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DETERMINATION OF LOW TEMPERATURE NOTCHED IMPACT STRENGTH OF 3/8 INCH "L.D." STEEL PLATE

by

D. E. PARSONS

Physical Metallurgy Division

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SUMMARY OF RESULTS

Impact results were obtained on Charpy V notch bars broken at temperatures between 200°F and -40°F and gave 15 ft-lb transition temperatures of 80°F, 107°F and 42°F on three samples of 3/8 inch plate. The plate samples represented three heats of "L.D." steel purchased by the Canadian National Railways.

The difference in the transition temperatures was ascribed to the finer ferrite grain size and to the higher manganese-to-carbon ratio of the good (42°F) heat.

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* Scientific Officer, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa.

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(3 tables; 14 illustrations)

ORIGIN AND SCOPE OF INVESTIGATION

Three samples of steel plate, 3/8 in. x 12 in. x 10 in. in size, were submitted by the Department of Research and Development, Canadian National Railways, 1801 LeBer Street, Montreal, Quebec, to the Physical Metallurgy Division, Mines Branch, Ottawa. The covering letter, File "LAB" 55/4825/4652, dated September 25, 1957, stated that the plates represented three heats, Nos. 10512, 10519 and 10525, of "L.D." steel manufactured by Dominion Foundries and Steel Ltd., and requested that the low temperature notched impact strength of the plates be determined.

Accordingly, Charpy V notch bars, standard and half-size, were prepared with the notch-axes normal to the plate surface. Bars cut in the longitudinal and transverse direction from each of the three plates were broken at -40°F, 32°F, 80°F, 140°F and 200°F. The results of these tests were reported by letter, C.N.R. file "LAB" 55/4825, on November 28, 1957, and it was decided that an additional examination would be made of the three plates to determine, if possible, the reason for the higher transition temperature observed in heats 10512 and 10519 compared with heat 10525.

The results of the impact tests and the subsequent metallurgical examination of the plates are included in the present report.

MATERIAL

The plates representing heats Nos. 10512, 10519 and 10525 were designated "A", "B", "C" respectively. Figures 1, 2 and 3 illustrate the plate specimens and show the location of the substandard Charpy V notch specimens. These substandard bars were cut from the centre of the plate sections and had an area under the notch of half the standard area. Standard Charpy V notch impact bars were also cut from adjoining areas. In the latter instance the mill surface was not removed, since no extra material was available for clean-up.

Fig. 1.

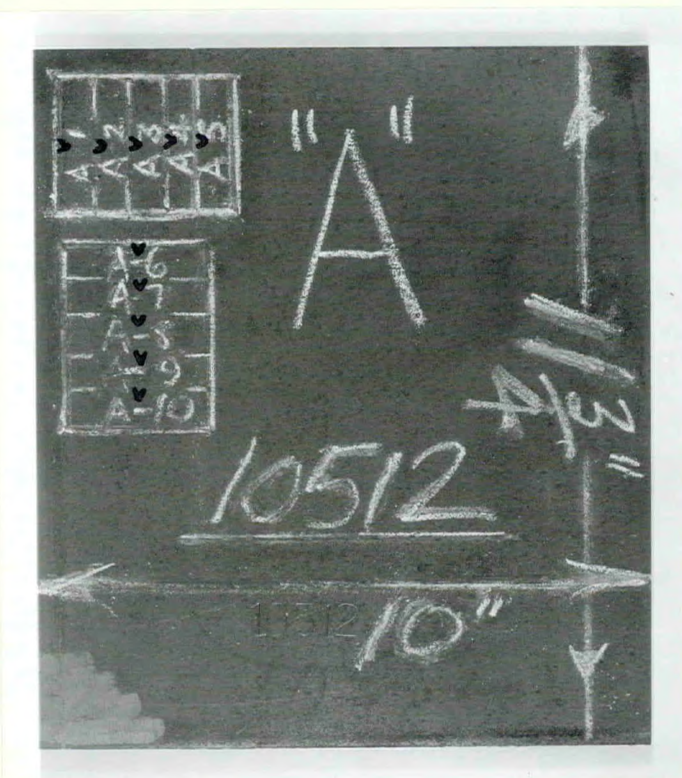

Plate A

Fig. 2.

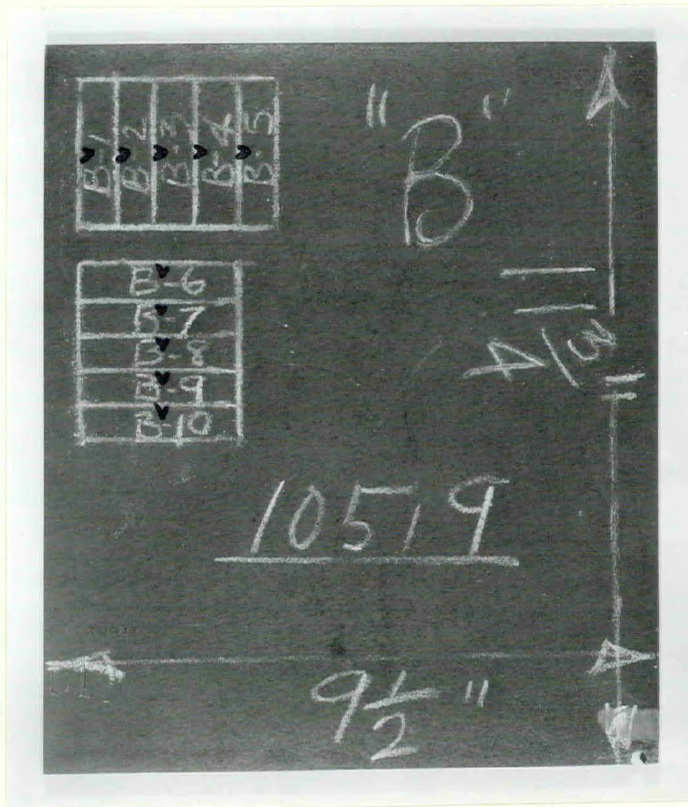

Plate B

Fig. 3.

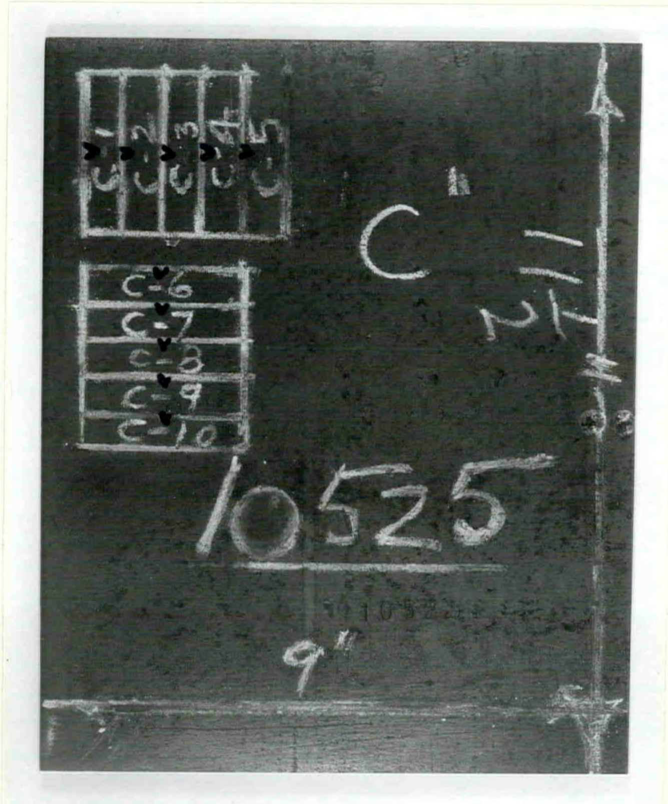

Plate C

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PROCEDURES AND RESULTS

The examination was carried out as follows:

1. Determination of 15 ft-lb Charpy V notch transition temperature, using substandard and standard Charpy V notch impact bars.

2. Chemical, spectrographic and gas analysis of the plates.

3. Metallographic examination and deep etch of plate sections.

4. Ferrite and austenite grain size comparisons.

5. Hardness tests.

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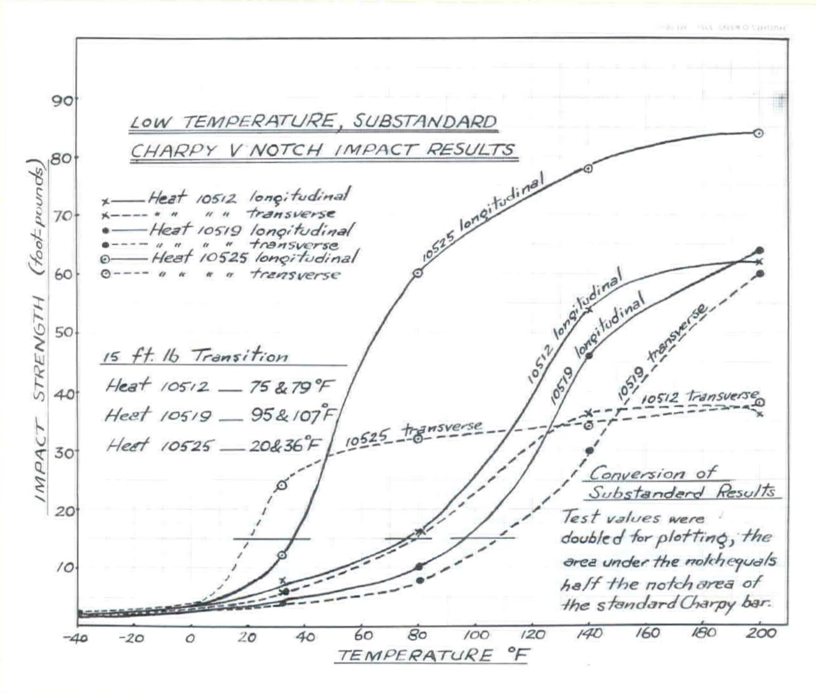
1. Notched Bar Impact Tests.

The results of the impact tests using "substandard" Charpy V notch bars are shown in Figure 4.

Fig. 4.



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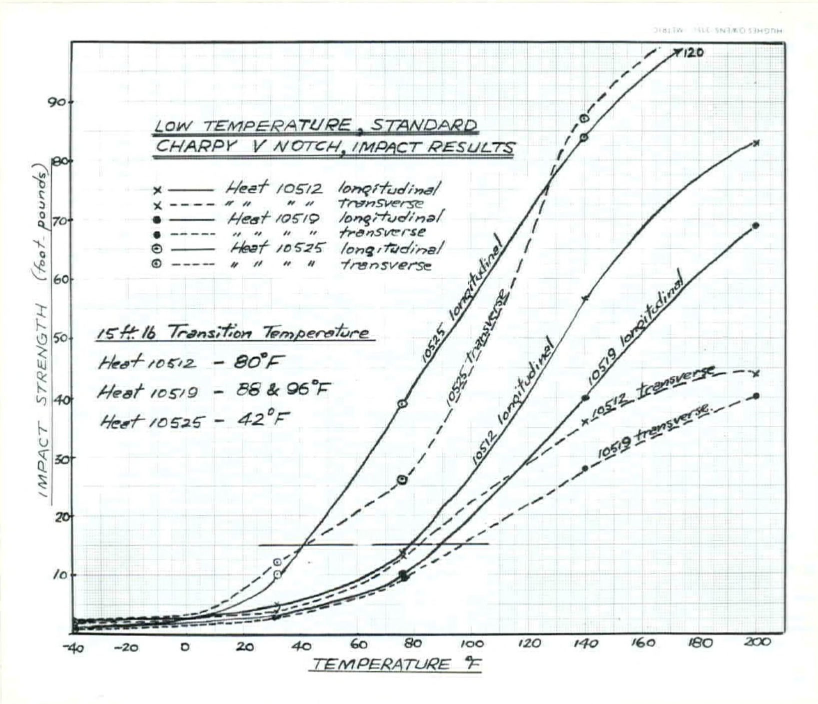
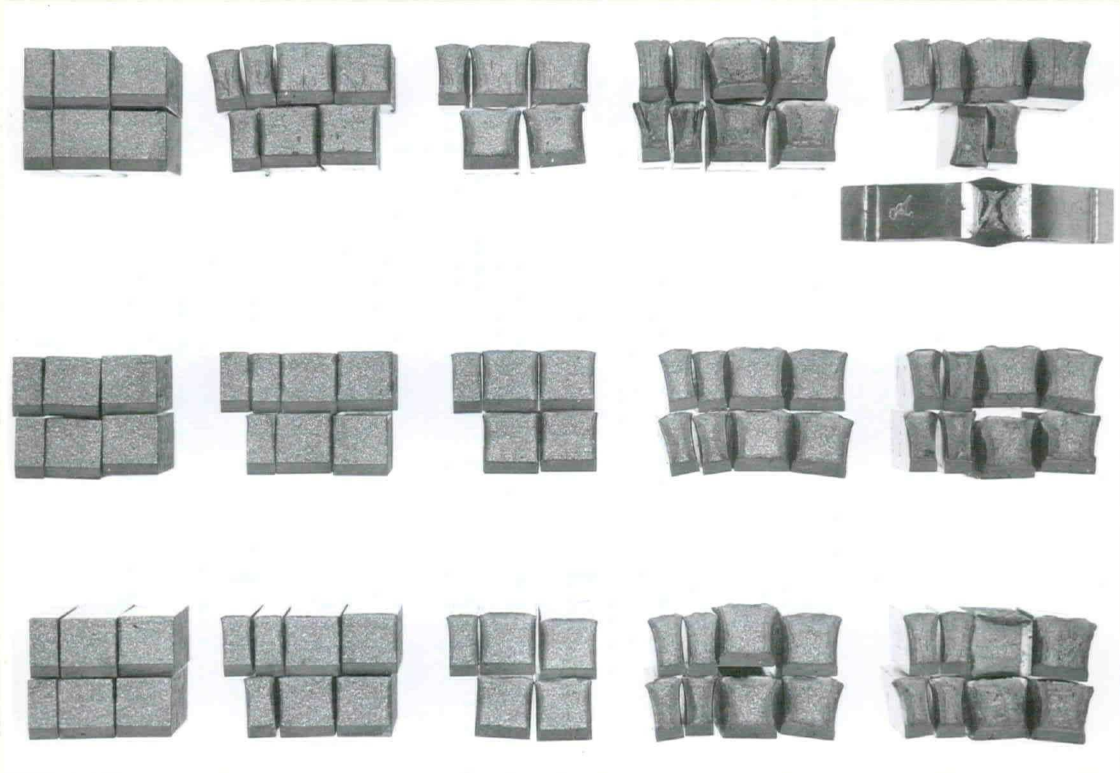
The results of the impact tests using "standard" (unmachined side surfaces) Charpy V notch bars are shown in Figure 5.

Fig. 5.



The appearance of the broken impact test bars is shown in Figure 6.

Fig. 6.



10525-T
10525-L
A

10519-T
10519-L
B

10512-T
10512-L
C

-40°F 32°F 80°F 140°F 200°F

APPEARANCE OF IMPACT BAR FRACTURES,
3/8 IN. L.D. PLATE.

Code: L - longitudinal; T - transverse.

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Table 1. - Estimated % Cleavage Fracture.

	$-40^{\circ}F$	$32^{\circ}F$	$80^{\circ}F$	$140^{\circ}F$	$200^{\circ}F$	50% shear transition temperature
10525 trans.	100	75	75	10	0	-
10525 long.	100	80	50	5*	0	$80^{\circ}F$
10519 trans.	100	95	80	50	5	$140^{\circ}F$
10519 long.	100	95	80	50	5	$140^{\circ}F$
10512 trans.	100	95	75	50	10	$140^{\circ}F$
10512 long.	100	95	75	50	30	$140^{\circ}F$

The ferrite grain size of heat 10525 was considerably finer than that of heats 10512 or 10519.

*Striations were observed in the fracture.

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2. Chemical, Spectrographic and Gas Analyses.

Table 2.

	C	Mn	Si	S	P	** N_2	* Al	* Cu	* Ni	* Cr	* Sn	*** O_2	*** H_2	*** N_2
10512	.17	.32	.03	.014	.005	.005	.002	.3	.06	.01	.007	.01	1/3 ppm.	.003
10519	.19	.35	.03	.016	.014	.008	.003	.3	.06	.02	.005	.009	1/2 ppm.	.006
10525	.12	.37	.04	.011	.009	.008	.003	.3	.03	.02	.009	.025	$<$1/2 ppm.	.006

(1 ppm. = 0.0001 wt%)

Zirconium, titanium, vanadium, molybdenum and tungsten were not detected spectrographically.

*Semi-quantitative spectrographic analysis.

**Kjeldahl wet analysis for nitrogen.

***Vacuum fusion analysis for residual oxygen, hydrogen, nitrogen.

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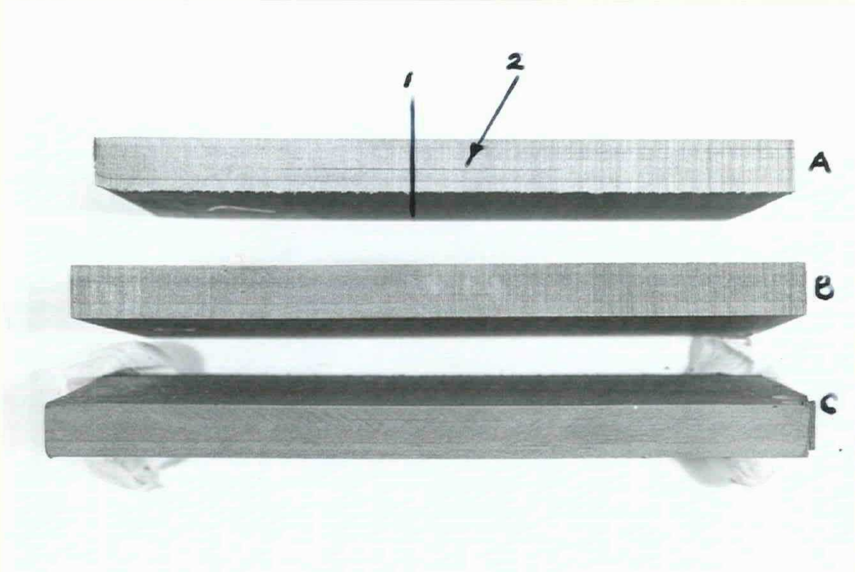
The analyses show that the plates conform to the specification for AISI 1015 steel in the instance of heats 10512 and 10525. Heat 10519, having 0.19% carbon, conforms to the analysis specified for AISI 1017 steel.

The steels were semi-killed and no unusual concentrations of residual elements or of residual oxygen, nitrogen or hydrogen were detected. The residual oxygen content of heat 10525 was higher than that of heats 10512 and 10519. This higher oxygen analysis correlated with a slightly higher residual aluminium content and the appearance of more numerous Al_2O_3 inclusions in the microstructure of heat 10525.

3. Metallography and Deep Etch.

The appearance of etched cross sections and plate surface sections is illustrated in Figures 7 and 8 respectively.

Fig. 7.



CROSS SECTIONS ETCHED 15 MINUTES IN
1:1 HCl AT 160°F.

(Approximately 4/5 actual size)

Microexamination at section 1 showed that the lamination (arrow 2) resulted from attack by the etchant on elongated slag stringers. The presence of slag stringers on the cross section was most evident in specimen A, although traces of stringers were seen in specimens B and C.

Fig. 8.

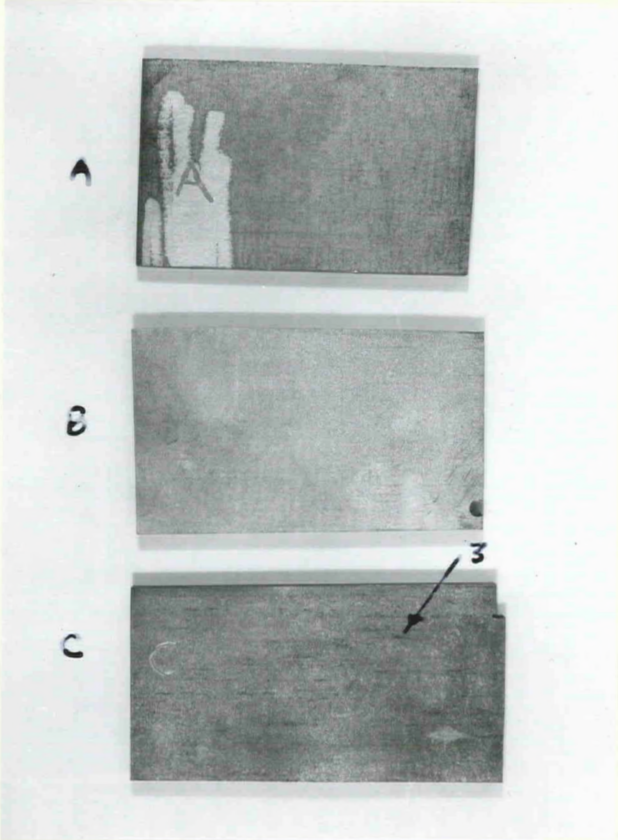


PLATE SURFACES ETCHED 15 MINUTES
IN 1:1 HCl AT 160°F.

(Approximately 2/5 actual size)

The plate surfaces of specimens A and B were considerably cleaner than that of plate C. The location of an inclusion at the surface of plate C is indicated by arrow 3.

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Examination of samples from each melt showed that heat 10519 was cleanest, both the surface and the cross section appearing satisfactory when deep-etched.

The plate surface of melt 10512 appeared satisfactory when deep-etched, but stringer inclusions were observed in the deep-etched cross section (arrow 2, Figure 7).

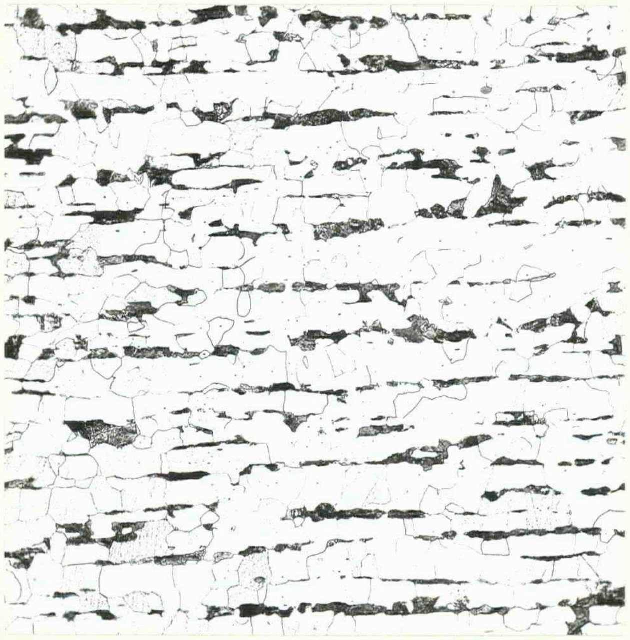
Heat 10525 appeared to be the least clean of the three melts, and evidence of inclusion clusters at the surface was observed on deep-etched plate section (arrow 3, Figure 8).

In the "as-polished" condition, examination of microspecimens from each melt showed that the inclusions consisted of duplex oxide-alumina type inclusions which lacked plasticity at the rolling temperature, together with slag-oxide and manganese sulphide inclusions which were plastic during rolling.

Since the inclusion direction was normal to the notch and fracture direction of the Charpy V notch test bars, the presence of the inclusions probably did not affect the values of impact strength obtained. Heat 10525, which contained the most numerous oxide inclusions, also had the lowest transition temperature of the plates tested.

Examination of etched samples from the three heats showed evidence of pearlite banding in longitudinal sections from the three melts. The ferrite grain sizes (ASTM, E-89-52) were No. 6, No. 6 and No. 8 for heats 10512, 10519 and 10525, respectively. The microstructures of transverse and longitudinal specimens etched in 2% nital are illustrated in Figures 9 to 14, inclusive.

Fig. 9.



ASTM No. 6 - (ferrite)
15 ft-lb V notch impact

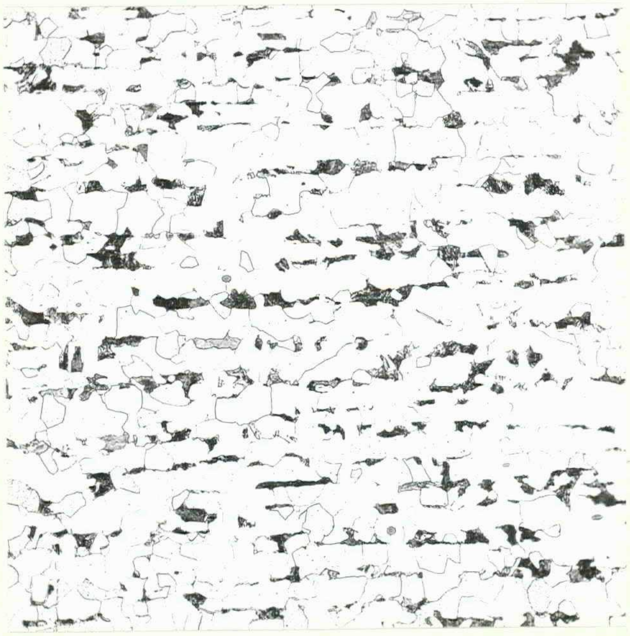
Transition temp. = 80°F

Carbon = 0.17%

(X100; etched in 2% nital)

Transverse Section, Specimen A, Heat 10512.

Fig. 10.



ASTM No. 6 - (ferrite)
15 ft-lb V notch impact

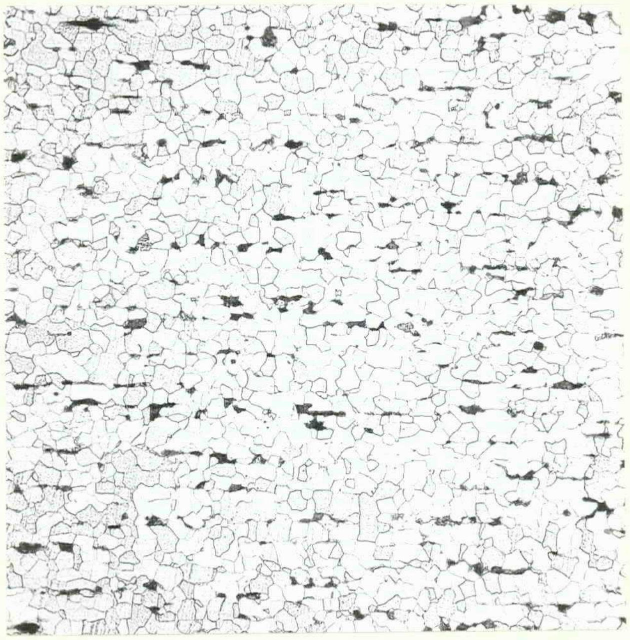
Transition temp. = 107°F

Carbon = 0.19%

(X100; etched in 2% nital)

Transverse Section, Specimen B, Heat 10519.

Fig. 11.



ASTM No. 8 - (ferrite)
15 ft-lb V notch impact

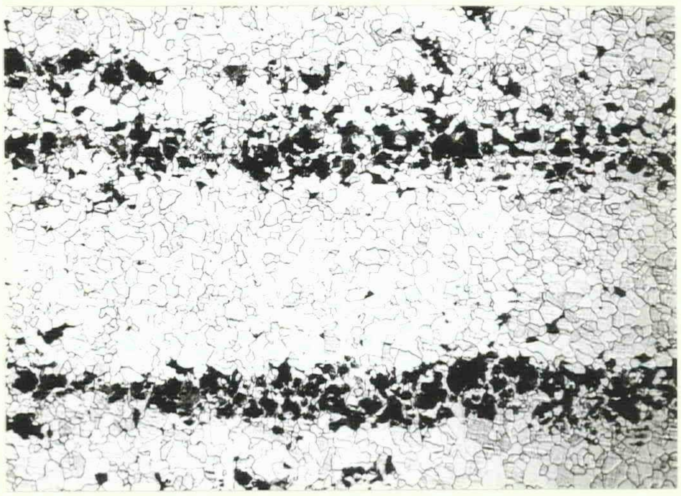
Transition temp. = 42°F

Carbon = 0.12%

(X100; etched in 2% nital)

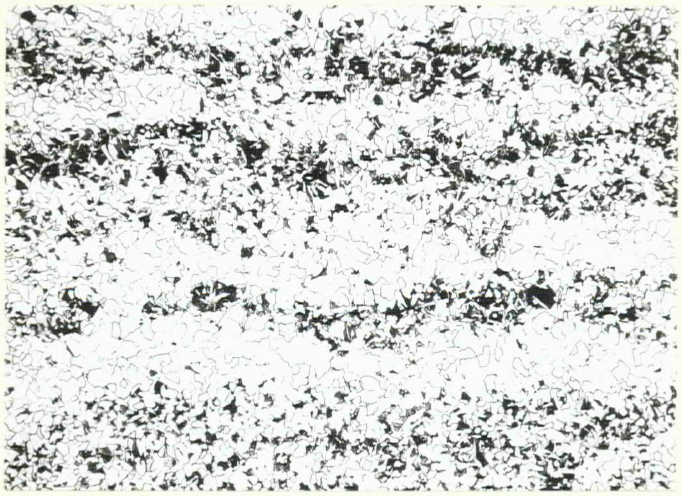
Transverse Section, Specimen C, Heat 10525.

Fig. 12.



Longitudinal Section, Specimen A, Heat 10512.
(X40; etched in 2% nital)

Fig. 13.



Longitudinal Section, Specimen B, Heat 10519.
(X40; etched in 2% nital)

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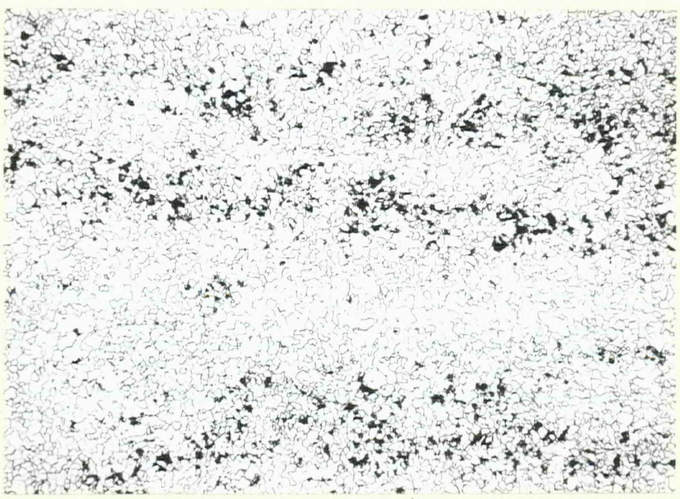
Fig. 14.



Longitudinal Section, Specimen C, Heat 10525.
(X40; etched in 2% nital)

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4. Ferrite and Austenite Grain Size Comparison.

The ferrite grain sizes (ASTM E-89-52) were measured on the transverse microspecimens illustrated in Figures 9 to 11, inclusive. McQuaid-Ehn specimens were also prepared and the austenite grain sizes at 1700°F were determined. The results of the grain size determinations are summarized in Table 3.

Table 3.

Heat No.	Ferrite Grain Size at X100 (ASTM E-89-52 - No.)	Austenite Grain Size (McQuaid-Ehn No.)
10512	6	Predominantly No. 1(range 1-4)*
10519	6	Predominantly No. 2(range 1-4)**
10525	8	Predominantly No. 3(range 1-6)*

** Steel is normal by the McQuaid-Ehn test.

* Steel is abnormal by the McQuaid-Ehn test.

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5. Hardness Tests.

The average of three Brinell impressions taken on each ground plate sample gave results of 109, 116 and 111 Brinell, respectively, for heats 10512, 10519 and 10525.

DISCUSSION

The three heats of steel were semi-killed and were relatively fine-grained according to the ASTM (E-89-52) ferrite grain size classification. Of the three heats, the ferrite grain size of heat 10525 was considerably finer (ASTM, No. 8) than that of heats 10512 and 10519 (ASTM, No. 6). Heat 10525 possessed the lowest (42°F) 15 ft-lb V notch transition temperature. Better low temperature impact properties in heat 10525 than in heats 10512 and 10519 would be anticipated because of its lower carbon content (higher Mn/C ratio) and its finer ferrite grain size. The residual aluminium content of heat 10525 was slightly higher than that of heats 10512 and 10519.

The three heats were coarse-grained in the McQuaid-Ehn austenite grain size test, heats 10512 and 10525 possessing abnormal McQuaid-Ehn characteristics whereas heat 10519 appeared normal.

The plates were all very soft, of the order of 110 Brinell, and were in the hot-rolled and slow-cooled condition, the microstructure consisting of banded pearlite and ferrite.

The striated appearance of impact fractures made in the transverse direction was believed explained by the presence of pearlite banding and stringer inclusions.

SUMMARY

1. The highest 15 ft-lb transition temperatures determined for heats 10512, 10519 and 10525 were 80°F, 107°F and 42°F, respectively. Good agreement was obtained between standard and substandard impact tests, and between longitudinal and transverse specimens.

2. The higher notch impact strength observed in heat 10525 at low temperatures, compared with heats 10512 and 10519, was believed explained by its lower carbon content and finer ferrite grain size. (The finer grain size possibly reflected a lower finishing temperature during rolling, and use of a larger quantity of deoxidizer.)

3. Pearlite banding, and a Brinell hardness of the order of 110, indicated that the plates cooled slowly after rolling.

4. Slag and oxide stringers were observed in the cross section of plate 10512, and inclusion clusters were observed at the surface of plate 10525.

Melt 10525 appeared to contain more inclusions than melt 10519; melt 10512 was intermediate in this respect.

5. The steels were semi-killed, having silicon contents of the order of 0.05% and residual (total) aluminium contents of the order of 0.002 to 0.008%. The residual oxygen, hydrogen and nitrogen contents appeared normal, except that more oxygen was held by the residual aluminium in heat 10525 than in heats 10512 and 10519. The Mn/C ratios tended to be low, being approximately 2:1, except in the instance of heat 10525 where the lower carbon content resulted in a 3:1 Mn/C ratio.

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