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EXAMINATION OF A/S-S.V. PROPELLER CASTING COUPONS NOS. 29158, 29159 AND 29160

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Coupons representing cast steel icebreaker propellers (Nos. 158, 159 and 160) ordered for the CCGS MacDonald and CCGS Gilbert were examined and compared with previous castings (Nos. 307, 309) supplied by the same manufacturer for CCGS d'Iberville. Aside from any power differences (steam turbine vs diesel) and differences in inspection standards, the metallurgical properties of the new samples appear superior to the previous order, judged on the basis of Charpy V-notch impact transition data. Except for a slightly high aluminum content, in sample 158, all castings conformed to the chemical requirements of the 1963 specification.

It was concluded that future tests should be made on metal from a 6 in. x 6 in. x 12 in. block casting rather than from 1 in. section coupons and that minimum impact strength determined using metal from this block should be specified as 35 ft-lb at +80°F, 25 ft-lb at +20°F, and 15 ft-lb at -40°F. The 25 ft-lb value at +20°F (service temperature) approximately corresponds to a NDT of -30°F for conditions of incipient yielding when gross casting defects are not present. Use of the 6 in. x 6 in. x 12 in. casting would allow determination of NDT and Charpy V-notch impact transition temperatures and would replace the 4 in. x 4 in. x 8 in. notched block presently specified.

The results obtained indicate no apparent advantage for castings containing 1.7% or 2.0% Ni in comparison with 1.5% for casting No. 159,

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so that the specification should be changed from "minimum 2% Ni" to read "minimum 1.5% Ni."

The results confirm that aluminum can be used in quantities to provide an acid soluble content of 0.025% maximum; that the vanadium content should be restricted to 0.10% maximum, and that the silicon should be restricted to 0.50% maximum. The manganese range should be specified as 0.60% to 0.90%. These test castings contained no Type 2 sulphides, with the sulphur restricted to 0.025% maximum and had phosphorus less than 0.015%. Residual copper contents of 0.19% to 0.24% were observed. Residual chromium was present to give contents of 0.12% to 0.19%.

It was concluded that mechanical tests made on 1 in. section detached or attached coupons tended to give high impact results at ambient temperature but that impact values at -40°F were less dependent on section size and that future check tests at the Mines Branch should be made on 6 in. section metal rather than on 1 in. coupons.

INTRODUCTION

On June 9, 1966, three boxes, each containing a set of metal coupons and broken test bars representing three cast nickel vanadium steel propellers, were received from the Department of Transport (DOT) for metallurgical examination by the Physical Metallurgy Division, Mines Branch, Department of Energy, Mines and Resources.

The three sets of bars are identified as Nos. 158, 159 and 160 throughout this report to conform to the manufacturer's (A/S Strommens Vaerksted) Nos. SV29158, SV29159 and SV29160. Samples 158 and 159 represent two propellers for CCGS Sir Humphrey Gilbert, sample 160 represents a propeller for CCGS Sir John A. MacDonald. The propellers are all 4-bladed, integrally-cast, and were purchased to the DOT 1963 specification for nickel-vanadium cast steel propellers.

SCOPE

This report lists test data supplied by the manufacturer and results of additional tensile, Charpy V-notch impact, metallographic, and check chemical analyses done at the Mines Branch. The latter tests were done using test bars cut from 1 in. section coupons and from the 4 in. x 4 in. x 4 in. (broken) blocks, which had been cast and heat treated in company with the castings.

An appendix summarizes some of the Charpy V-notch impact results obtained on bars cut from coupons and sectioned castings manufactured since 1955. Data pertaining to chemical composition, tensile properties and service life of the castings are also listed for comparison with the subject samples, Nos. 158, 159 and 160.

CHEMICAL ANALYSES

Mines Branch, Check Chemical Analyses, Coupons 158, 159, 160

The chemical composition, obtained by check analyses of millings from the sets of coupons, is shown in Table 1.

Table 1 also lists data for two previous (d'Iberville) castings and one Swedish casting (Helsingborg Varfs) supplied by the same manufacturer for comparison purposes: Strommens Nos. SV27307, SV27309, SV26848 (referred to in this report as 307, 309 and HV, respectively).

TABLE 1

Mines Branch, Check Chemical Analyses (158, 159, 160, 307, 309) and Manufacturer's Analysis for Sample HV

Element	Composition, Per Cent					
	158	159	160	307*	309*	HV*
Carbon	0.17	0.17	0.18	0.18	0.14	0.17
Manganese	0.77	0.87	0.65	0.85	0.56	0.87
Silicon	0.50	0.43	0.38	0.52	0.28	0.45
Sulphur	0.020	0.018	0.026	0.011	0.019	0.011
Phosphorus	0.008	0.010	0.012	0.002	0.009	0.008
Nickel	1.94	1.44	1.66	1.74	1.70	1.55
Vanadium	0.08	0.10	0.10	0.17	0.11	0.17
Sol. Aluminum	0.057	0.011	0.010	-	0.026	0.015
Nitrogen	0.008	0.008	0.006	0.006	0.005	-
Copper	0.24	0.21	0.19	-	0.14	-
Chromium	0.19	0.12	0.12	-	0.05	0.07
Molybdenum	0.01	0.01	0.01	-	<0.01	-
Titanium	-	-	-	-	nil	-
Zirconium	-	-	-	-	nil	-

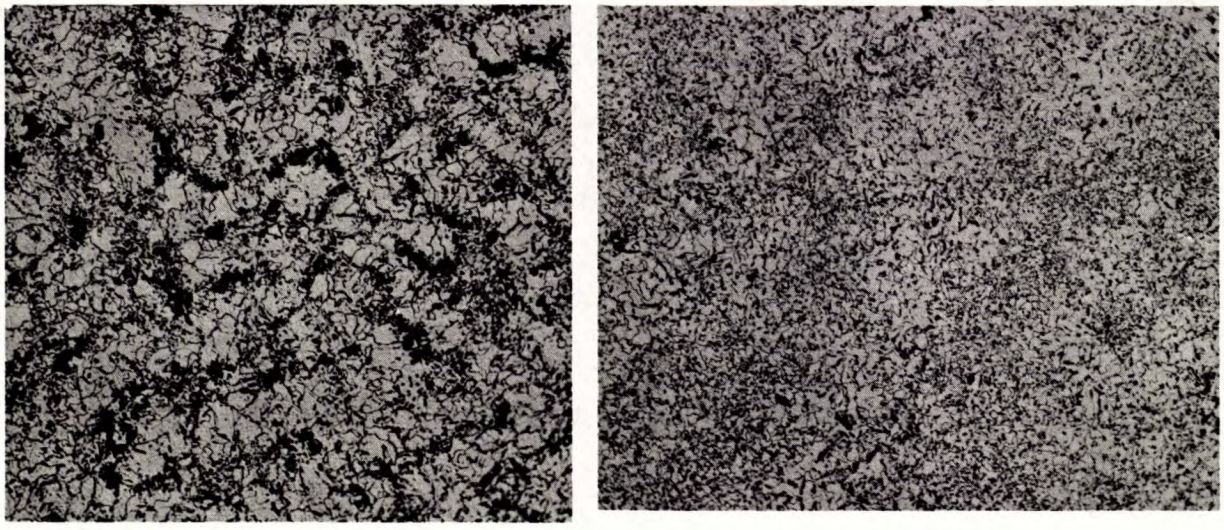
* Helsingborg Varfs, SV26848, and d'Iberville castings, SV27307 and SV27309 (Mines Branch Investigation Report IR 64-21), are included for comparison with the subject samples, SV29158, SV29159, and SV29160.

The melt compositions, 158, 159, 160, are similar with respect to carbon and manganese contents and have silicon at or below the specified maximum 0.50%. The vanadium contents are at or below the 0.10% level. The sulphur and phosphorus contents are all below the 0.025% maximum, as specified for electric furnace steel - in fact the phosphorus contents are held below 0.015%.

Sample 158 approximates 2% Ni, samples 159 and HV approximate the 1.5% Ni level, while samples 160, 307 and 309 are around the 1.7% Ni level. Sample 158 has an acid soluble aluminum content of 0.057%, considerably higher than that of other Strommens castings. The other samples all have aluminum below the specified 0.025% maximum.

METALLOGRAPHIC EXAMINATION

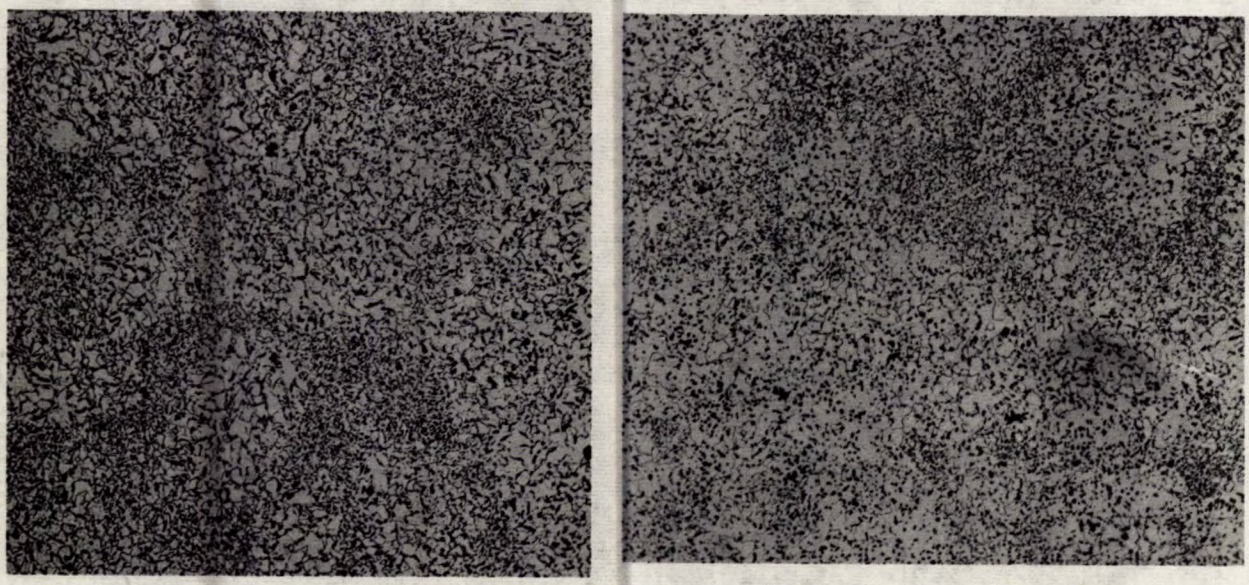
The microstructure observed in 1 in. coupons and 4 in. blocks is illustrated in Figures 1, 2 and 3 for samples 158, 159 and 160, respectively. Figures 4 and 5 illustrate the microstructure present in the two sets of test bars (Nos. 307 and 309) previously examined.



(a) X100, 2% nital etch (b)

(1 in. section) BHN-174 (4 in. section) BHN-174

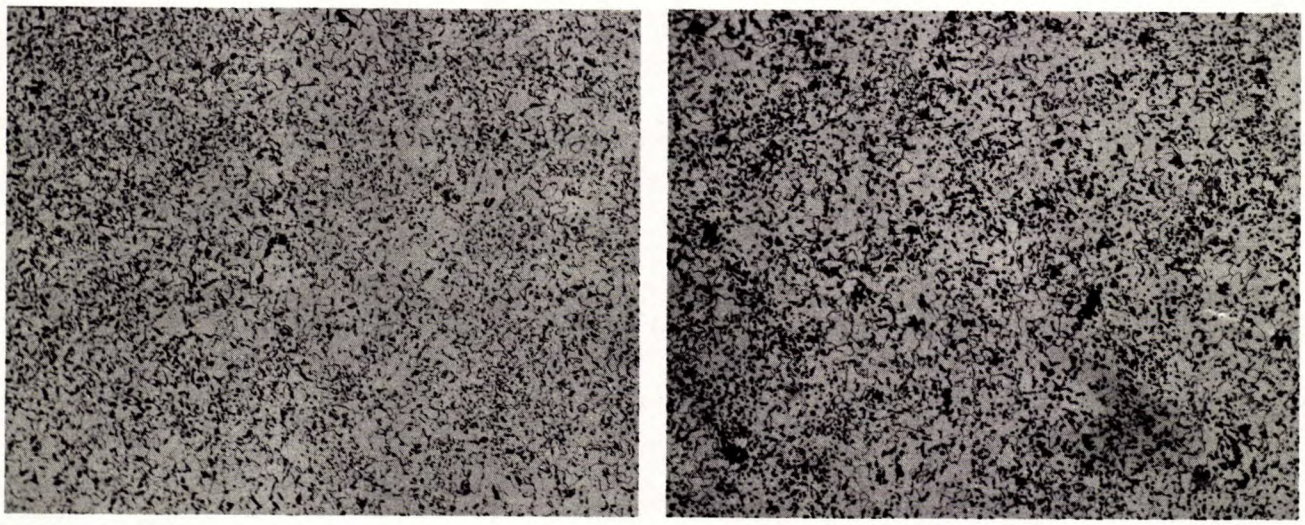
Figure 1. Sample No. 158, As-Received (V = 0.08%, Al = 0.057%). The ferrite grain size in this sample (ASTM No. 8) is relatively fine but is coarser than that observed in samples 159 and 160. The pearlite was present in network form in the 1 in. section. Spheroidization of the pearlite (due to tempering) has commenced. The pearlite distribution and ferrite grain size in the 4 in. section block section are similar to those observed in samples 159, 160 and 309. The steel is clean, inclusions are few in number and are small. No Type 2 manganese sulphide inclusions were observed.



(a) X100, 2% nital (b)

(1 in. section) BHN-165 (4 in. section) BHN-150

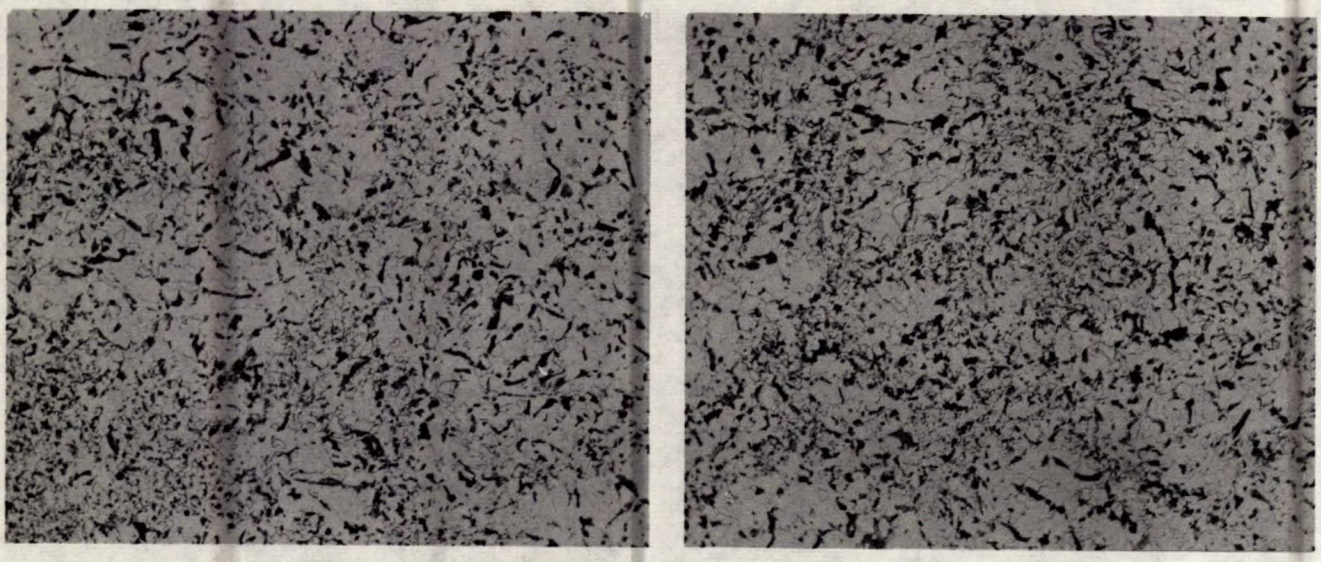
Figure 2. Sample No. 159, As-Received (V = 0.10%, Al = 0.011%). The microstructure is characterized by an extremely fine ferrite grain size (ASTM No. 10) and by uniform distribution of partially spheroidized pearlite. Inclusions were very scarce and small. The inclusions consisted of small spherical sulphides and small duplexed oxides. No Type 2 sulphide inclusions were observed.



(a) X100, 2% nital (b)

(1 in. section) BHN-165 (4 in. section) BHN-155

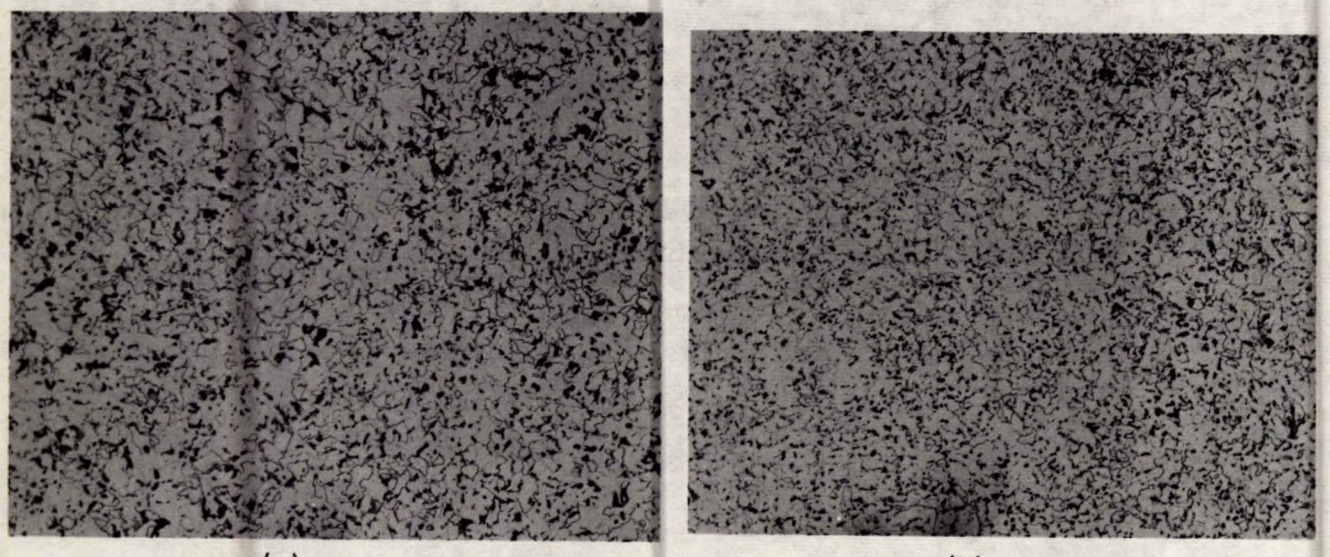
Figure 3. Sample No. 160, As-Received (V = 0.10%, Al = 0.010%). The ferrite grain size is fine (ASTM No. 10). The microstructure resembles that of sample 159. The steel is clean, containing a small number of small inclusions. No Type 2 sulphide inclusions were observed.



(a) (b)

(1 in. section) BHN-197 (4 in. section) BHN-173

Figure 4. Sample No. 307, As-Received (V = 0.17%).
The ferrite grain size (ASTM No. 7) is relatively coarse in comparison to that observed in samples 159 and 160.



(a) (b)

(1 in. section) BHN-174 (4 in. section) BHN-

Figure 5. Sample No. 309, As-Received (V = 0.11%, Al = 0.026%).
The ferrite grain size (ASTM No. 8) is slightly coarser than that of samples 159 and 160 but is finer than that of 307. The ferrite grain size of samples 158 and 309 is the same but there appears to be less carbon segregation in sample 309 than in sample 158.

MECHANICAL TESTS

The results of tensile tests made by the manufacturer and at the Mines Branch, on separately-cast 1 in. coupons, are listed in Table 2.

TABLE 2

Results of Tensile Tests on Separately-Cast, 1 in. Section, Coupons Heat Treated with the Castings

Sample	Ultimate Tensile Strength, kpsi	Yield Strength, kpsi	Elongation in 2 in., %	R.A. %	BHN, 3000 kg Load	Fracture
158 S.V.	81.5	-	31.0	-	-	Fibrous, cup-cone
158 S.V.	82.0	-	31.2	-	-	" "
158 M.B.	90.6	61.0	30.7	66.0	173	" "
159 S.V.	77.5	-	30.4	-	-	Fibrous, cup-cone
159 S.V.	78.0	-	32.4	-	-	" "
159 M.B.	79.2	61.4	31.3	67.2	165	" "
160 S.V.	-	-	-	-	-	Fibrous, cup-cone
160 S.V.	-	-	-	-	-	" "
160 M.B.	74.4	55.0	31.3	63.4	165	" "
307	-	-	-	-	-	-
307	-	-	-	-	-	-
307 M.B.	-	-	-	-	197	-
309 S.V.	79.9	60.5	32.0	53.9		Fibrous, cup-cone
309 M.B.	75.0	57.9	29.5	58.4		" "
309 M.B.	74.1	56.5	30.5	58.4	174	" "

The Mines Branch and manufacturer's results using test bars cut from 1 in. separately-cast coupons were in good agreement; however, separately-cast coupons do not necessarily reproduce values obtained when actual castings are sectioned because of the difference in cooling rates during solidification and subsequent heat treatment.

The results of Charpy V-notch impact tests made on test bars cut from 1 in. x 1-1/2 in. x 8 in. coupons and from 4 in. x 4 in. x 4 in. blocks,

heat treated with the castings, are listed in Table 3. The Charpy values are usually slightly lower in the 4 in. sections in comparison with the 1 in. sections. Sample 309 is an exception. Table 3 lists results for 1 in. and 4 in. separately-cast sections. The only "attached" 1 in. section coupons obtainable were from sample No. 309. Bars from this sample were tested to compare impact results for 1 in. "detached", and 1 in. "attached" sections.

The Charpy V-notch impact values, measured at 20°F, on separately cast 1 in. sections were 53, 94 and 41 ft-lb for samples Nos. 158, 159 and 160 respectively. The values for 4 in. sections at 20°F were reduced to 33, 31 and 25 ft-lb respectively. The 4 in. section results seem to afford a better estimate of actual casting properties than those from 1 in. section castings.

The only results available for "attached" coupons (1 in. section - sample No. 309) were similar to those obtained by using separately-cast 1 in. coupons; however, the location of the attached coupons was not known. The results from separately-cast 4 in. blocks appear to be less subject to casting variables and would seem to provide a more realistic and conservative estimate of impact strength as related to chemical composition and microstructure.

Impact values in excess of 35 ft-lb were obtained from 1 in. sections at 20°F for samples 158, 159 and 160 and were higher than those for previous castings 307 and 309. Impact results, at 20°F for 4 in. sections, from samples 158, 159 and 160 were in the range 25-33 ft-lb. Impact results for all sections in the subject castings at -40°F were 14 ft-lb or greater. These results at -40°F represent an improvement over results previously obtained for the d'Iberville castings, 307 and 309, where impact strength at -40°F varied between 6 and 12 ft-lb.

The manufacturer's results for separately-cast 1 in. sections, using bars tested at -40°F, are listed in Table 4 for samples 158, 159 and HV. These results are compared with corresponding values for 1 in. and 4 in. sections tested at the Mines Branch. The results are in agreement for 1 in. sections but are higher than those observed for the more representative 4 in. section.

Inspection of the impact data, Table 3, suggests that impact tests should preferably be made on a 4 in. or 6 in. section test block and that Charpy V-notch impact results of the order of 35 ft-lb at +80°F; 25 ft-lb at +20°F; and 15 ft-lb at -40°F could be specified. The 25 ft-lb value at +20°F can also be approximately correlated with NDT and per cent shear fracture for this composition and strength level[1].

TABLE 3

Charpy V-Notch Impact Results (ft-lb) For 1 in. and 4 in. Sections

Temperature °F	158-SV29158		159-SV29159		160-SV29160		307-SV27307		309-SV27309			
	ft-lb 1 in.	ft-lb 4 in.	ft-lb 1 in.	ft-lb 4 in.	ft-lb 1 in.	ft-lb 4 in.	ft-lb 1 in.	ft-lb 4 in.	ft-lb 1 in.	ft-lb* 1 in.	ft-lb* 1 in.	ft-lb* 4 in.
+80°	47	35	103	66	57	54	29	36	27	32	31	54
+40°	56	35	87	50	43	25	19	25	24	24	21	32
+20°	53	33	94	31	41	25	19	18	23	23	17	30
0°	27	29	66	29	27	28	15	15	15	15	13	23
-20°	-	21	-	22	-	14	-	11	-	-	-	17
-40°	17	23	44	19	21	14	10	9	8	8	6	12
-80°	11	17	39	19	15	11	6	4	-	-	-	7

*Results for "attached" 1 in. section coupons from sample 309.

TABLE 4

Manufacturer's (Strommens) Charpy V-Notch Impact Results, At -40°F, For Separately-Cast, 1 in. Coupons

Sample No.	Strommens Vaerkens (-40°F) Charpy V-Notch Impact Strength for Separately-Cast 1 in. Sections	SV - 1 in. Average ft-lb at -40°F	MB - 1 in. Average ft-lb at -40°F	MB - 4 in. Average ft-lb at -40°F
158	26, 26, 30, 23, 21, 21	25	17	23
159	41, 39, 39, 35, 34, 34	37	44	19
160			21	14
307			10	9
309			7	12
848 (HV)*	36, 39, 26	34	-	-

SV - Strommens
MB - Mines Branch
* Swedish propeller casting, Helsingborg Varfs (Bar No. SV26848).

In the future, data could be collected, for information purposes, where actual NDT is measured and is directly compared with the Charpy V-notch value at +20°F (approximate service temperature) and with the impact transition curve determined by impact tests at 80°F, 20°F, -40°F, etc. using metal, separately-cast as a 6 in. x 6 in. x 12 in. test block and given the same heat treatment as the propeller casting. Use of this test casting and determination of NDT would also act as a test for the presence of intergranular fracture, so that the notched 4 in. x 4 in. x 4 in. notched block could be replaced by the 6 in. x 6 in. x 12 in. block casting.

A comparison was made of Charpy V-notch impact results, as measured in attached 1 in. and separately-cast (detached) 1 in. section coupons for sample No. 309. These results are listed in Table 5 and are compared with the 4 in. section result for this sample.

TABLE 5

Charpy V-Notch Impact Results for Sample 309, Attached 1 in. Section Coupons vs Detached 1 in. Section Keel Block Legs Heat Treated with the Casting (SV27309) (Results on the 4 in. x 4 in. x 4 in. Block are Shown for Comparison)

Temperature	1 in. (Attached Coupon)	1 in. Keel Block (Detached Coupon)	4 in. x 4 in. x 4 in. Block
°F	ft-lb av	ft-lb av	ft-lb av
+80	32	32	53
+40	24	22	33
+32	24	-	-
+20	23	20	31
0	15	14	23
-20	-	-	17
-40	8	7	13

Sample 309 was unusual in having higher impact strength in the 4 in. x 4 in. x 4 in. block sample than was obtained in either the attached or detached 1 in. section coupons. The impact test results for samples 158, 159 and 160 were normal in showing some reduction of impact strength in 4 in. x 4 in. x 4 in. blocks in comparison with 1 in. sections.

Tables 6 and 7 record the per cent shear fracture visible on fractured Charpy impact bars and suggest a possible correlation between per cent shear fracture, the Charpy V-notch, impact transition results and NDT. (Insufficient metal was available for determination of the actual NDT for samples 158, 159 and 160.)

Results from Table 6 are summarized in Table 7.

TABLE 6

(FATT) Fracture Appearance Transition Temperature (% Shear) Estimated from Charpy V-Notch Fractures According to ASTM-A443-64 and A-370
Test Temperature (°F) vs Per Cent Shear Fracture

Temperature	158		159		160		307		309		CSF MacD.	2% Ni
	1 in.	4 in.	1 in.	4 in.	1 in.	4 in.	1 in.	4 in.	1 in.	4 in.	1 in.	1 in.
°F	% Shear		% Shear		% Shear		% Shear		% Shear		% Shear	% Shear
+80	50	50	90	75	90	60	30	30	50	80	70	100
+40	40	30	70	40	70	30	20	20	30	50	50	
+32	-	30	-	30	-	30	-	20	-	-	-	100
+20	30	20	60	20	50	20	20	15	20	40	40	
0	20	-	40	-	30	-	15	-	15	35	20	60
-20	-	20	-	20	-	20	-	15	-	30	10	
-40	10	10	30	20	15	20	10	10	10	15	5	40
-80	1	1	10	10	1	1	1	1	1	1	1	10

*158 - fine grain practice (0.05% soluble aluminum).
CSF MacD. - CCGS MacDonald propeller casting, Mines Branch Investigation Report (IR 66-49).
2% Ni - Results on 2% Ni, 0% V, test block, Internal Report (PM-R-66-9).

TABLE 7

Temperature (°F) for Per Cent Shear (Data from Table 6)

Shear	158		159		160		307		309		MacD.	2% Ni
Fracture	1 in.	4 in.	1 in.	4 in.	1 in.	4 in.	1 in.	4 in.	1 in.	4 in.	6 in.	6 in.
%	Temperature (°F)											
40	+40	+60	0	+40	+10	+45		-	60	+20	+20	-40
30	+20	+40	-40	+32	0	+45	+80	+80	40	-20	+10	-53
20	0	-20	-60	-40	-30	-40	+20	+32	+20	-32	0	-66
10	-40	-40	-80	-80	-45	-	-40	-40	-40	-55	-20	-80
1	-80	-80	-	-	-80	-80	-80	-80	-80		-80	
NDT*							<+20		<+20		≈-15	-70

The NDT figure appears to fall within the range 10% to 30% shear fracture.
MacD. sample failed despite good impact values; however, fracture was possibly initiated by the presence of an unusual casting defect.

*NDT - (Modified test, 350 ft-lb, 200 lb hammer, 2.5 mm deflection calibrated against standard drop weight test.) NDT for samples 307 and 309 was estimated using 1 in. separately-cast sections.

DISCUSSION

Comparison of the subject samples 158, 159, 160 with two previous d'Iberville castings 307, 309, and with a Swedish propeller (HV) all manufactured by Strommens Vaerkens, show a carbon range of 0.14% to 0.18%. Silicon has been held at or below 0.50% maximum. The sulphur and phosphorus are below the levels specified for electric furnace steel. With one exception, the vanadium has been restricted to 0.10% maximum. Two of the castings aim at 1.5%, two at 1.7% and one at 2% Ni. Except for melt 158, the acid soluble aluminum content was less than 0.025%.

The tensile and impact results on 1 in. separately-cast coupons heat treated with the casting were close to or in excess of 75 kpsi UTS and 55 kpsi yield strength with 30% elongation and 58 to 67% RA. The hardness was BHN 165 to 174, except that one casting (No. 307) having 0.17% V, had a hardness of BHN 197.

Charpy V-notch results at 20°F for 1 in. separate coupons from samples 158, 159 and 160 were 53, 94 and 41 ft-lb (all in excess of 35 ft-lb) respectively. Similar results at 20°F for 4 in. blocks were more realistic and were reduced to 33, 31 and 25 ft-lb respectively. Sample 159 gave higher than average impact values, samples 158 and 160 gave high average values. The aluminum content of melt 158 was considerably above that of other Strommens' melts.

Comparison of samples 158, 159, 160 with samples 307 and 309 suggests that in the absence of casting defects the new castings should be superior to those in service on the d'Iberville.

The impact results indicate that acceptance tests should preferably be made on metal cast into a 4 in. or 6 in. section rather than a 1 in. section, and that there is no special advantage in use of attached coupons particularly when their location and cooling rates are not known. The results determined by all impact tests suggest that best practice for specification purposes would be to require 35 ft-lb at +80°F, 25 ft-lb at +20°F and 15 ft-lb at -40°F for separately-cast 4 in. or 6 in. sections cast without special deoxidation practice and heat treated in company with the casting. (The effect of section - mass effect - was least noticeable at -40°F.)

A previous investigation (Internal Report PM-R-66-9[1]) suggests that the 25 ft-lb value, at the sea water service temperature +20°F, may correspond to a NDT (-30°F or lower) where brittle fracture does not occur

under conditions of incipient yielding in the presence of normal casting flaws. The qualifications with respect to the amount of plastic deformation and the size of casting defects are important as indicated by higher incidence of brittle fracture in diesel-powered than in turbine-powered ships due to differences in rate of application of load and to evidence[2], that brittle fracture may initiate at a localized segregate (inhomogeneity) in a casting which otherwise met the specification[3].

An attempt was made to correlate properties of attached coupons to the separately-cast 1 in. and 4 in. sections; however, this was dependent on full knowledge of coupon location and cooling rate of the casting—knowledge which is not usually available when castings are purchased from different sources. It was concluded that separately-cast 4 in. or 6 in. section test blocks offered a better source of test metal prepared under standard conditions.

Hence, it would be desirable if the size of the block (required by the present specification[3], to be notched and broken as an inspection procedure for intergranular fracture) were either to be increased so that NDT drop weight bars 5 in. x 2 in. x 3/4 in. could be cut for determination of NDT or that the notched test be eliminated and be replaced by use of a 6 in. x 6 in. x 12 in. block of metal, cut after heat treatment to provide 5 in. x 2 in. x 3/4 in. bars for drop weight tests. These tests, in addition to determining NDT, would also allow determination of Charpy V-notch transition temperature and would serve as a test for intergranular fracture.

CONCLUSIONS

(1) The quality of castings 158, 159 and 160, insofar as this can be determined from inspection of coupons and cast 4 in. blocks, appears satisfactory and appears superior to similar castings previously supplied for the CCGS d'Iberville (Nos. 307 and 309). Castings 159 and 160 appear to have above average mechanical properties. Casting 158 appears average but does contain a higher than normal aluminum content.

(2) Charpy V-notch impact strength for 4 in. cast and heat treated sections gave values of 35-66 ft-lb at +80°F; 25-33 ft-lb at +20°F; 14-23 ft-lb at -40°F. Impact results for the subject castings were higher than those obtained for samples 307 and 309.

(3) The mechanical results and microstructures obtained in the 4 in. cast sections more closely resembled sectioned castings than did those from 1 in. separately-cast or 1 in. attached coupons - hence, a more realistic comparison of metallurgical quality of propeller castings can be achieved by use of heavier sections, which also facilitate NDT determination.

(4) The results confirm, excepting sample 158, that Strommens restrict aluminum to the 0.025% maximum acid soluble content, that vanadium is restricted to 0.10%, silicon is restricted to 0.50% maximum, sulphur is less than 0.025% and phosphorus is held below 0.015%. Variation of nickel between 1.5% and 2.0% is observed. Manganese variation occurs between 0.60% and 0.90%. Significant residual quantities of copper and chromium are present.

(5) Use of aluminum deoxidation to obtain acid soluble levels of 0.025% maximum appears acceptable with vanadium content below 0.10%. (The effect of vanadium in the range 0% to 0.10% should also be investigated.)

(6) NDT drop weight tests should be carried out on the same metal and section used to provide Charpy V-notch bars. The block size should be increased to 6 in. x 6 in. x 12 in., either with or without discontinuance of the 4 in. x 4 in. x 4 in. notched block test, to provide metal, heat treated in company with the castings, for test purposes. Use of this larger block would enable the manufacturer to supply twenty 5 in. x 2 in. x 3/4 in. drop weight test bars.

(7) The value of tests presently made on attached coupons is in doubt and their use would appear unnecessary providing that the 6 in. x 6 in. x 12 in. block is available for tests. Attached coupons, if used, should be identified with respect to casting location and should be clearly marked to distinguish them from separately-cast 1 in. section test coupons.

RECOMMENDATIONS

(1) Except for the excessive aluminum content of melt 158, the range of chemical composition represented by melts 158, 159 and 160, in the heat treated condition has provided superior mechanical properties. Best properties were observed in melt 159 having nickel close to the lower limit of the specification (1.5% Ni). Aim at the composition and heat treatment given to sample 159.

(2) The maximum allowable vanadium content should be set at 0.10% to be consistent with available foundry heat treatment equipment. The maximum acid soluble aluminum content should be maintained at 0.025%. Investigate the mechanical properties obtained with vanadium in the range 0% to 0.10%.

(3) Provide a cast and heat treated 6 in. x 6 in. x 12 in. block representing the casting. This block should be sectioned by the manufacturer to provide twenty 5 in. x 2 in. x 3/4 in. drop weight test bars for determination of NDT and impact transition temperature. This test block could replace the 4 in. x 4 in. x 8 in. notched and broken test block presently required.

(4) If attached and detached 1 in. coupons are provided, these should be clearly identified with respect to casting position and as to whether they are separately-cast or cast integral with the casting. All metal for test purposes should receive the same deoxidation and heat treatments as the actual casting.

(5) Lower NDT temperatures are obtained using a 1725°F normalizing-1100°F tempering heat treatment than by furnace annealing from 1550°F to the same hardness (BHN 170). The influence of heat treatment variables on NDT should be investigated.

The laboratory NDT temperature is determined for conditions of incipient yielding not for overload conditions involving large plastic deformation and is affected by inhomogeneity of the casting. This may explain increased incidence of fracture in diesel as contrasted with turbine-powered ships and may also explain a failure where phosphorus segregation was observed close to a fracture origin in an otherwise sound casting.

REFERENCES

(1) "Effect of Silicon, Vanadium and Nickel on NDT Results for Nickel-Vanadium Cast Steel," Physical Metallurgy Division Internal Report PM-R-66-9, August 3, 1966.

(2) "Examination of Two CSF Icebreaker Propeller Castings," Mines Branch Investigation Report IR 66-49, June 21, 1966.

(3) "Specification for Cast Nickel Steel Propellers and Propeller Blades." (Revised June 1, November 25, 1966.)

(4) "Per Cent Shear Fracture in Charpy V-Notch Impact Tests," Chart, ASTM Standard A-370, 1966.

DEP:bb

APPENDIX

Charpy V-notch, impact, and tensile results on 1 in., 2 in., 4 in. and 6 in. sections from coupons, test blocks and sectioned propeller castings are listed in Table 1 (Appendix) with chemical composition. Figure 1 (Appendix) illustrates the ASTM standard[4], A-370, page 510, used for estimation of the per cent shear fracture.

TABLE 1

Chemical Composition, Charpy V-Notch Impact and Tensile Strength for Some DOT Propellers - 1-6 in. Sections

	Ship and Sample See Code	Service Record	Chemical Composition (Per Cent) C	Mn	Si	S	P	Ni	V	Tot. Al	Sol. Al	N	Ti	Zr	Cr	Cu	Mo	Charpy V-Notch Impact Strength Ft-lb vs. Temperature (°F) 80°	40°	32°	20°	0°	-20°	-40°	-80°	Section Thickness	BHN 3000 kgm	Tensile Results UTS psi	Y. P. psi	Elong. %	RA %	NDT °F	Remarks
1	Camsell-A	Broken	.11	.81	.86	.021	.019	1.90	.15	.23	-	.007	Nil	.06	-	-	-	31.	-	17	-	9.	10.	2.		6"		77.	54.5	19.	25.		Brittle Fracture
1	Camsell-B	"	.17	.81	.76	.010	.018	1.94	.20	.10	-	.009	Nil	.05	-	-	-	26.	-	17	-	13.	2.	-		6"		71.	54.9	6.	16.		" "
2	McD-R-thick	"	.18	.84	.84	.019	.015	1.68	.14	.08	-	.009	ND	.04	-	-	-	20.	13.	-	10.	7.	-	-		6"	177.	74.	55.	Nil	Nil		IR-63-107 Brittle Fracture
2	" -R-thin	"	.16	.84	.84	.019	.015	1.70	.13	.08	-	.009	ND	.04	-	-	-	15.	9.	-	10.	6.	-	-		2"		86.	61.	16.	22.		" " "
2	" -S-thick	"	.21	.80	.91	.037	.027	1.80	.13	.07	-	.009	ND	.05	-	-	-	8.	9.	-	4.	3.	-	-		6"		74.	57.	6.	11.		" " "
2	" -S-thin	"	.21	.80	.90	.033	.029	1.80	.13	.08	-	.009	ND	.05	-	-	-	11.	9.	-	6.	2.	-	-		2"	181.	85.	60.	14.	18.		" " "
3	McD-Stub 1	Unbroken	.14	.80	.55	.022	.012	2.10	.13	.05	.05	.009	-	.01	-	-	-	34.	-	25	-	-	-	-		1"		-	-	-	-		Unbroken IR-62-106
3	McD-Stub 2	"	.12	.73	.33	.019	.016	1.98	.13	.02		.009	.024	.01	.28	.12	< .01	-	-	-	-	-	-	-		1"	-	-	-	-	-		" "
4	McD-Integ-B	Broken*	.21	.83	.45	.023	.004	1.76	.09	-	< .005	.004	< .01	< .01	.14	.15	.05	71.	-	-	47.	-	31.	32.	11.	6"	174.	80.	58.	26.	43.	-15	IR-66-49 possible flaw
4	McD-Integ-T	Broken**	.18	.86	.41	.023	.005	1.74	.08	-	< .002	.006	< .01	< .01	.09	.18	.02	-	-	-	-	-	-	-	-	2"	-	-	-	-	-		Ductile (overload) fracture
5	d'Iberv (27309)	Unbroken	.14	.56	.28	.019	.009	1.70	.11	.030	.026	.005	Nil	Nil	.05	.14	< .01	35/57	/35	24/31	-	/22	-	/14	-	1"/4"	174/	76/	57/	30/	58/		Unbroken IR-64-21 SV-27309
5	H. V. (26848)	"	.17	.87	.45	.011	.008	1.55	.17	-	.015	-	-	-	.07	-	-	-	-	-	-	-	-	34.	-	1"	-	-	-	-			SV-26848
5	Gilbert Integ (29158)	NEW	.17	.77	.51	.020	.008	1.94	.08	-	.057	.008	-	-	.19	.24	.01	47/35	56/35	-	53/33	27/29	/21	17/23	11/17	1"/4"	174/	81/	61/	31/	66/		SV-29158
5	Gilbert Integ (29159)	NEW	.17	.87	.43	.018	.010	1.44	.10	-	.011	.008	-	-	.12	.21	.01	103/66	87/50	-	94/31	61/29	/22	39/19	39/19	1"/4/	165/	79/	61/	31/	67/		SV-29159
5	McD-Integ (29160)	NEW	.18	.65	.38	.026	.012	1.66	.10	-	.010	.006	-	-	.12	.19	.01	57/54	43/25	-	41/25	27/28	/14	21/14	14/11	1"/4"	165/	74/	55/	31/	63/		SV-29160
6	Narwahl	Bent 90°	.15	11.97	.81	.016	-	5.21	-	-	-	.26	-	-	15.87			108	-	-	108	118	80	83	57	6"	170	75.	39.	31.	35 to 52.	≈ -200	Overload fracture IR-66-55

*Casting failed in service, despite having in excess of 35 ft-lb V-notch impact strength at the service temperature (approx 20°F) - however a casting defect was present - NDT temperature = -15°F.
**This casting failed possibly due to overload, since the fracture was ductile and had a 1/8 in. shear lip.

1. CCGS Camsell - 2 broken stub blade castings, A and B - Normalized from 1650°F.
2. CCGS MacDonald - 2 broken stub blade castings, R and S - tests made in blade sections, R-thin; S-thin and in hub region R-thick; S-thick.
3. CCGS MacDonald - 2 unbroken CSF stubs removed from service - tests on "boat" samples cut at hub-root surface.
4. CCGS MacDonald - 2 broken CSF 4-bladed integral propellers - B-blade examined by sectioning; T-blade showing shear lip and ductile fracture.
5. Strommens - castings for d'Iberville, Helsingborg Varfs, CCGS MacDonald and CCGS Gilbert.
6. CCGS Narwahl - Mn-Cr Austenitic Steel Casting.

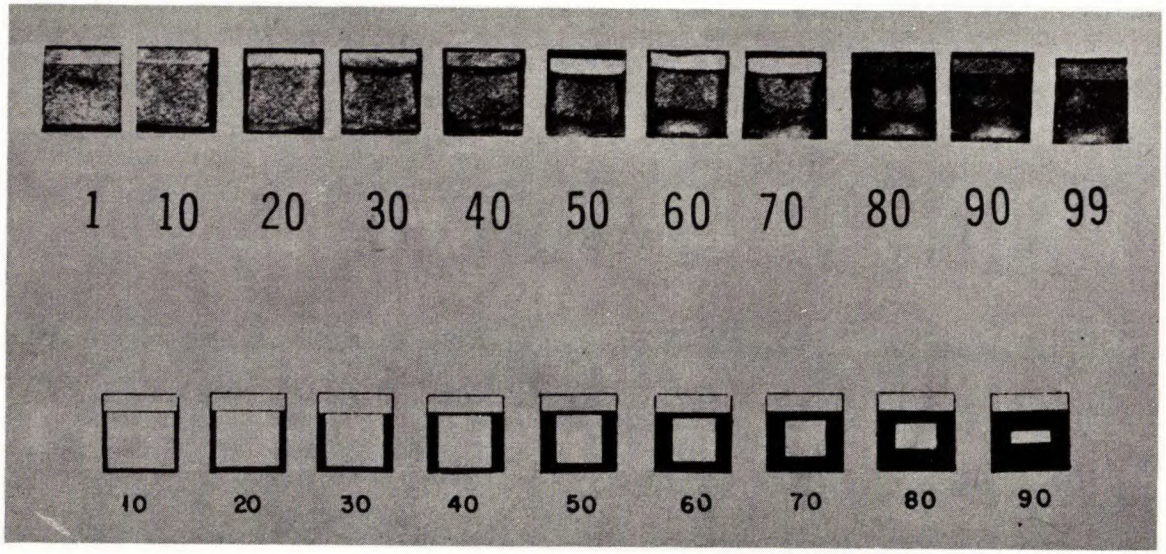


Figure 1. ASTM A-370 - Standard for Estimation of Per Cent Shear Fracture.