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EXAMINATION OF CAST "13-4" STEEL D.O.T. TEST BLOCK

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Results obtained by metallurgical examination of a steel casting (6 in. x 6 in. x 6½ in.) supplied and heat treated by Canadian Steel Foundries, Montreal, Quebec, as part of commercial melt 2-4049 (CA 6 NM(13)), are reported, having regard to the possible application of this cast steel for icebreaker propeller service.

The tensile and 0.2% yield strengths obtained in the 6-in. section were approximately 115 kpsi and 80 kpsi respectively.

A very low, nil-ductility transition (NDT) temperature, of below -255°F, was obtained. Charpy V-notch impact test results, of the order of 50 ft-lb at -100°F, with no evidence of cleavage fracture, and 30 ft-lb at -200°F confirmed the "NDT" drop-weight tests.

Microstructure, critical transformation temperatures, inclusion analysis, determination of retained austenite, and study of the grain size and homogeneity of the cast section were reported.

It was concluded that the possible use of this material for cast steel icebreaker propellers warranted further study provided that its fatigue, corrosion, and weldability were acceptable.

INTRODUCTION

On September 29, 1969, Canadian Steel Foundries Division, Hawker Siddeley Canada Limited, submitted a cast 6-in. x 6-in. x 6½-in. "D.O.T."* test block of CA 6 NM(13) steel for metallurgical examination. The test block was supplied at the request of Mr. S. L. Gertsman, Chief of Division, Physical Metallurgy Division (PMD), Mines Branch, Department of Energy, Mines and Resources for determination of the Charpy V-notch impact and tensile strengths, having regard to possible future use of this material for cast steel, icebreaker propellers. The test block was supplied in the heat-treated condition (i.e., heat treated as a 6-in. x 6-in. x 6½-in. block) and was tested at the PMD by sectioning without any additional heat treatment.

The covering letter, September 29, 1969, stated that the test block was cast as part of Canadian Steel Foundries heat 2-4049, having the composition listed in Table 1.

RESULTS

TABLE 1

Chemical Composition (%) of CA 6 NM(13) Test Block*

Element	CSF Analysis	PMD Check Analysis
Carbon	0.05	0.04
Manganese	0.62	0.64
Silicon	0.38	0.49
Sulphur	0.028	0.028
Phosphorus	0.018	0.011
Chromium	11.1	11.18
Nickel	4.1	4.12
Molybdenum	0.42	0.63

*6-in. x 6-in. x 6½-in.,- 1825°F, air cooled, reheated to 1100°F, air cooled .

The covering letter stated that, "According to the Shaefler's diagram, this steel should not contain any delta ferrite and microscopic examination of a steel sample of the same heat confirmed the absence of delta ferrite".

*"D.O.T." Department of Transport (C.C.G.S.) Ottawa.

Canadian Steel Foundry tests, April 1969, on material from heat 2-4049, in the 1825°F, air cooled, reheated to 1100°F, air-cooled condition of heat treatment gave the tensile and Charpy V-notch impact results listed in Tables 2 and 3 respectively. PMD results obtained on the 6-in. thick-section test block are included for comparison.

TENSILE AND CHARPY V-NOTCH IMPACT TESTS

TABLE 2

Tensile Results, Heat 2-4049 (Heat Treated at CSF*)

CSF Tensile Results (coupons) - PMD Tensile Results (6-in. x 6-in. x 6½-in. test block)

Samples	UTS, kpsi	YS, kpsi	% El. in 2 in.	RA, %	BHN, 3000 kg	Fracture Description
CSF, April Tests coupons	118.5	103.5	18.0	63.5	262	
PMD (No.1) 6 in. sect.	116.7	87.9	22.0	63.5	241	Cup-cone, ductile
" (No.2) " "	114.8	82.4	22.0	61.8	"	" " "
" (No.3) " "	115.2	82.6	22.0	62.5	"	" " "

*All tests done on material in the "as-received" condition of heat treatment.

Comparison of Charpy V-notch results obtained by CSF and of triplicate Charpy V-notch impact tests made at PMD on bars representing the 6-in. thick section are listed in Table 3.

TABLE 3

Charpy V-Notch Impact Results, Heat 2-4049

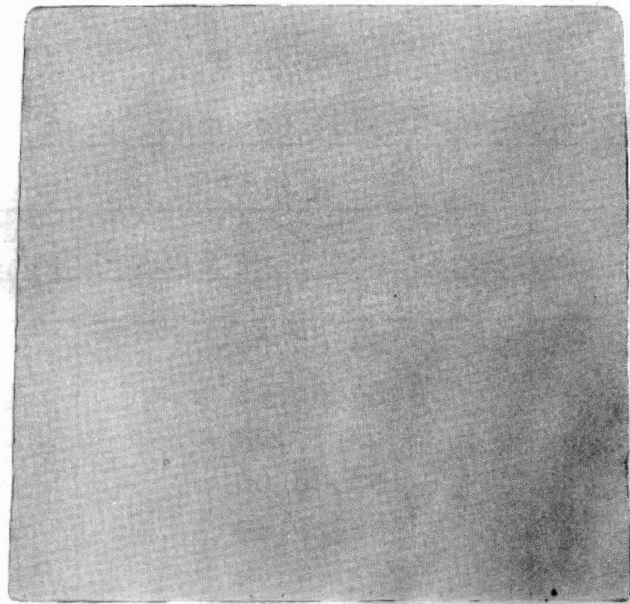
Test Temp. (°F)	CSF (coupons) ft-lb	PMD 6-in. DOT Test Block* ft-lb	Charpy Bar Fracture Description % Shear	% Cleavage
+80	64,62,70	55,63,58	100	0
+40	- - -	54,55,65	100	0
+20	- - -	59,55,58	100	0
0	63,64,66	58,60,60	100	0
-40	- - -	59,56,60	100	0
-50	59,58,58	- - -	100	0
-100	52,50,50	48,48,48	100	0
-200	- - -	33,29,31	80	20
-320	- - -	9, 9, 9	50	50

* 1825°F, air cooled, reheated to 1100°F, air cooled.

DEEP ETCHED TRANSVERSE SECTION

The appearance of a ground section, deep-etched for 5 minutes in 40% HNO_3, 10% HF, 50% H_2O at ambient temperature, is illustrated in Figure 1. The deep-etched section appears clean, homogeneous, and has a uniform response to etching. ASTM ferrite grain size varies between Nos. 5 and 6.

Figure 2 shows the reduction in area (necking), tensile ductility, and cup-cone tensile fractures of 0.505-in.-diameter test bars after tensile testing; these pieces were cut from the as-received 6 x 6 x 6½-in. test block.



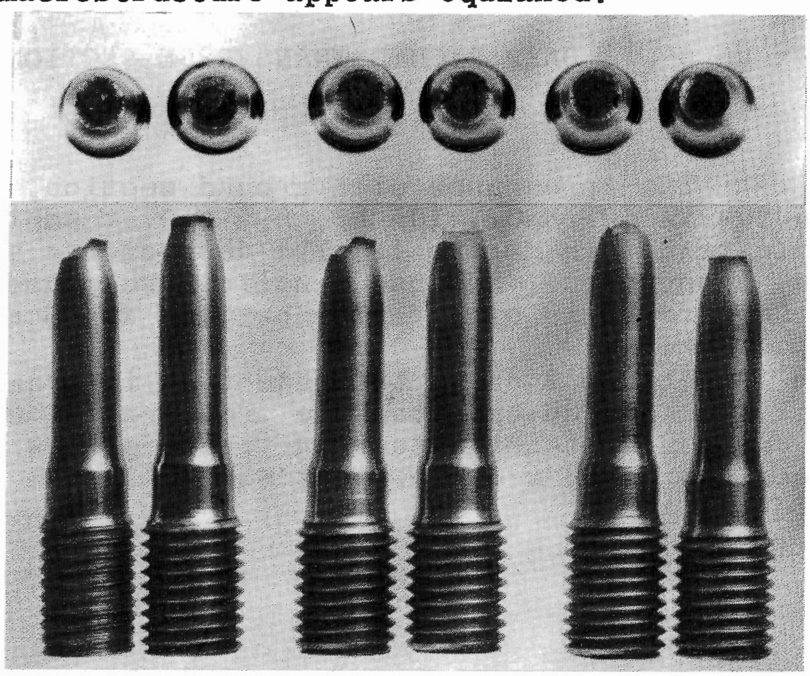
X1/2 - Deep-Etched, 5 min at ambient temperature in 40% HNO_3, 10% HF, 50% H_2O

Figure 1. Ground and Deep-Etched Mid-Section Through 6-in. x 6-in. x $6\frac{1}{2}$-in. DOT Test Block.

The macrostructure appears equiaxed.

(a)

(b)



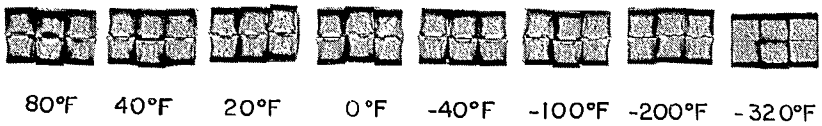
X2/3

Figure 2. Broken Tensile Test Bars (BHN-241, Heat 2-4049)

The fractures are of the cup-cone type and are consistent with the excellent tensile ductility demonstrated by RA values in excess of 60% and 22.% elongation in a 2-in. gauge length.

The Charpy V-notch impact-bar fractures, corresponding to the PMD impact tests listed in Table 3, are illustrated in Figure 3. These test bars deformed plastically, were fine-grained and remained free from cleavage fracture to temperatures below -100°F.

Approximately 20% cleavage at -200°F was observed; however, a considerable shear-lip and plastic deformation remained, corresponding to an average impact strength of 30 ft-lb at -200°F in the thick section. The tests made at -320°F in liquid nitrogen, developed about 40% cleavage in the fracture area corresponding to 9 ft-lb energy values.



X1/3 approx.

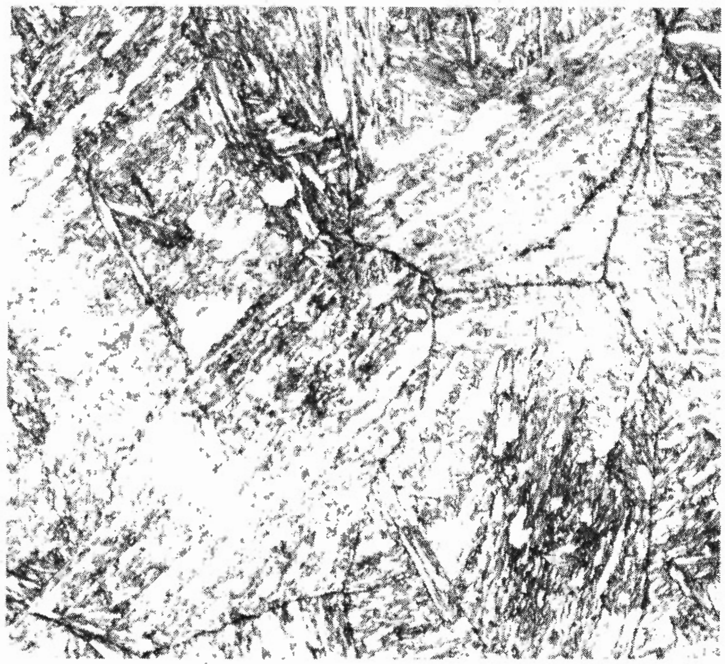
Figure 3. Charpy V-Notch Impact Bar Fractures (Triplicate Results)

All fractures in the temperature range, +80°F to -200°F, appeared tough and exhibited considerable plastic deformation.

METALLOGRAPHY

The appearance of a typical metallographic section, containing tempered low-carbon martensite is illustrated in Figure 4.

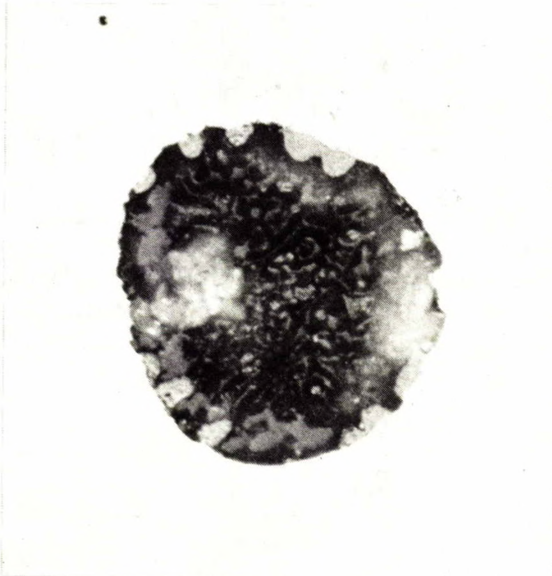
Figure 5 illustrates the appearance of typical spherical, duplexed inclusions. Microprobe analysis of three of these inclusions gave the averaged results listed in Table 4. The inclusions consist mainly of zirconium oxide duplexed with manganese sulphide.



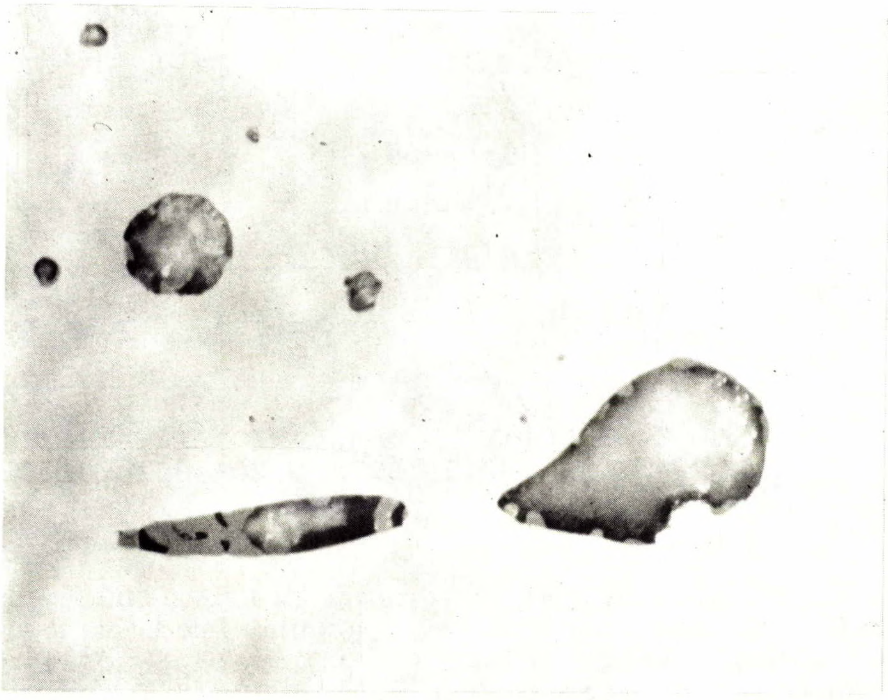
X500 - Etched in Vilella's Reagent

Figure 4. <u>Microstructure, Low-Carbon Tempered Martensite</u>
(1825°F air cooled, reheated 1100°F, air cooled).

X-ray diffraction results indicated trace quantities of retained austenite of the order of 1%. No hardness change was detected when the metal was cooled to -320°F.
The grain size is ASTM No. 5-6, the grain boundaries are visible, having been etched preferentially by Vilella's reagent.



(a)



(b)

X1000 - Etched in Vilella's Reagent

Figure 5. Typical Duplexed, Deoxidation-Type Inclusions
The results of microprobe analysis of three inclusions, averaged, indicate that their primary constituents are zirconium oxide and manganese sulphide.

MICROPROBE ANALYSIS OF INCLUSIONS

Averaged Microprobe Analysis of Typical Inclusions (Heat 2-4049)

Three inclusions were analysed as a whole without differentiating between the sulphide and matrix phase. The electron beam caused inclusions to glow, which further complicated the analysis. The results are listed in Table 4.

TABLE 4

Approximate Inclusion Composition, Average of Three Inclusions

Element	Per Cent
Zirconium	50
Oxygen	33
Manganese	5
Sulphur	2-4
Silicon	3-4
Aluminum	1 or less
Calcium	0.3
Titanium	0.3
Zinc	0.1 (same level as the matrix)

No cerium or lanthanum were detected.

NIL DUCTILITY TRANSITION TEMPERATURE DROP-WEIGHT TESTS (ASTM E 208-66T,Vol.31,1968)

Drop-weight test bars 5/8 in. thick, 2 in. wide, 5 in. long were machined and ground from the 6-in. x 6-in. x $6\frac{1}{2}$-in. test block. Longitudinal (Murex) weld beads were deposited and notched in accordance with ASTM E 208-66T and were tested at +80°F, -112°F, -130°F, -238°F, -255°F and -320°F by use of a 60-lb weight and 5-ft drop distance. Cooling to -112°F and to -130°F was done by use of ethyl alcohol and dry ice; cooling to -238°F and to -255°F was done by use of isopentane immersed in liquid nitrogen; the -320°F temperature was obtained by immersion of the test bars in liquid nitrogen. The results of the "NDT" temperature drop-weight tests are listed in Table 5.

TABLE 5

Drop-Weight Test Results on 5/8-in. x 2-in. x 5-in. Test Bars
60-lb wt dropped 5 ft(Murex, Notched Weld Bead)

Test Temp. (°F)	Coolant	Result
+80	air	passed
-112	alcohol and dry ice	passed
-130	alcohol, dry ice, liquid nitrogen	passed
-238	isopentane liquid nitrogen	passed($\frac{3}{8}$ in. crack)
-255	" " "	passed($\frac{3}{8}$ in. crack)
-320	liquid nitrogen	broken

The nil-ductility transition temperature was lower than -255°F and was higher than -320°F, indicating exceptional low-temperature toughness for 6-in. cast steel. The "NDT" temperature results were consistent with the high Charpy V-notch impact results obtained at low temperatures.

Fracture Toughness and Corrosion Tests

Metal samples (5/8 in. x 2 in. x 5 in.) were submitted to the Engineering Physics and Corrosion Sections respectively, for their retention and information. Unbroken Charpy V-notch impact test bars were also retained for any future test of pre-cracked, impact test bars.

DILATOMETER TEST

Figure 6 illustrates the dilatometer curve and location of the critical transformation temperatures for samples heated and cooled at 270 F°/hr.

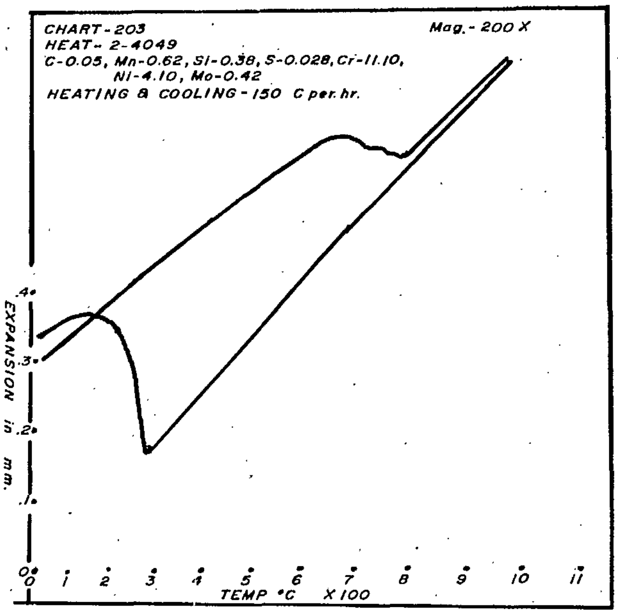


Figure 6. Dilatometer Curve, Heat 2-4049,(Ca 6 NM(13))Steel.

Cast steel 6-in. x 6-in. x 6½-in. test block. Heated to 1825°F, air cooled, reheated to 1100°F, air cooled. An expansion of 0.0016 in./1.648 in., test bar length, occurred on the first dilatometer run. Subsequent reruns of the same bar resulted in contractions of 0.0004 in. and 0.0006 in. respectively.

DISCUSSION OF RESULTS

The tensile ductility and fracture appearance of tensile bar and Charpy V-notch fractures were excellent for the section thickness (6-in.), heat treatment, and tensile strength (UTS ≈ 115 kpsi approx. and YS ≈ 80 kpsi approx.) investigated.

Charpy V-notch impact results, of 48 ft-lb at -100°F in 6-in. cast steel sections, were exceptional and substantiated the CSF results reported in April 1969.

The nil-ductility transition temperature (NDT temperature) was extremely low (below -255°F) indicating the probability of exceptionally tough behaviour at sea water and lower temperatures.

The deep-etched macrosection was equiaxed, relatively fine-grained, and homogeneous in its response to deep etching. Microprobe analysis indicated that deoxidation was achieved primarily by use of zirconium rather than aluminum.

The cast steel was stable with respect to retained austenite as indicated by no change of hardness during sub zero quenching and by the small quantity of austenite (1% approx.) detected by X-ray diffraction.

Dilatometer results resembled those previously reported for CSF heat 4694 at heating and cooling rates of 270 F° per hour.

The tensile strength, Brinell hardness and, particularly, the yield strength were lower than those reported for coupon tests made by CSF in April 1969. Since the results were reported for the same heat in the same condition of heat treatment, this difference is attributed to the mass-effect difference between the 1-in. and 6-in. sections. The most significant difference concerned the yield strength of 103.5 kpsi reported for coupons and the yield strengths of 82.4 kpsi obtained for the DOT 6-in. test block casting. Charpy V-notch impact values were similar for both the coupon and 6-in. section tests.

CONCLUSION

Study of the CA 6 NM(13) grade of cast steel, as represented by the DOT 6-in. x 6-in. x 6½-in. test block, for use in icebreaker propeller castings at UTS = 115 kpsi and 0.2% YS = 80 kpsi, is warranted from the viewpoint of potential increase of strength and low-temperature impact strength, providing other properties such as endurance limit, corrosion resistance in sea water[1,3], and weldability are acceptable.

ACKNOWLEDGEMENT

The writer gratefully acknowledges the assistance of Mr. C. M. Webster in obtaining the dilatometric data.

References

1. H. Souresny and H. Sauer (BSCRA Abstract, vol. 19, Jan. No. 1, 1970 - 152)
"Chromium Containing Cast Steels for Water Turbine Construction", Giesserei-Rundschau 1968, 15(12),Dec. 29-32.
"Communication from the R&D Division of Schoeller-Bleckmann Stahlwerke, Austria re German Std. DIN-GX5-CrNiMo13,4.
includes data
   (a) resistance to cavitation erosion
   (b) resistance to sand erosion
   (c) drop-impact abrasion resistance
   (d) performance of notched and unnotched specimens in alternating bend tests both in wet and dry condition
   (e) weldability

2. M. Notte, Plant Planning Manager, Canadian Steel Foundries Division, Hawker Siddeley Ltd., Montreal.

DEP/DAM/sg