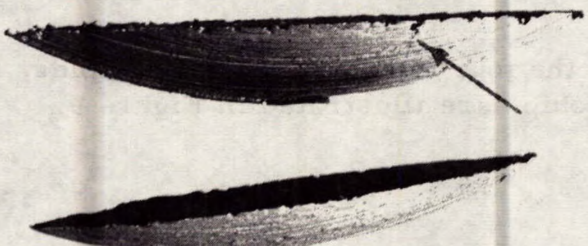
The appearance of the surface of the boat samples at higher magnification is shown in Figure 10.



Actual Size

Figure 10. Sample cut at the surface of blade No. 1 R.H. is shown (top) and a sample cut from blade No. 2 R.H. is shown (bottom).

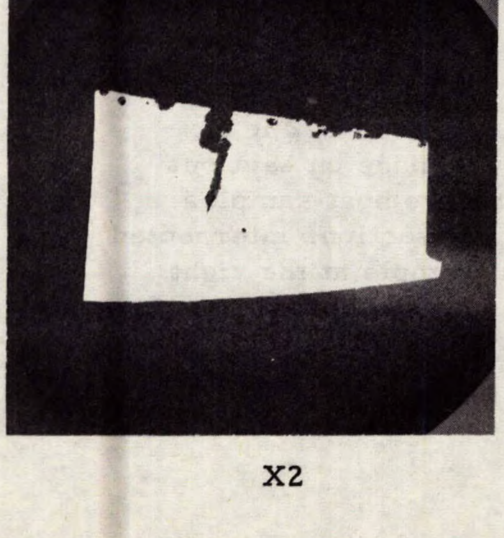
The appearance of the boat samples, viewed in elevation, is shown in Figure 11. The appearance of the crevice on the cut section is marked by the arrow.



X1.2

Figure 11. Side view of boat samples illustrated in Fig. 10. The appearance and depth of the crevice, in section, is illustrated (arrow)

The appearance of a section cut to intersect the crevice illustrated in Figures 10 and 11 and polished for metallographic examination is shown in Figure 12.



X2

Figure 12. Appearance of pits and crevice, viewed in cross section.

Figure 13 illustrates the appearance of the crevice shown in Fig. 12. The crevice is filled with corrosion product, has a sharp tip and is progressing along a sulphide film present in the primary austenite grain boundaries.

as polished X50 Approx Etched: 2% nital

Figure 13. Appearance of oxidized crevice with the tip of the crack following sulphides present in primary grain boundaries.

Figure 14 shows sulphides adjacent to the tip of the crack where corrosion has commenced and has oxidized the surface of the sulphide inclusions.

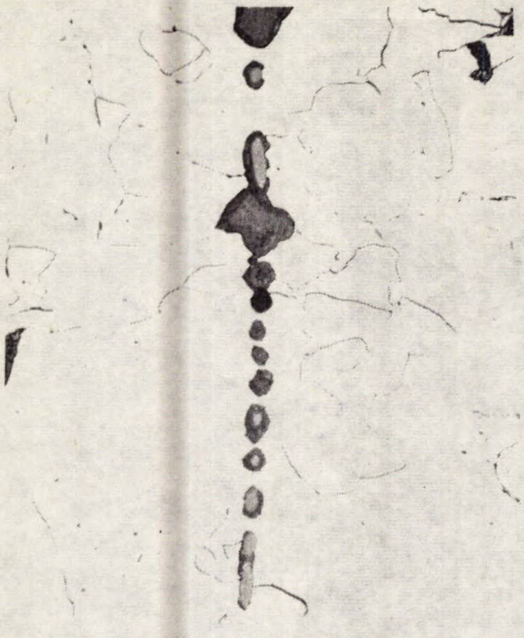


Figure 14. Sulphide particles adjacent to the tip of the crevice after corrosive attack. The surface of the sulphide inclusions is oxidized.

X500 Etched 2% nital

Figure 15 illustrates the appearance of part of the chain of sulphides in a region remote from the tip of the crevice.

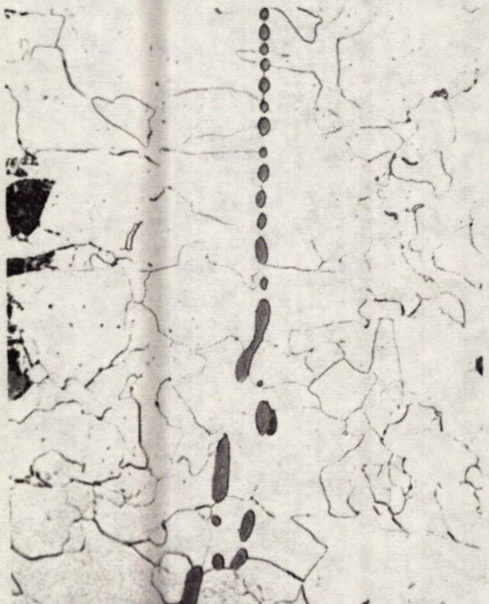


Figure 15. Sulphides forming the grain boundary film in a region remote from the tip of the crack. Corrosion and oxidation have not started in this region.

X500

The continuous chain sulphides were only observed in the location (primary grain boundary) coinciding with the crevice in the sample examined. Minor quantities of eutectic sulphides were observed in regions other than primary austenite grain boundaries. Titanium-zirconium nitride inclusions were also observed. Duplexed inclusions which were typical of areas other than those of the primary austenite grains are illustrated in Figures 16(a) and (b) and in Figures 17(a) and (b).

(a) X500 (b) X500

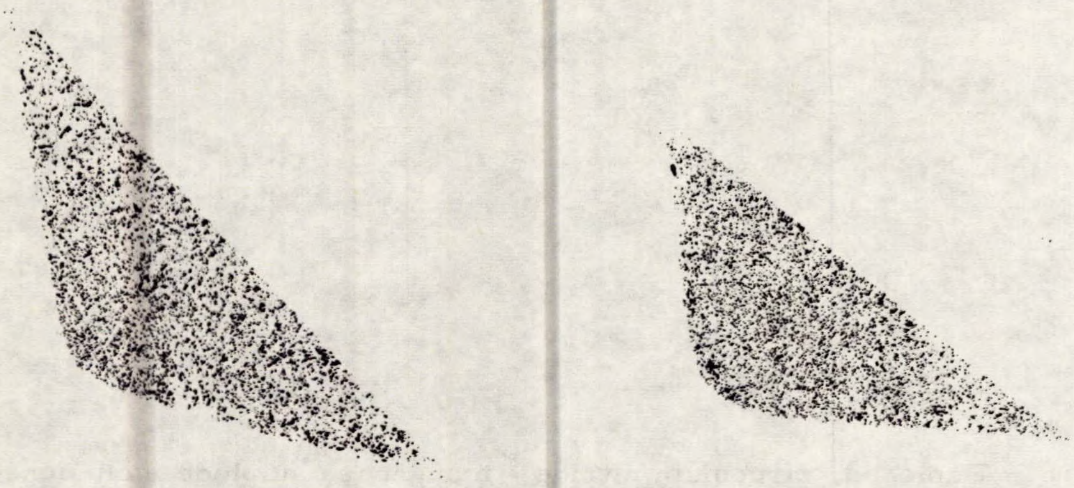
Figure 16. Duplexed, zirconium nitride - manganese sulphide inclusions.

(a) X500 (b) X500

Figure 17. Duplexed inclusions representing the types observed in areas other than primary austenite grain boundaries.

Impact Results

Four Charpy V-notch impact bars were prepared from part of each of the four triangular samples. These bars did not contain any chain sulphides comparable to those that offered a path for corrosion. The appearance of sulphur prints on ground sections used for the impact bars are shown in Figure 18 (a) and (b). The results obtained on the impact bars are shown in Table 4. (The ends of the impact bars were extended by welding with the notch zone cooled by submersion in water).



Actual Size
(a)
No. 1 R.H.

Actual Size
(b)
No. 2 R.H.

Figure 18. Sulphur distribution in triangular samples used for room temperature impact bars. Sulphides comparable to those illustrated in Figure 13 were not observed in this location.

TABLE 4

Charpy V-Notch Impact Strength Measured in Metal Which Did Not Contain Chain Sulphides

	Charpy V-Notch Impact Strength (ft-lb)	
	26°C (80°F)	0°C (32°F)
Sample No. 1 R.H.(a)	*34 ft-lb	*25 ft-lb
Sample No. 2 R.H. (a)	**43 ft-lb	*64 ft-lb

Insufficient metal was available for determination of the effect of chain sulphides on impact strength.

* - Full size 0.394 in Charpy V-notch specimen.
** - Three quarter size 0.270 in. Charpy V-notch specimen.
(The impact bars broke with normal deformation at room temperature The fractures showed cleavage over 70% of the fracture surfaces but did not exhibit any intergranular tendency in the part of the casting which was tested).

DISCUSSION

The crevices appear to be caused by preferential corrosion following chains of sulphides situated in primary grain boundaries. The presence of this type of sulphide is consistent with the low residual quantities of aluminum and titanium-zirconium as determined by analysis. Chain sulphides can result from low recovery of deoxidizing additions of aluminum and zirconium particularly in low carbon steels and even at low sulphur contents(1, 2). The effect of the section size on the tendency to formation of sulphide films is not known. However, in thin sections, silicon deoxidation or aluminum-calcium-silicon deoxidation tend to form spherical "birdseye" inclusions rather than sulphide films (2). Vanadium is stated not to contribute to formation of chain sulphides during solidification (1). Some published data indicate that, for low carbon steel, a residual aluminum content greater than 0.05% is required to avoid the formation of chain sulphides but at or above this level of residual aluminum, difficulty with conchoidal, aluminum nitride, fracture can occur as a consequence of slow cooling and segregation of sulphur in heavy sections.

The present (C.S.F.) practice of using silicon-killed metal cast in dry sand moulds in the presence of a vanadium content of 0.13% should be satisfactory with respect to formation of aluminum nitrides and may avoid the formation of sulphide films. However, few data are available concerning the avoidance of sulphide films in heavy sections having slow cooling rates.

Vacuum deoxidation is very effective in reducing oxygen content to levels where silicon-deoxidized metal without strong deoxidation by aluminum and containing sufficient vanadium for control of grain size, would be less susceptible to gas-porosity (for example, with green sand moulds). Avoidance of excessive furnace superheat may also assist in minimizing gas content while avoiding necessity for strong deoxidizers (aluminum, zirconium or titanium). If stronger deoxidation is necessary, use of aluminum and calcium-silicon might be investigated for the section required, having regard to the formation of grain boundary sulphide and aluminum nitride grain boundary constituent. Use of aluminum, aluminum-titanium, and aluminum-zirconium combinations is not recommended for heavy sections (1).

Possibly use of 3 - 4 lb/ton zirconium without aluminum or titanium would be suitable if strong deoxidation is necessary, providing the recovery of zirconium is sufficient to obtain residual zirconium contents in excess of 0.03% (1). If this practice is contemplated, some experimental work or corroborative information should be obtained to establish the effect of section and cooling rate on the formation of sulphide and nitride films. The use of silicon-killed metal containing approximately 0.10% to 0.15% vanadium followed by pouring into dry sand moulds should afford maximum protection against the formation of aluminum nitrides and may minimize the effect of sulphur segregation in the heavy section.

CONCLUSIONS

1. Surface damage occurred as a result of selective corrosion attack along chain sulphides present at primary grain boundaries.

2. The impact strength at room temperature in areas not affected by chain sulphides, was satisfactory. No tests were carried out in samples in which chains of sulphides were present because of the need to retain the stubs in usable condition until integrally cast propellers are available.

3. The presence of chain sulphides was associated with low recovery of aluminum and zirconium deoxidizing additions. There was no evidence of aluminum nitrides and no rock candy fractures were observed in the broken impact specimens.

4. Titanium-zirconium nitride inclusions were randomly distributed throughout the steel with occasional small quantities duplexed with the chain sulphides in the primary grain boundaries.

5. Numerous pits (4), (deep etched-appearance) were observed at the surface but these did not form crevices except at the primary grain boundaries when continuous chain sulphides were present. Types I and III sulphides, often duplexed with alumina were observed in areas other than the primary grain boundaries.

RECOMMENDATIONS

1. Present C.S.F. practice be continued for integrally cast propellers poured in dry sand moulds using silicon-killed metal, having an adequate vanadium content for deoxidation and grain size control, but having regard to the possible formation of grain boundary sulphides or nitride primary grain boundary films.

2. Data be obtained to allow evaluation of the corrosion resistance and maintenance costs for Ni V steel propellers in comparison with (400 series) chromium stainless and high yield strength austenitic (200 series) stainless steels.

3. Investigation be made of the possibility of accelerated corrosion on this ship due to electrolytic action, stray currents or unusual service conditions.

DEP:ac

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