CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 64-21

EXAMINATION OF CAST STEEL PROPELLER TEST COUPON

by

D. E. PARSONS

PHYSICAL METALLURGY DIVISION

COPY NO. 16

MARCH 9, 1964

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SUMMARY OF RESULTS

Metallurgical examination of a coupon from a four-bladed Ni-V steel propeller cast for the C.C.G.S. d'Iberville showed that, except for deviation of manganese content, the metal conformed to the chemical requirements of the Department of Transport (D.O.T.) specification.

The tensile properties at room temperature were good but the Charpy V-notch impact values at 75°F and 32°F, while judged to be adequate, were lower than anticipated. The Charpy bar fractures were characterized by the presence of partly crystalline fractures. The presence of some crystallinity in Charpy V-notch impact bars broken at 32°F indicated the need for determination of nil ductility and crack arrest temperatures (N.D.T. and C.A.T.), and for correlation of these with the Charpy V-notch impact transition temperature curve.

No evidence of rock candy embrittlement was observed in the microstructure or on the fracture surface of this test coupon.

Experimentation to determine impact toughness properties at service temperature, in the as-received condition of heat treatment and after reheat treatment, was recommended. It was also recommended that N.D.T. and C.A.T. data and impact transition (Charpy V-notch) data be acquired by testing of future propeller castings.

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* Senior Scientific Officer, Ferrous Metals Section, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

INTRODUCTION

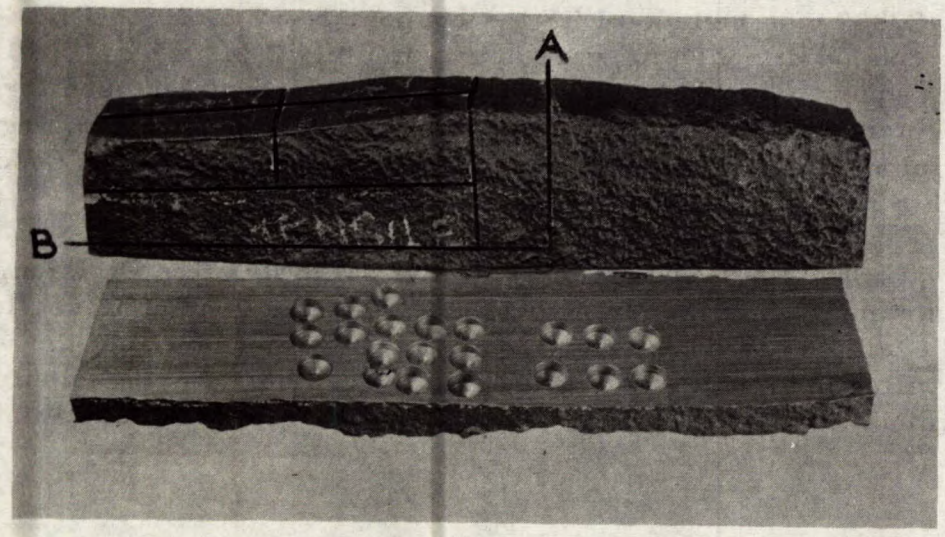
In December 1963, the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, received a test coupon cut from a four-bladed cast steel propeller ordered as a replacement for C.C.G.S. d'Iberville. The propeller was manufactured and inspected by Strömmens Vaerksted Steel Works, Oslo, Norway, for the Department of Transport, Shipbuilding Branch, Ottawa, (D.O.T. file 9172-D15 (S-Rep): letters, November 28, December 11, 1963 - One propeller, Order No. B-1553, d'Iberville) to requirements outlined in D.O.T. Specification (1963) - "Cast Nickel-Vanadium Steel Propellers and Propeller Blades."

A copy of Strömmens Vaerksted Steel Works test certificate No. 27309 was included with the coupon, R-SV-27309, CHR-11893. The coupon dimensions were approximately 2 in. x 2 in. x 10 in. (Subsequently, in February 1964, additional samples used for acceptance purposes were received by the Physical Metallurgy Division--these materials have been retained but are not described in this report).

Mr. A. MacClements, Chief, Ship Repairs Division, Department of Transport, requested that this coupon be sectioned and examined to obtain supplementary information about the propeller, particularly with respect to content of acid-soluble aluminum and presence or absence of intergranular constituent.

TEST MATERIAL - LOCATION OF SECTIONS AND TEST BARS

The appearance of the test coupon is illustrated in Figure 1, after removal of the flame cut surface and drilling for check analysis of the chemical composition. Four Charpy V-notch test bars were obtained at the left side (top) of the coupon. Two 0.505 in. diameter x 6 in. tensile bars were cut from the region below the Charpy bars. A transverse section (A) and a longitudinal section (B) were also cut and were surface ground for examination. The location of the test pieces is shown in Figure 1.



X1/2

Figure 1. Coupon Cut from Heavy Section d'Iberville Propeller Casting. The location of four Charpy V-notch impact bars (top left) two 0.505 in. tensile bars (bottom left) and two sections - transverse (A), longitudinal (B) are shown.

METALLURGICAL EXAMINATION

Chemical and Spectrographic Analysis

Chemical and quantitative spectrographic analyses were made on metal from the test coupon. The results are shown in Table 1 and are compared with the D.O.T. specification.

TABLE 1

Results of Chemical Analyses on d'Iberville Cast Steel Propeller Coupon (Order B-1553).

	D.O.T. Specification	Propeller Coupon
Carbon	0.20 max	0.14
Manganese	0.75 - 1.10	0.56
Silicon	0.50 max	0.28
Sulphur	0.020 max	0.019
Phosphorus	0.025 max	0.009
Nickel	1.5 min	1.70
Vanadium	0.07 - 0.17	0.11
*Copper	-	0.14
*Chromium	0.20 max	0.05
Zirconium	Nil	Nil
Titanium	Nil	Nil
**Aluminum (acid soluble)	0.020 max	0.026
Molybdenum	1.0 max	<0.01
Nitrogen (Kjeldahl)	-	0.005
**Total Aluminum		0.030

* Residual content ** Deoxidation (insoluble Al = 0.004%)

This metal conforms to the chemical requirement of the specification except for lower than specified manganese content. The manganese content (0.56%) was accepted as a deviation.

Mechanical Tests

The results of tensile tests made on two bars cut from the coupon are shown in Table 2. Table 2 also lists one result (test No. 27309) reported by Strömmens Vaerksted, Nov. 20, 1963, Order No. B-1553 (d'Iberville), Chge 11893.

TABLE 2

Results of Tensile Tests on Metal from Coupons

Test No.	Material	Test bar dia.	Area	Tensile Strength kpsi	Yield Point kpsi	% El in 2 in.	% RA	Charge No.
A	Ni-V Steel	0.501 in.	0.197 $in.^2$	75.0	57.9	29.5	58.4	
B	"	0.507 in.	0.202 $in.^2$	74.1	56.5	30.5	58.4	
27309	"	14 mm.	153.86 mm^2	79.9	57.9	29.5	58.4	11893

Tests A and B done at Mines Branch.
Test 27309 reported by Strömmens Vaerksted.

The results of Charpy V-notch impact tests made at room temperature and at 32°F (at the Mines Branch) are shown in Table 3.

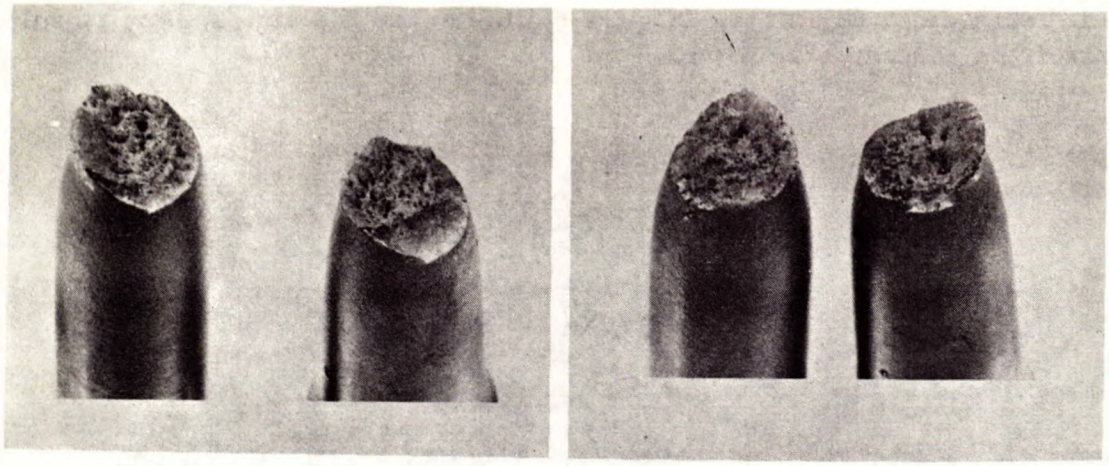
TABLE 3

Results of Impact Tests on *Metal from Coupon

Test No.	Test Temp. °F	Impact Strength ft-lb	Impact Strength ft-lb	Description of Fracture
C	75	36	-	50% Crystalline
E	75	34	-	" "
D	32	-	24	70% Crystalline
F	32	-	24	" "

* Receipt of additional material will allow preparation of additional Charpy V-notch impact specimens. Work is underway to determine the impact transition temperature (1 in. and 5 in. sections) for the temperature range 200°F to -40°F.

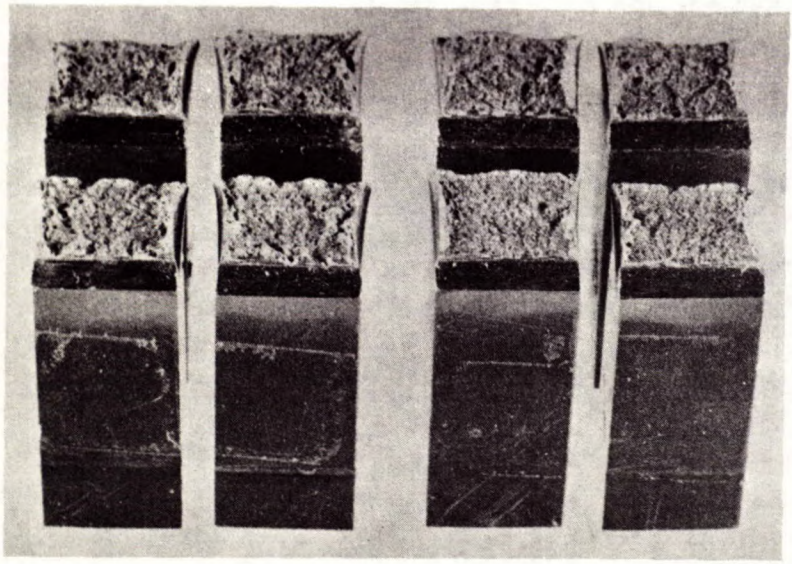
The appearance of the fractures obtained in the tensile bars, tests A and B, Table 2, are illustrated in Figure 2. The tensile ductility at ambient temperature appears to be good. The fractures are fibrous and are of the cup-cone category.



Test Bar A X1-1/2 Test Bar B

Figure 2. The tensile fractures are fibrous, are partially cup-cone and show good reduction in area. (Results shown in Table 2).

Figure 3 illustrates the appearance of Charpy V-notch fractures on bars broken at 75°F or 32°F.



C E D F

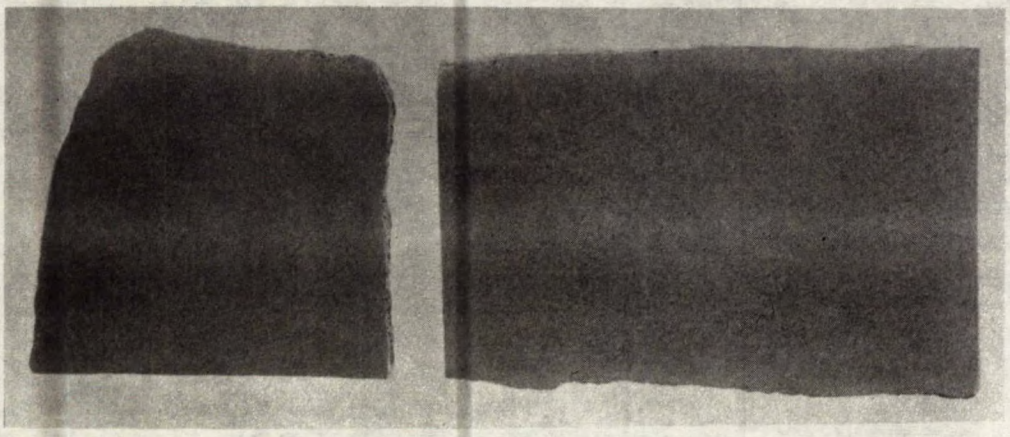
Bars C and E show approximately 50% fine-grained crystalline fracture; 50% shear (lip). Plastic deformation is visible at edge surfaces.

Bars D and F show approximately 70% fine-grained crystalline fracture; 30% shear (lip). Plastic deformation is visible at edge surfaces.

Figure 3. Charpy V-notch Impact Bar Fractures (Results shown in Table 3). Bars C and E were broken at 75°F; bars D and F were broken at 32°F.

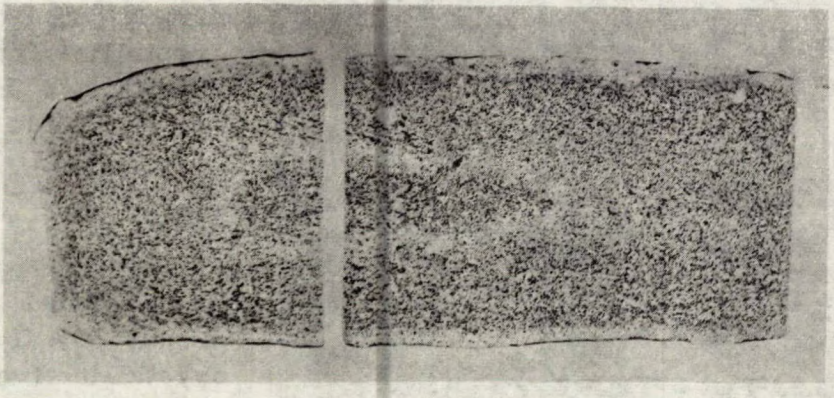
Deep Etch and Sulphur Print

The appearance of deep etched transverse and longitudinal sections are illustrated in Figure 4. Figure 5 illustrates the appearance of sulphur prints from the same section.



X1

Figure 4. Deep Etched Transverse Section (left). Longitudinal Section (right). The macrostructure and inclusion content of this cast section appear normal.

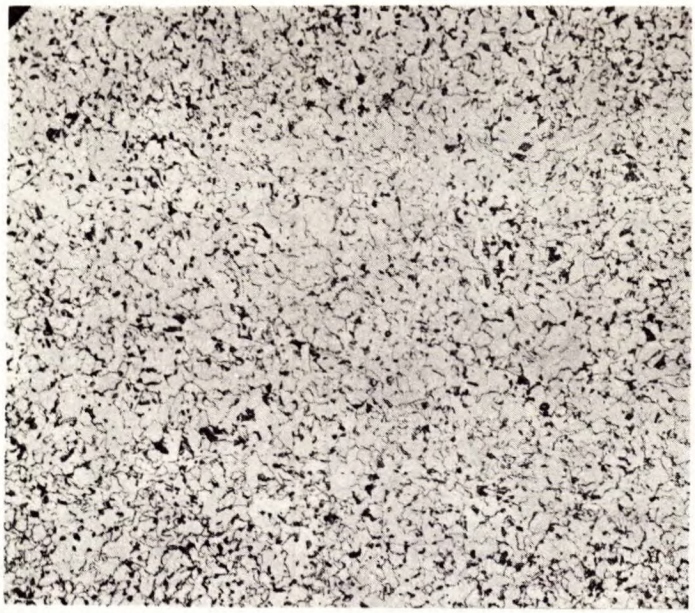


X3/4

Figure 5. Sulphur Print - Same Sections as Figure 4. The appearance and distribution of the sulphides appear normal for a content of 0.019% sulphur in the test section.

Metallographic Examination

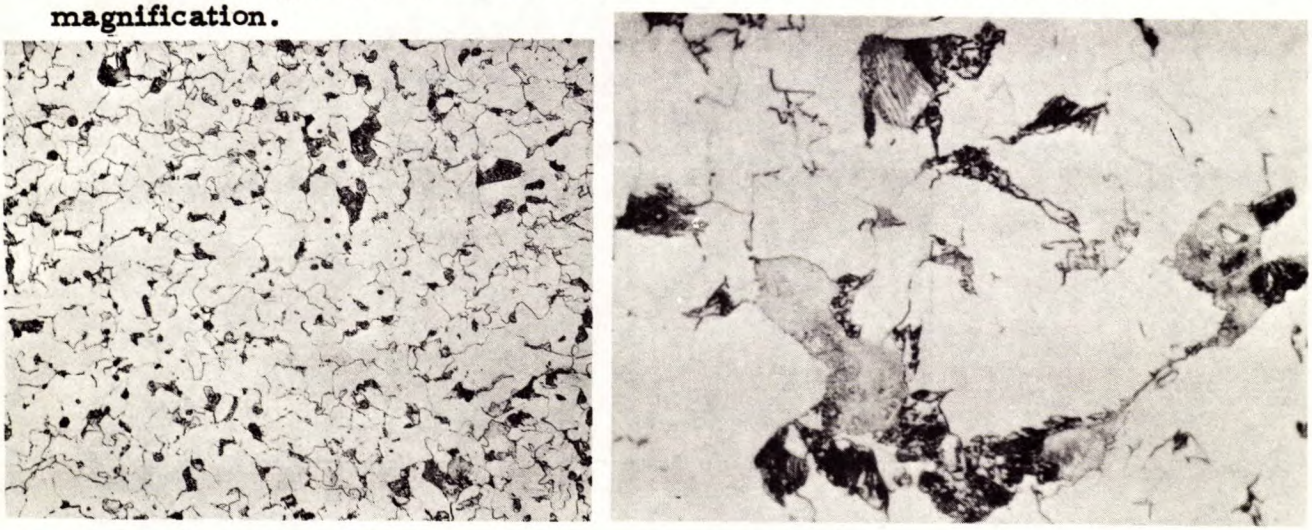
The ferrite grain size and microstructure observed in the test coupon are illustrated in Figure 6.



Etched 2% nital X100

Figure 6. Microstructure Observed in Test Coupon. The ferrite grain size (ASTM 7) observed in this coupon shows that the grain refining additions and heat treatment have been effective in the test section from the viewpoint of grain size.

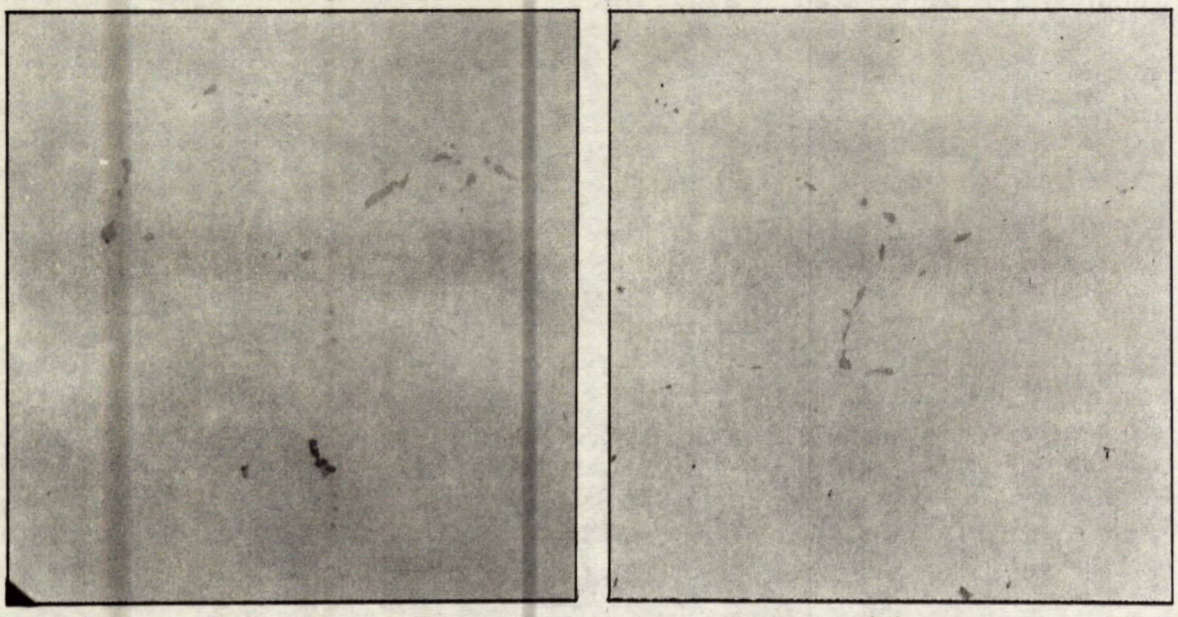
Figure 7 illustrates the etched microstructure at higher magnification.



Etched 2% nital (a) X250 Etched 2% nital (b) X1000

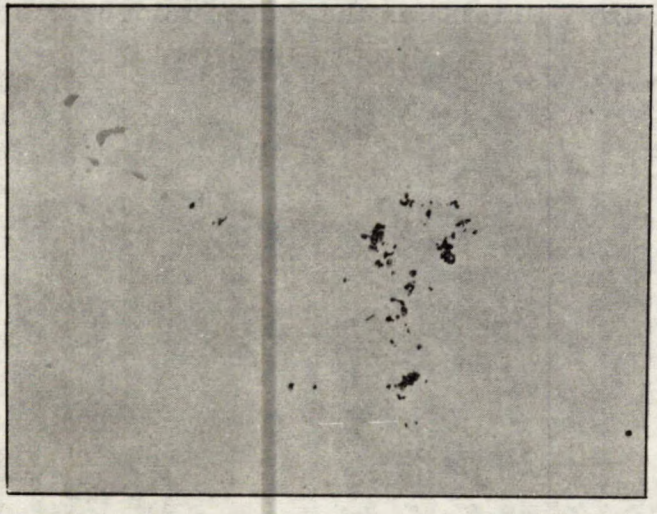
Figure 7. Microstructure Observed in Test Coupon. The microstructure consists of ferrite and fine pearlite and is consistent with the heat treatment and mechanical properties obtained.

The appearance of sulphide inclusions observed in the test coupon is shown in Figure 8. The appearance of isolated alumina (cluster) inclusions is shown in Figure 9.



As-polished (a) (b) X250

Figure 8. Appearance of Sulphide Inclusions. The sulphide inclusions are present as types 1 and 2. Approximately half of the sulphide is present as the discontinuous eutectic type illustrated in this figure. The remaining sulphide appears to be present in globular (type 1) form.



X250

Figure 9. Appearance of Alumina Inclusions. Occasional areas containing alumina inclusions were observed in this test coupon. (The acid soluble aluminum analysis was in accordance with requirements of the D.O.T. Specification).

DISCUSSION

Examination of this test coupon, cut from a heavy section of a Strömmens Vaerksted (d'Iberville) propeller blade, did not reveal any evidence of aluminum nitride (rock candy) embrittlement. The tensile ductility of the material, at ambient temperature, appeared to be satisfactory. Except for the low manganese content (0.56%, allowed as a special deviation) and for the slightly high, acid soluble aluminum content (within check analysis limits), the chemical composition obtained in this sample conformed to the requirements of the specification.

The Charpy V-notch results obtained at 75°F and 32°F are judged to be adequate but might have been higher if the specified manganese content had been attained. The N.D.T. and C.A.T. temperatures have not yet been established; however, recent receipt of additional metal for testing will allow these temperatures to be determined by drop-weight test.

The sulphur content of this coupon, 0.019%, is within specification but is at the high side of the range. A lower sulphur content would have minimized any detrimental effect due to formation of eutectic sulphide inclusions, without excessive addition of aluminum and with attendent increase of Charpy V-notch values. Determination of the N.D.T. temperature is warranted since Charpy V-notch test bars broken at 75°F and 32°F show 50% and 70% crystalline fractures, respectively. (N.D.T., and C.A.T. temperatures for icebreaker propeller castings should be considerably lower than the 32°F service temperature).

The acid soluble aluminum content (0.026%) is slightly higher than the 0.020 maximum specified; however, this is considered acceptable (as a deviation or check analysis) in the test coupon. This aluminum content, in conjunction with the vanadium alloy addition and heat treatment, achieved grain refinement in the test coupon without formation of rock candy constituent.

The mechanical properties obtained on this coupon are affected by section and, as expected, are slightly lower than the values obtained in 1 in. keel block sections for acceptance purposes.

CONCLUSIONS

1. The chemical composition of the coupon metal meets the specification except that the manganese content is low. This lower manganese content has been accepted as a deviation for this particular casting. The specified, higher, manganese content may be preferred since impact values tend to increase with higher ratios of manganese to carbon. The acid soluble aluminum result is considered to be acceptable and to fall within check analysis limits of the 0.020% maximum specified.

2. No evidence of intergranular rock candy constituent was observed in test bar fractures or in metallographic sections cut from this coupon. Room temperature tensile ductility, as indicated by tensile bar fracture and reduction of area, appeared to be good despite the presence of some eutectic sulphide in the microstructure.

3. The impact strength at 75° and 32°F was judged to be adequate but might have been higher if the specified manganese content had been combined with a lower sulphur content. The appearance of 50% and 70% crystalline fracture on the Charpy V-test bar fracture, despite fine grain size and 1.7% nickel content, suggests that the N.D.T. and C.A.T. temperatures should be investigated for 1 in. and 5 in. sections.

4. Sulphide inclusions were present as type 1 (globular) and type 2 (discontinuous eutectic film) in approximately equal proportions. The eutectic sulphides are undesirable from the viewpoint of maximum impact strength but are considered less hazardous than aluminum nitride constituent. Control of type 2 sulphide inclusions can best be achieved by use of metal having minimum sulphur content, (e.g., 0.010% target S).

RECOMMENDATIONS

1. The N.D.T. and C.A.T. temperatures for the steel used in this casting should be determined. Similar data for 1 in. and 5 in. sections should be acquired when future castings are manufactured.

2. The effect of heat treatment on Charpy V-notch impact transition temperature and on fracture appearance should be determined for the double-normalized and the double-normalized, tempered conditions of heat treatment.

3. The effect of variation of manganese nickel and vanadium contents on the impact strength and N.D.T. temperature for Ni-V cast propeller steel should be determined for this material in the optimum condition of heat treatment.

4. Consideration should be given to inclusion of a requirement in the D.O.T. specification that test pieces be cast and heat treated with each propeller for measurement of the N.D.T. temperature obtained in standard section. Correlation of the N.D.T. and C.A.T. temperatures with the Charpy V-notch impact transition curve should be made for 1 in. and 5 in. section.

5. Quantitative analysis for aluminum nitride should be made in this casting for comparison with results obtained from CCGS MacDonald.

DEP:ac