SSC-106

MILL SAMPLING TECHNIQUES FOR QUALITY DETERMINATION OF SHIP PLATE STEEL

by

Charles L. Staugaitis

SHIP STRUCTURE COMMITTEE

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ADDRESS CORRESPONDENCE TO:

SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

January 31, 1958

Dear Sir:

The Ship Structure Committee and the American Iron and Steel Institute are jointly sponsoring a study at the National Bureau of Standards to determine the notch toughness of currently produced ship plate steels. Herewith is a copy of SSC-106, First Progress Report on "Mill Sampling Techniques for Quality Determination of Ship Plate Steel," by C. L. Staugaitis.

The project is being conducted with the advisory assistance of the Committee on Ship Steel of the National Academy of Sciences-National Research Council.

Any questions, comments, criticism, or other matters pertaining to the report should be addressed to the Secretary, Ship Structure Committee.

This report is being distributed to those individuals and agencies associated with and interested in the work of the Ship Structure Committee.

Yours sincerely,

K. K. Cowart

K. K. Cowart, Rear Admiral
U. S. Coast Guard
Chairman, Ship Structure
Committee

Serial No. SSC-106

First Progress Report
of
Project SR-139

to the

SHIP STRUCTURE COMMITTEE

on

MILL SAMPLING TECHNIQUES FOR QUALITY DETERMINATION OF SHIP PLATE STEEL

by

Charles L. Staugaitis

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MILL SAMPLING TECHNIQUES FOR QUALITY DETERMINATION OF SHIP PLATE STEEL

ABSTRACT

In order to obtain information on the variation of mechanical properties within typical heats of currently produced ship plate steel, 54 plates from 6 heats were obtained from two producers, United States Steel Corporation and Bethlehem Steel Company. The former contributed 27 plates of 3/4-in. ABS-Class B, and the latter contributed 27 plates of 1 1/4-in. ABS-Class C. All were made to the ABS Specification in effect prior to February 1, 1956. A sample of 24 of these plates was selected to provide data on the variations among plates, ingots, and heats. Five additional plates were subsequently tested to resolve doubtful cases. Although primary interest was on the notch toughness characteristics, the static tensile properties, ferrite grain size, and chemical composition were also measured. In addition, the severity and extent of segregation in some of the plates was studied, and the influence of segregation on impact test results was examined.

Analysis of the results on the 29 plates indicates that the mechanical properties of plates in an entire heat can be satisfactorily evaluated by tests on two properly chosen sample plates.

TABLE OF CONTENTS

MILL SAMPLING TECHNIQUES FOR QUALITY DETERMINATION OF SHIP PLATE STEEL

I. INTRODUCTION

This investigation was initiated as a result of a survey of the ship steel research program made in 1953[1]. One of the recommendations in the report of this survey was that a test program be undertaken to determine the notch toughness of currently produced ship plate steels and to evaluate those factors that may significantly influence this property. The project thus established has been sponsored jointly by the Ship Structure Committee and the American Iron and Steel Institute. Dr. W. J. Harris, Jr., is chairman of the project advisory committee.

The first steps of this investigation were to assess the degree of variation that exists within a heat and to determine the best location and minimum number of test samples necessary to describe adequately the notch toughness characteristics of a heat of ship steel. Thus the work described in this report was confined to only six heats of steel.

Dr. W. J. Youden of the National Bureau of Standards, Statistical Engineering Section, served as consultant on the project

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(1) C. S. Barrett and W. E. Mahin, "A Review of Ship Steel Research and Recommendations for Future Studies," Review Report, Ship Structure Committee Report Serial No. SSC-70, February 15, 1954.

and laid out the schedule of tests for certain portions of the investigation. Personnel of the statistical group also made extensive statistical computations from these test data. Results and discussion of the statistical computations are given in Appendix A.

II. MATERIAL

The first phase of this investigation is concerned only with those steels made to the specifications of the American Bureau of Shipping prior to February 1, 1956. Twenty-seven samples of 3/4-in. ABS Class B Steel were contributed by the United States Steel Corporation and a like number of 1 1/4-in. ABS Class C plates by the Bethlehem Steel Company. Each group of twenty-seven plate samples was obtained from three separate heats. The test samples were chosen from the top, center, and bottom plates of the second, middle and next-to-last ingots of each heat. The mills contributing the steel plate provided data sheets which gave extensive information on the manufacturing and processing of the individual samples. These sheets allowed complete identification of each heat, ingot, and plate. They also included information on melting practice, ingot practice, and rolling practice.

The ladle analyses of each heat are given in Table 1 and conform to the 1954 ABS requirements (now slightly changed) as shown in the same table.

TABLE 1. Ladle Analyses

3/4-in. ABS--Class B Steel

Heats	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
B1	.20	.78	.016	.028	.047	.07	.12	-	-
B2	.19	.74	.017	.032	.039	.03	.03	-	-
B3	.20	.82	.019	.026	.046	.09	.07	-	-
(ABS Class B Requirements)									
1954	.23 max	.60/.90	.04 max	.05 max					
1956	.21 max	.80/1.10	.04 max	.05 max					

1 1/4-in. ABS--Class C Steel

Heats	C	Mn	P	S	Si	Cu	Ni	Cr	Sn	Al
C1	.14	.67	.010	.025	.185	.065	.035	.020	.005	.033
C2	.15	.68	.012	.027	.19	.12	.04	.025	.010	.041
C3	.14	.69	.016	.033	.18	.11	.056	.030	.009	.045
(ABS Class C Requirements)										
1954	.25 max	.60/.90	.04 max	.05 max	.15/.30					
1956	.24 max	.60/.90	.04 max	.05 max	.15/.30					

Summaries of plate analyses for carbon, manganese, phosphorus, sulfur, and silicon of the plates tested are given in Tables 2 and 3.

The test samples furnished by both mills were approximately six feet in length (in the direction of rolling) by the full plate width. However, in the event that some plates were less than five feet in width, the length was correspondingly increased to provide at least thirty square feet of material.

From these test samples, a piece 18 in. long (in direction of rolling) by half plate width (usually 40 in. to 50 in. wide)

TABLE 2. Chemical Composition of 3/4-in. pre-1956 ABS-B Steel

Heat	Ingot (1)	Plate (2)	NBS No.	Carbon Edge	Carbon Center	Manganese(3) Edge	Manganese(3) Center	Phosphorus Edge	Phosphorus Center	Sulphur Edge	Sulphur Center	Silicon(3) Edge	Silicon(3) Center
B1	S	T	201	.21	.20	.74	.74	.013	.013	.029	.026	.052	.049
"	S	C	202	.20	.21	.77	.75	.013	.014	.027	.027	.051	.050
"	M	T	203	.21	.21	.78	.76	.013	.014	.028	.028	.050	.049
"	M	B	204	.20	.19	.77	.75	.011	.010	.027	.025	.046	.051
"	L	T	225	.20	.20	.75	.76	.013	.012	.027	.025	.05	.05
"	M	C	226	.22	.22	.80	.80	.014	.014	.031	.030	.052	.054
B2	S	C	205	.20	.20	.74	.75	.015	.015	.030	.029	.042	.041
"	S	B	206	.20	.19	.75	.73	.016	.015	.030	.027	.042	.046
"	L	T	207	.19	.18	.74	.70	.017	.017	.028	.027	.046	.044
					.12*		.66*		.012*		.015*		.043*
"	L	C	208	.19	.19	.75	.78	.017	.017	.028	.029	.043	.045
"	S	T	227	.20	.20	.78	.80	.017	.017	.031	.028	.051	.054
					.14*		.80*		.012*		.020*		.051*
"	M	C	228	.20	.20	.77	.76	.017	.018	.029	.031	.053	.048
B3	M	C	209	.20	.20	.82	.82	.015	.015	.029	.028	.053	.050
"	M	B	210	.19	.19	.78	.80	.014	.014	.027	.024	.047	.054
"	L	T	211	.20	.20	.81	.81	.015	.015	.028	.028	.049	.047
					.40*		.92*		.034*		.070*		.047*
"	L	B	212	.19	.19	.82	.80	.015	.015	.028	.027	.046	.047
"	L	C	229	.21	.21	.86	.84	.016	.016	.029	.030	.050	.049

(1) S--Second, M--Middle, L--Next-to-last
(2) T--Top, C--Center, B--Bottom
(3) Spectrochemical analysis
*Composition of segregated area

TABLE 3. Chemical Composition of 1 1/4-in. ABS-C Steel

Heat	Ingot (1)	Plate (2)	NBS No.	Carbon Edge	Carbon Center	Manganese(3) Edge	Manganese(3) Center	Phosphorus Edge	Phosphorus Center	Sulphur Edge	Sulphur Center	Silicon(3) Edge	Silicon(3) Center
C1	S	T	213	.15	.15	.71	.74	.006	.007	.022	.022	.21	.20
"	S	C	214	.14	.15	.75	.70	.008	.007	.019	.021	.20	.20
"	M	T	215	.14	.15	.72	.72	.008	.008	.021	.022	.20	.19
"	M	B	216	.14	.13	.71	.65	.006	.006	.020	.018	.20	.20
C2	S	C	217	.15	.15	.75	.67	.009	.010	.022	.022	.22	.22
"	S	B	218	.13	.12	.68	.66	.009	.007	.020	.018	.22	.22
"	L	T	219	.15	.17	.68	.70	.014	.015	.024	.025	.21	.21
"	L	C	220	.15	.14	.70	.68	.014	.014	.023	.023	.22	.22
C3	M	C	221	.14	.14	.69	.72	.014	.014	.030	.031	.23	.24
"	M	B	222	.13	.12	.75	.71	.013	.011	.028	.026	.23	.22
"	L	T	223	.13	.13	.75	.72	.015	.016	.029	.030	.22	.22
"	L	B	224	.14	.12	.77	.66	.015	.013	.029	.026	.21	.21

(1) S--Second, M--Middle, L--Next-to-last
(2) T--Top, C--Center, B--Bottom
(3) Spectrochemical analysis

was removed by flame cutting. Two 18-in. x 16-in. sections were then removed from this piece, one adjacent to the edge and the other nearest the center of the original plate. The sheet metal template shown in Fig. 1 was employed to facilitate laying out specimen coupons from these two sections. The small holes provide reference points for punch marks to indicate where blanks should be sawed for the various test specimens. The large holes locate the positions where identification numbers are stamped. Utilization of this template insured that the orientation of specimens in each plate sample was always the same.

In order to determine what variations, if any, exist between plates, ingots, and heats, the sampling scheme shown in Table 4 was employed for the initial phase of the investigation. The selection of the 12 plate numbers shown without

TABLE 4. Location of Samples

	Second Ingot			Middle Ingot			Next to Last Ingot		
	Top	Cen.	Bot.	Top	Cen.	Bot.	Top	Cen.	Bot.
B-Steel									
Heat 1	201	202	---	203	226*	204	225*	---	---
Heat 2	227*	205	206	---	228*	---	207	208	---
Heat 3	---	---	---	---	209	210	211	229*	212
C-Steel									
Heat 1	213	214	---	215	---	216	---	---	---
Heat 2	---	217	218	---	---	---	219	220	---
Heat 3	---	---	---	---	221	222	223	---	224

*Second sampling

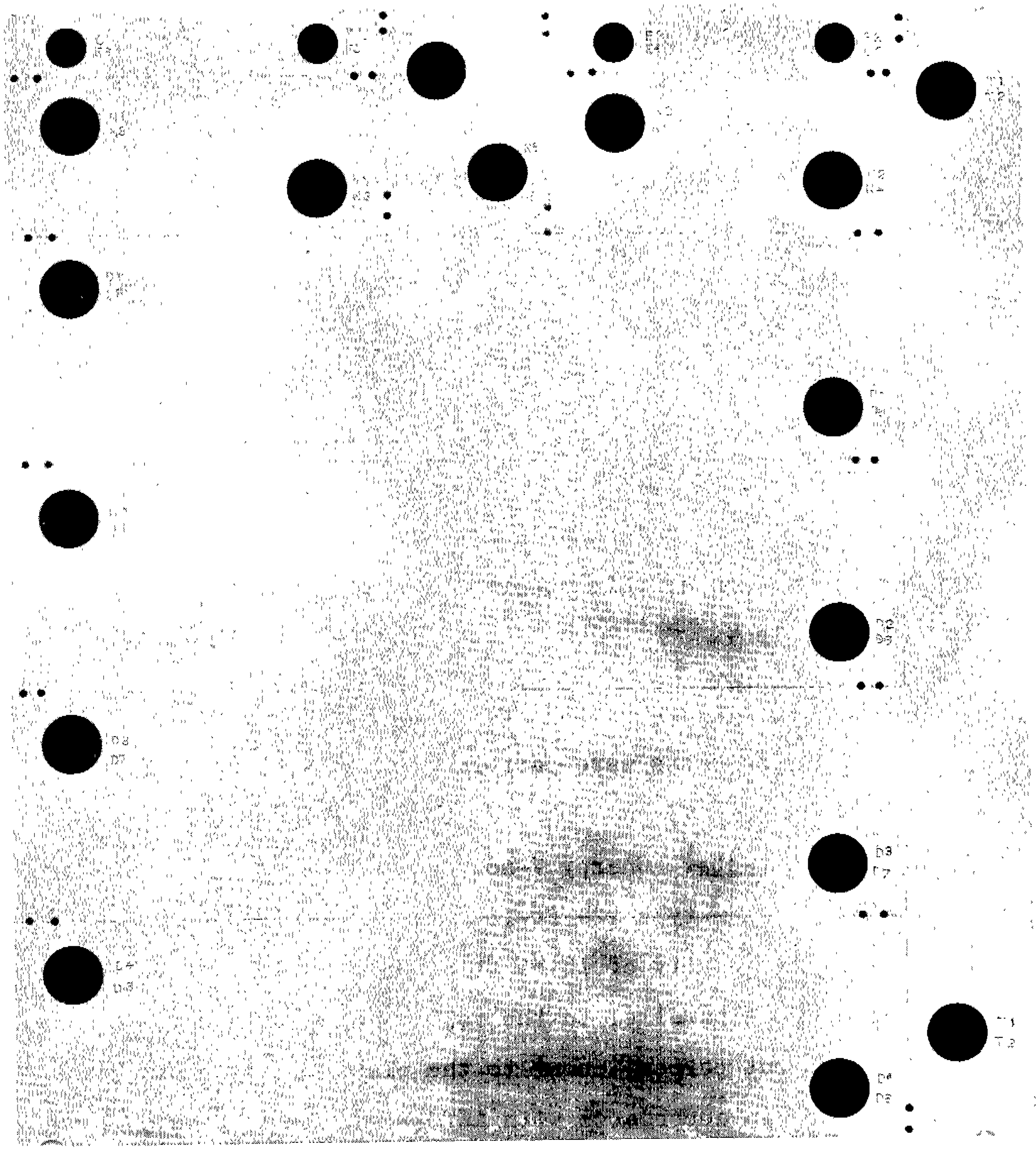

Fig 1. Sheet metal template for specimen layout. The small holes orient the various test blanks while the larger holes serve to locate the same areas for stamping of identification symbols. X 1/2

asterisks permits comparisons to be made between plates of the same ingot, between ingots of the same heat, and between ingots of different heats. The same sampling procedure was followed for the B and C steels. However, in the case of the B heats, this plate selection was supplemented by a second sampling indicated by asterisks in order to analyze more rigorously the variations in this grade of steel which exhibited rather marked differences in plate segregation. Therefore, in this preliminary program, 29 plates were fully tested. This figure represents 17 samples of B Steel and 12 of C Steel. Numbers in the table are the NBS identification code as used throughout this report. The sampling scheme is as shown in table 4.

III. TESTING PROCEDURE

The following tests were performed on each plate sample selected.

(a) Impact tests. Charpy V-notch impact tests were conducted on a pendulum-type 224 ft-lb capacity Charpy machine with a striking velocity of 16.85 ft per sec. The impact specimens were cut parallel to the rolling direction, and the V-notches were cut perpendicular to the plate surface. The dimensions were in accordance with ASTM specifications E23-47T for type A. The specimens were immersed in a bath* for at least 20 minutes before testing. The temperature was carefully controlled within ±1 F. Tests were made at intervals of 10 F over a temperature range that included energy values from 10 to 30 ft-lb. (See Appendix C).

(b) Tensile tests. All tensile tests were carried out on a 200,000-lb capacity Riehle hydraulic testing machine. An averaging extensometer of 8-in. gauge length was used to obtain stress-strain curves for all full-plate thickness coupons tested.

(c) Chemical and spectrochemical analyses. One blank for analysis was obtained near the edge of each plate and one near the center. Carbon, phosphorus, sulfur, and nickel were determined by chemical analysis; manganese, silicon, copper, nickel, chromium, vanadium, molybdenum, aluminum, tin, titanium and arsenic by spectrochemical methods.

(d) Full-plate thickness tests. Drop-weight crack starter tests were made on each plate sample at the Naval Research Laboratory. Results and discussion of these tests are given in Appendix B.

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*For temperatures above 40 F--a water bath cooled with chipped ice was used.
For temperatures below 40 F--a mixture of glycol and water cooled with dry ice was used.
For temperatures below -30 F--a mixture of CCl_4 and chloroform cooled with dry ice was used.

(e) Metallographic examination. Ferrite grain size measurements were made by the Heyn Intercept Method*. In addition, a cross section of each plate was etched with 5% Nital and examined to determine the degree of segregation. These etched samples were located adjacent to the impact specimens and thus represent accurately the degree of segregation of the impact specimens. Photomicrographs were taken of significant features.

IV. RESULTS AND DISCUSSION

Tables 5 and 6 summarize the results of all tests on the 29 plate samples tested. These tables include the static properties, ferrite grain size and impact test results, in terms of both fracture appearance and transition temperature.

With one exception, the tensile properties of all plates were within 7% of the average and in most instances within 5%. However, B steel sample NBS No. 211 had a significantly higher yield point and tensile strength with a correspondingly lower per cent elongation. The deviations from the average were 15.6, 13.4 and 27.2%, respectively. An explanation for this variation is found in the high carbon content of the central portion of the plate, as shown in Fig. 2. The degree of segregation in this plate is emphasized by Fig. 3, which shows the microstructure at three locations in the plate. Chemical analysis indicated an average carbon content of 0.40% for material in the

*ASTM Recommended Practice E89-52

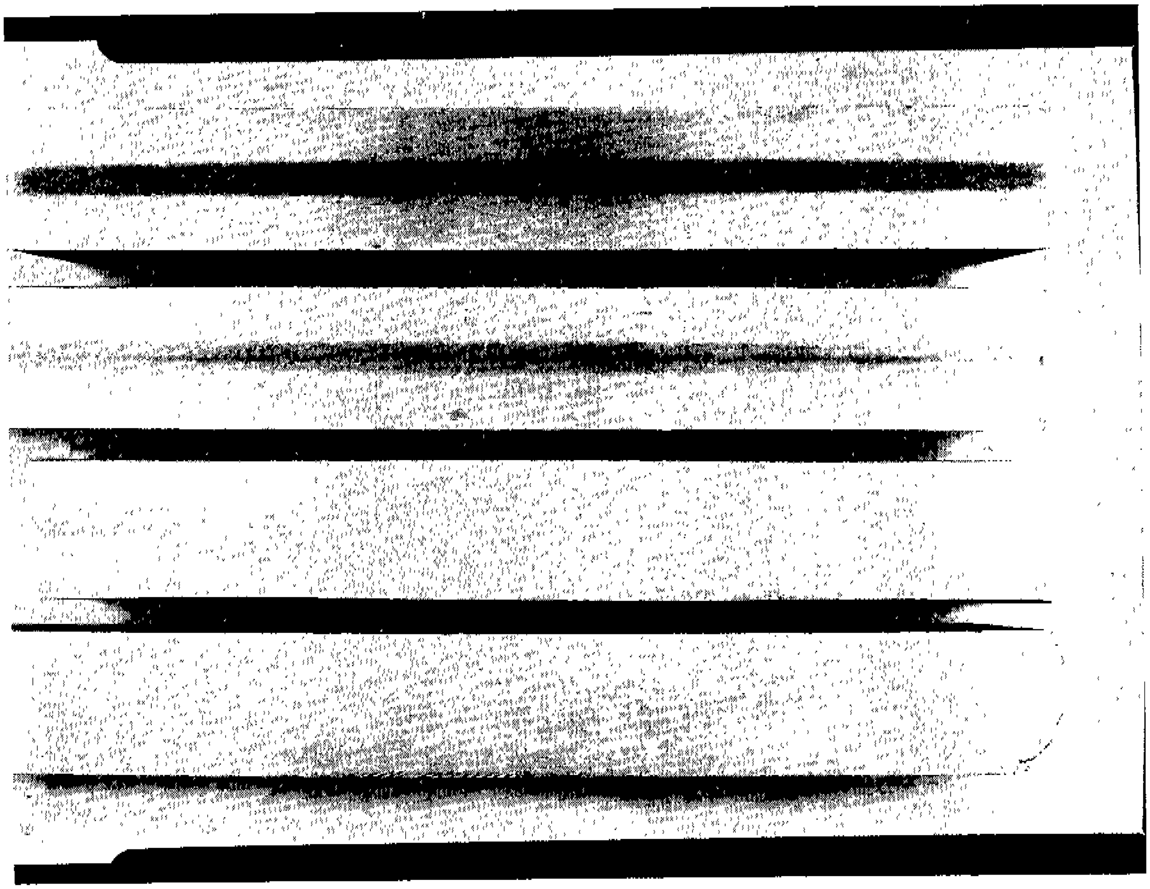
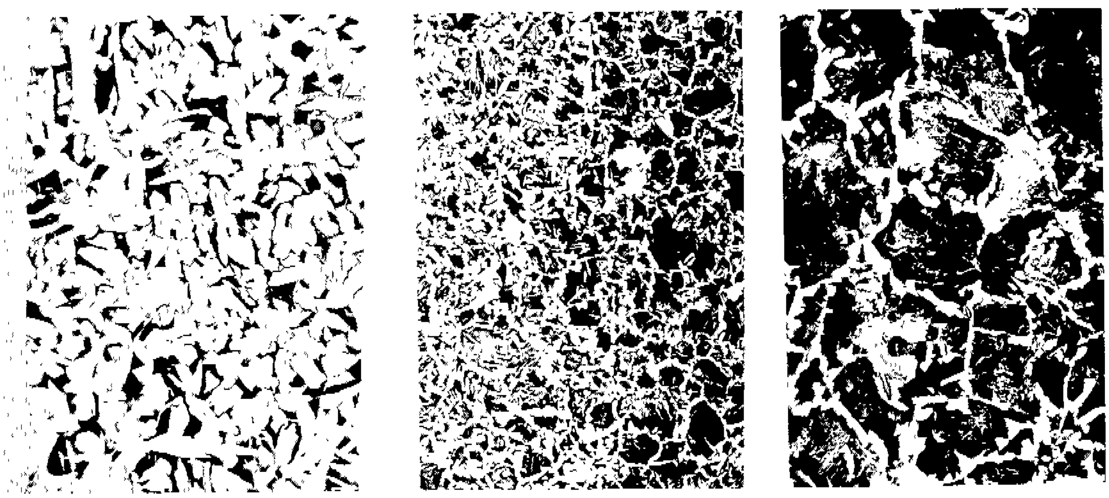


Fig. 2. Segregation zones present in four selected cross sections removed from plate No. 211, of ABS Class B steel (X 1). Cross section at top is from center of plate, and cross section at bottom is from edge.



a) Zone of normal carbon content. X 250

b) Boundary between normal and segregated areas. X 100

c) Segregated zone. X 250

Fig. 3. Photomicrographs representing the cross-section of plate No. 211.

center of the plate thickness, in contrast to 0.20% for the rest of the plate.

Samples from both grades of steel revealed zones of segregation; however, that in the plate just discussed (NBS No. 211) was the most severe. The segregation appeared to be more pronounced in the Class B than in the Class C steels. All top and center plates of the B heats exhibited areas of segregation in the center ranging from a very light to a very dark shade when compared with the rest of the plate. However, only one of the bottom plates showed this effect, and in this instance the degree of segregation was small. Some unusual examples of segregation that occurred in B steel are shown in Figs. 4 and 5.

With regard to the Class C steels, only heats C1 and C2 had sample plates that showed zones of segregation, and all of these zones came from the top and the center plates of the ingots. Furthermore, there appeared to be no difference in the type of segregation such as was found in the B heats (Figs. 2, 4 and 5). All center zones of C steel etched out a light shade in comparison with the rest of the cross section and in appearance were similar to the sample shown in Fig. 4.

Typical graphs of Charpy V-notch impact data of each grade of steel are shown in Figs. 6 and 7. The reversal in slope of the line drawn through the averages is characteristic

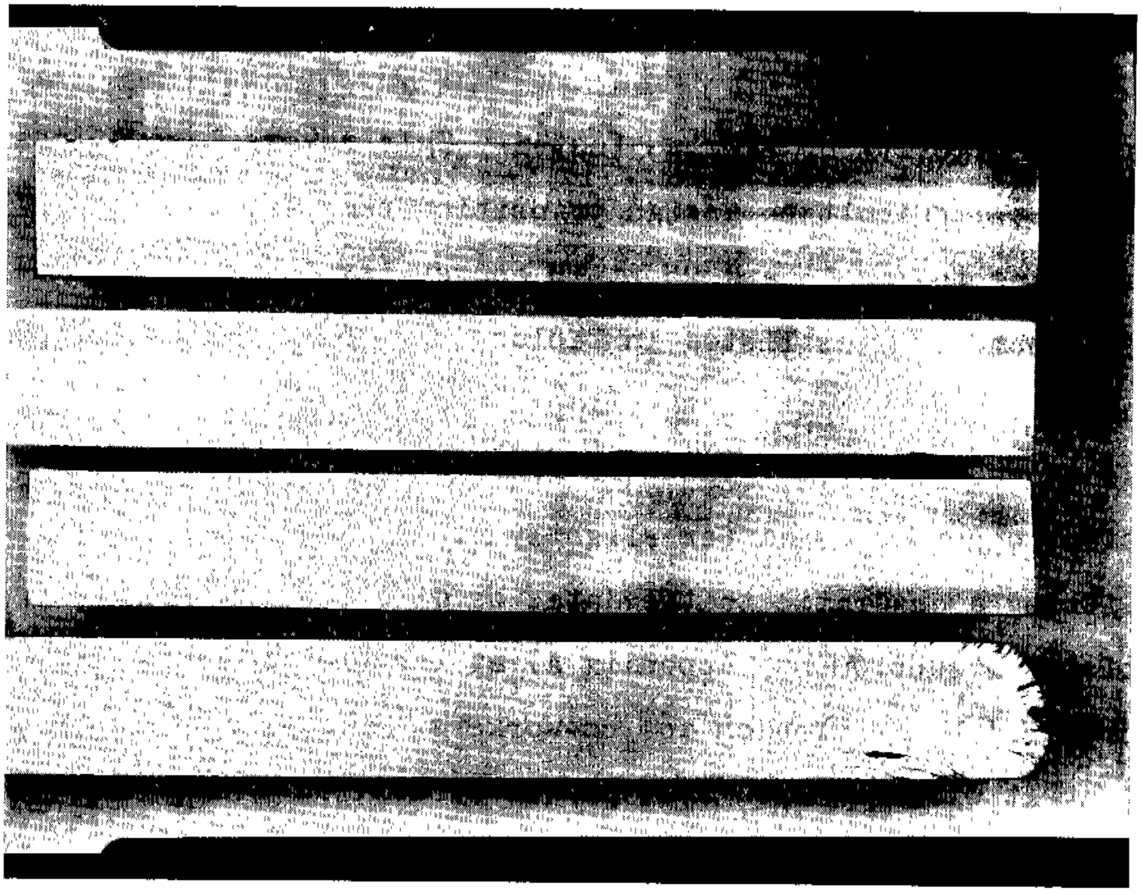


Fig. 4. Negative segregation of etch blanks from four locations across plate 207, of ABS Class B steel, X 1. Cross section at top is from center of plate, and cross section at bottom is from edge.

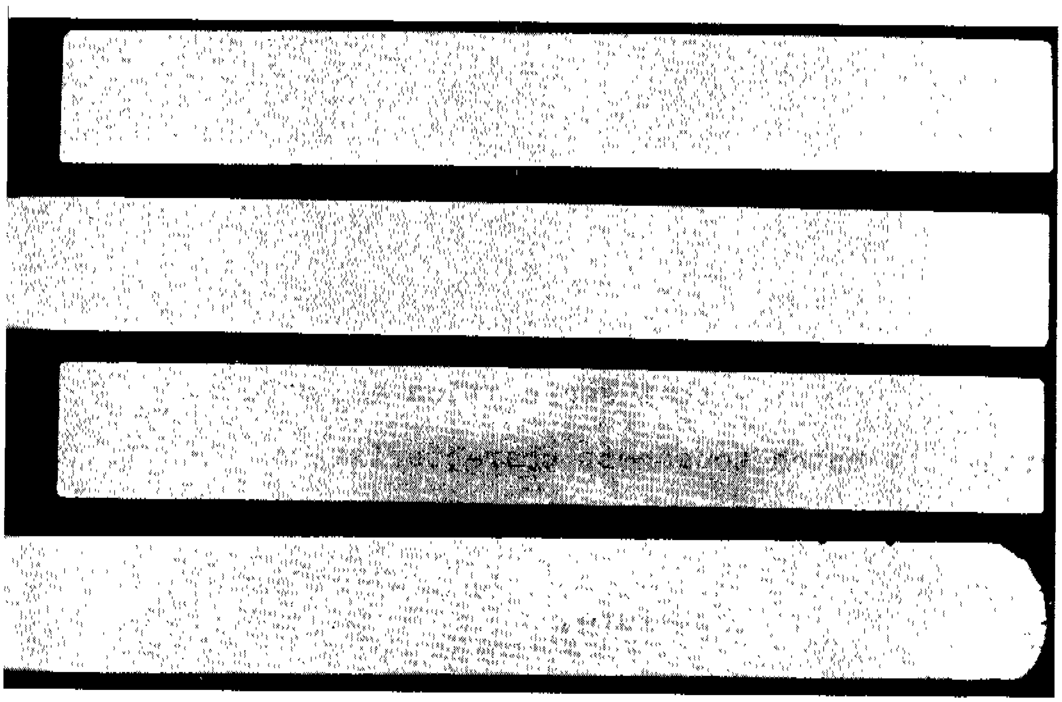


Fig. 5. Segregation bands in etch blanks from four locations across plate 203, of ABS Class B steel, X 1. Cross section at top is from center of plate, and cross section at bottom is from edge.

of the majority of samples tested. This reversal sometimes made it difficult to assign transition temperatures corresponding to the 15 and 25 ft-lb energy levels. The transition temperatures listed in Tables 5 and 6 were therefore obtained by connecting the midpoints of the straight lines as shown for typical cases in Figs. 6 and 7. These transition temperatures differ slightly from those obtained by fitting a quadratic to the data, as discussed in the statistical supplement (Appendix A) at the end of this report, prepared by Dr. Youden and co-workers.

It will be noted that plate No. 211, which had the high carbon segregation, also had significantly higher transition temperatures for both energy levels than the respective averages of all the plates. It is somewhat surprising that, while the B steels exhibited far more segregation and laminated* impact specimens from all but one plate tested, the dispersion of the Charpy data from these plates was less than that from the C steels. Only three of the C steel plates showed laminated fractures and, as was observed earlier, they displayed relatively slight segregation effects.

The precise role that segregation and laminations play in affecting the notch toughness characteristics is difficult to say

*An impact specimen was considered to be laminated when it was observed to have a split in the fracture surface in a plane parallel to the plate surface.

TABLE 5. 3/4-in. pre-1956 ABS Class B Steel

Heat	Ingot (1)	Plate (2)	NBS No.	Yield Point	Tensile Strength	Elongation	Ferrite Grain Size No.	T_{V15}**	T_{V25}**	Cleavage Fracture Area at 10°F	Cleavage Fracture Area at T_{V15}**	Cleavage Fracture Area at T_{V25}**
				ksi	ksi	%	(Avg)	°F	°F	%	%	%
B1	S	T	201	33.1	63.1	31.0	7.7	21	46	92	89	77
"	S	C	202	33.8	63.2	31.5	8.0	32	46	88	81	74
"	M	T	203	32.9	63.0	31.0	7.8	17	45	88	85	74
"	M	B	204	33.4	61.0	31.0	7.8	19	32	91	87	80
"	L	T	225	33.4	63.4	32.0	7.9	24	37	87	80	71
"	M	C	226	34.8	64.1	32.0	7.6	18	39	88	86	79
B2	S	C	205	32.8	61.2	30.0	7.2	36	48	95	90	86
"	S	B	206	32.8	60.5	29.0	7.5	34	46	92	88	85
"	L	T	207	31.8	58.9	30.5	7.1	26	37	89	83	78
								26*	45*	89*	83*	71*
"	L	C	208	32.2	62.0	30.5	7.7	38	54	92	81	72
"	S	T	227	32.0	59.8	33.0	7.4	29	41	88	80	74
"	M	C	228	31.5	62.5	32.0	7.2	38	55	89	82	74
B3	M	C	209	35.5	65.1	30.5	8.0	31	44	92	84	77
"	M	B	210	33.8	62.9	31.5	7.6	29	46	87	80	71
"	L	T	211	39.0	71.4	22.2	7.9	52	82	91	73	54
								42*	65*	89*	80*	68*
"	L	B	212	34.4	63.5	30.5	7.7	26	44	84	76	64
"	L	C	229	36.2	64.7	29.5	7.3	32	57	90	84	73
			Avg	33.7	63.0	30.5	7.6	30.0	47.8	89.5	82.7	73.8

(1) S--Second, M--Middle, L--Next to last.
(2) T--Top, C--Center, B--Bottom.
* Retest made on same plate.
** Charpy V-notch transition temperature corresponding to indicated energy level (15 or 25 ft-lb).

TABLE 6. 1 1/4-in. ABS Class C Steel (As Rolled)

Heat	Ingot (1)	Plate (2)	NBS No.	Yield Point	Tensile Strength	Elongation	Ferrite Grain Size No.	T_{V15}*	TV25*	Brittle Fracture Area at 10°F	Brittle Fracture Area at T_{V15}*	Brittle Fracture Area at T_{V25}*
				ksi	ksi	%	(Avg)	°F	°F	%	%	%
C1	S	T	213	29.3	58.1	35.0	7.3	-23	-15	69	92	88
"	S	C	214	29.8	58.1	34.0	7.1	-16	- 9	73	91	87
"	M	T	215	28.9	58.1	34.0	6.9	-14	- 5	74	88	84
"	M	B	216	28.7	56.5	33.0	7.5	-18	-13	75	86	84
C2	S	C	217	32.5	60.7	33.0	7.3	-19	- 6	85	92	90
"	S	B	218	29.2	56.1	36.0	7.6	-32	-13	66	92	86
"	L	T	219	32.2	61.1	33.5	6.8	-26	- 9	80	92	87
"	L	C	220	31.1	59.7	33.5	6.8	-30	-20	80	94	92
C3	M	C	221	32.2	59.5	33.5	7.0	-25	-16	63	89	84
"	M	B	222	30.5	57.5	34.0	7.3	- 9	+10	78	87	78
"	L	T	223	31.3	59.7	33.5	6.6	-13	-3 +18	85	89	87 80
"	L	T	224	30.0	56.6	35.0	6.7	- 2	+ 9	83	86	84
			Avg	30.5	58.5	34.0	7.1	-18.9	- 6.7	75.9	89.8	85.6

(1) S--Second, M--Middle, L--Next-to-last.
(2) T--Top, C--Center, B--Bottom.
* Charpy V-notch transition temperature corresponding to indicated energy level (15 or 25 ft-lb)

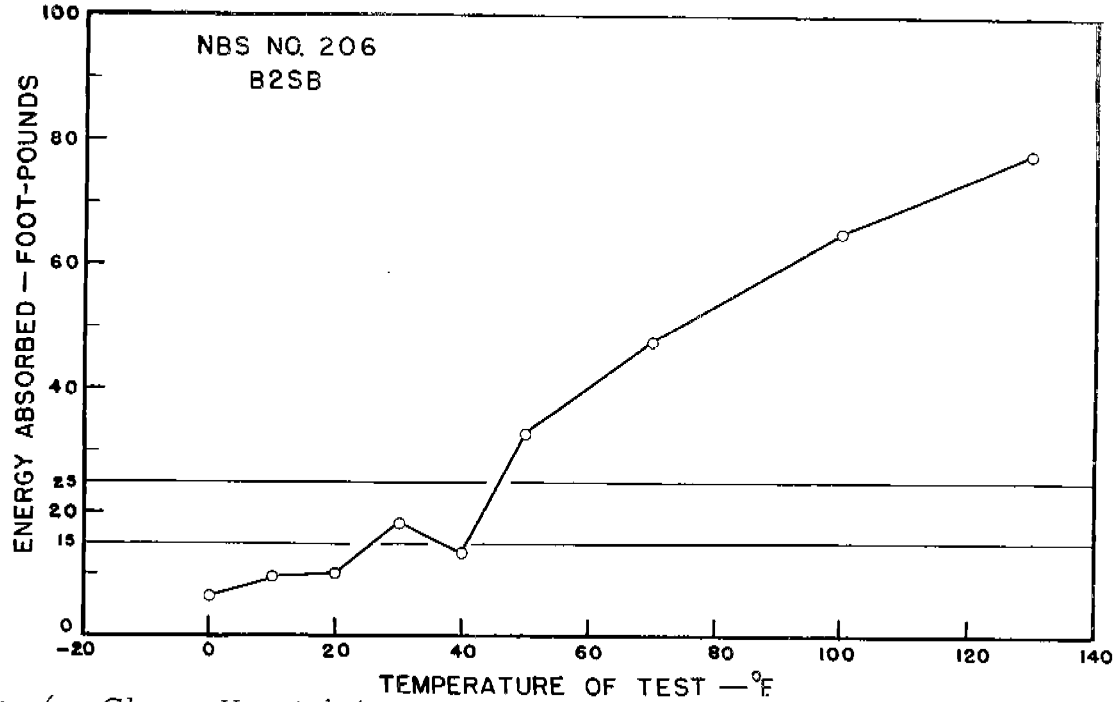


Fig. 6. Charpy V-notch impact curve of plate No. 206, 3/4-in. pre-1956 ABS-Class B steel. Average of at least 3 specimens at each temperature.

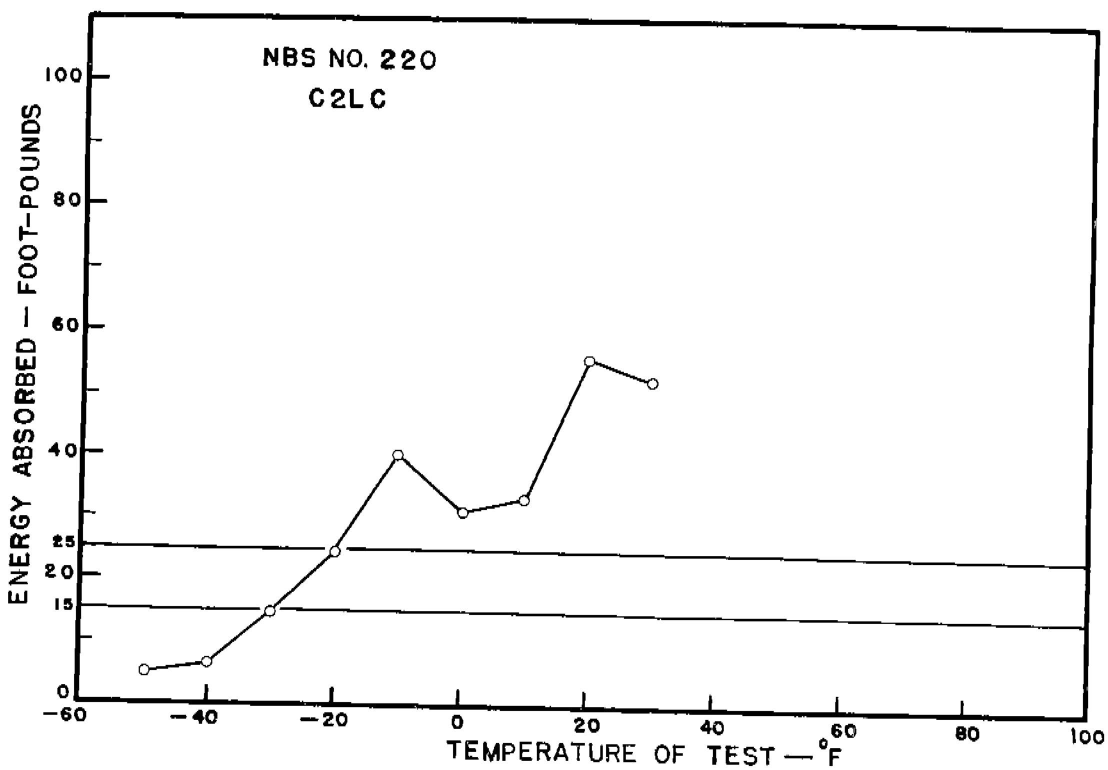


Fig. 7. Charpy V-notch impact curve of plate No. 220, 1 1/4-in. ABS-Class C steel. Average of 4 specimens at each temperature.

at this time. Impact specimens that revealed laminations also gave higher impact values than those that did not. Laminated specimens, however, were usually observed only at energy levels above 25 ft-lb and therefore probably did not have much effect on the observed transition temperature. Those plates having a high-carbon segregation zone displayed higher than average transition temperatures, but it is impossible to say how they would compare with homogeneous plates of the same average carbon content.

The proportion of cleavage fracture area to total fracture area was estimated visually for all impact specimens. The results were plotted from data in Appendix C, and the values (taken from the curves) at 10 F and at the two energy transition temperatures are listed in Tables 5 and 6. The variation in cleavage fracture area at the 15 and 25 ft-lb Charpy V-notch transition temperatures (T_{V15} and T_{V25}) is greater for the B steels than for the C steels, but the average values of cleavage fracture area for C steels are significantly higher than for B steels. For comparison, it is interesting to note that the corresponding average value at T_{V15} for the plates from fractured ships examined at the National Bureau of Standards was 77.5% cleavage fracture.

In order to obtain an estimate of the degree of variation of transition temperatures within an ingot, within a heat, and between heats, direct comparisons were made where possible. The results are given in Table 7 in terms of average differences:

TABLE 7

Comparisons	Average Differences			
	ABS-B		ABS-C	
	T_{V15} °F	T_{V25} °F	T_{V15} °F	T_{V25} °F
1. Between plates (same ingot and heat)	8.9	11.5	9.2	11.3
2. Between ingots (same heat and similarly located plates)	3.6	5.1	9.0	8.3
3. Between heats (similarly located ingots and plates)	10.4	11.7	8.3	14.0

These figures indicate that for the ABS-B steels the differences between ingots of the same heat are significantly less than differences found from plate to plate or heat to heat. In the Class C steels the differences appear to be about the same for all three comparisons.

V. CONCLUSIONS

While emphasis during the initial phase of this investigation was on the development of a sampling scheme suitable for future testing of many heats, some consideration was given to the problem of relating the mill variables for both grades of steel to their respective properties. However, examination of the mill data sheets brought out the fact that both mills employed rather uniform practices in the production of these heats; and consequently, studies of such relationships were deferred until a greater variety of data is available.

A statistical evaluation of the results obtained on these steels indicates that selection of at least two plates from the same ingot would provide satisfactory information on the characteristics of a heat. However, as pointed out in Appendix A, it would be desirable to test an additional plate from the same ingot and thus allow a better evaluation of the uniformity of the heat.

APPENDIX A

STATISTICAL EVALUATION OF ABS-B AND ABS-C STEEL DATA

W. J. Youden, M. Natrella, and J. M. Cameron

SAMPLING PROGRAM

The initial investigation of ship steel plates was directed toward devising a sampling scheme that would economically reveal the variation in properties among heats, among ingots from the same heat, and among plates from the same ingot. The more heats sampled for a given type and source of steel, the more certain would be the evaluation of the production process. On the other hand, it is also necessary to make sure that the examination given each heat will be intensive enough to give reliable values for the heat. It was essential to avoid oversampling a heat in order to be able to spread the total number of plates in the program over various types and sources of steel.

The problem was attacked by acquiring nine plates from each of three heats for ABS Class B steel and similarly for ABS Class C steel. Four of the nine plates from each heat were selected for examination with the understanding that additional plates from the heats would be examined if the four plates appeared inadequate to characterize the heat. The four plates were selected in pairs from each of two ingots in a given heat. The selection of the two ingots and the positions within the ingot were arranged so that it was easy to make the following direct comparisons:

1. Between plates from the same ingot
2. Between ingots using plates from comparable positions in the ingots.
3. Between heats using plates similarly located in the heats.

The sources of the twelve plates for each steel and the identifying numbers for the plates were given in Table 4 in the body of this report. The results were examined to see if a characteristic pattern appeared among plates from the same heat. The results from twelve plates for each steel were used to evaluate a set of seven constants for identifying heats, ingot positions in the heat, and plate positions in the ingot.

EDGE-TO-CENTER EFFECTS

Some thirty-six specimens for transition-temperature determination were taken from a strip running from the center to the edge of each plate of C steel. This strip was divided into four regions. Each region supplied one specimen for each of nine testing temperatures. Seven of the nine temperatures were common to all twelve plates (See Appendix C). The simple sum of the energies absorbed for these seven specimens may therefore be used to characterize each of the four parts. These sums for the C steel are tabulated in Table A-1 under their respective locations in the plates.

TABLE A-1

Sum of Energies (ft-lb) from Seven
Charpy V-notch Specimens from each Location

Plate No.	Edge	Next to Edge	Next to Center	Center	Avg
213	244	192	235	271	235.5
214	240	217	229	144	207.5
215	165	157	254	158	183.5
216	145	296	230	236	226.8
217	237	165	167	86	163.8
218	199	302	190	242	233.2
219	186	167	230	170	188.2
220	196	160	218	208	195.5
221	248	200	245	264	239.2
222	190	152	136	89	141.8
223	189	127	169	115	150.0
224	110	85	119	70	96.0
Avg	195.8	185.0	201.8	171.1	188.4

There is no evidence of a trend across the plate. Clearly the average energy absorbed for seven specimens (tested at seven pre-selected temperatures) varies much more from plate to plate than the averages between regions, even allowing statistically for the fact that the column averages are based on twelve entries as against four entries for the row averages.

For all other properties except grain size, two specimens were tested from each plate. This provided twelve paired values for each property. Of each pair one specimen was nearer the edge and one nearer the plate center. In general there appears to be little difference between the "edge" and "center" specimens, and in most cases the difference is not even statistically significant. The data do provide a good chance to estimate the standard deviation of a single test (based on 11 degrees of freedom). In the absence of center-to-edge differences this standard deviation reflects the uniformity <u>within</u> a plate and is shown in graphical form in Tables A-3 and A-4. The results are tabulated in Table A-2.

TABLE A-2

Average value of edge specimens compared with average value of center specimens.

Steel	Property	Average for Edge	Average for Center	Edge minus Center	Standard Deviation Avg diff.	Significance	Standard Deviation Single Test
B	YP	33550	34067	-517	258	Just	633
B	TS	62933	63050	-117	364	No	892
B	%Elong.	30.79	31.22	-0.54	0.50	No	1.22
B	C	.1983	.1975	0.0008	.0019	No	.0047
B	Mn	.7750	.7658	0.0092	.0061	No	.0149
B	P	.0145	.0145	0.0000	.00017	No	.00043
B	Si	.04725	.04775	-0.0005	.00096	No	.0023
C	YP	30208	30766	-558	169	Yes	413
C	TS	58492	58517	- 25	159	No	390
C	%Elong.	34.375	33.833	0.542	0.34	No	0.832
C	C	.1408	.1392	.0016	.0032	No	.0079
C	Mn	.7217	.6942	0.0275	.0126	Just	.0309
C	P	.0109	.0107	0.0002	.00035	No	.00086
C	Si	.1967	.1958	0.0009	.0017	No	.0041

PLATE-TO-PLATE VARIATIONS

The absence of trends across the plates meant that the two specimens from a plate could be regarded as duplicate measurements. The twelve plates for a steel thus furnished twelve such pairs. The twelve differences between the duplicates provide a reasonably adequate estimate of the standard deviation for the value of the property being considered. This standard deviation gives a measure of the minimum variation that could be achieved for the property if differences between heats, differences between ingots, and differences arising from the part of the ingot sampled could be eliminated. To obtain limits within which around 95 per cent of individual results might be expected to lie, it is conventional to add and subtract twice the standard deviation to the average value.

Tables A-3 and A-4 show on a horizontal line the average value of the property. Short vertical marks extending above the horizontal line designate the limits based on two standard deviations above and below the average value. In most cases there are individual measurements that fall outside these limits. The maximum and minimum values have been located by short vertical lines crossing the horizontal line. Attached to each of these vertical lines is the code number (See Table 4 of main report) of the plate from which the specimen came, together with the letter E or C to designate whether the specimen came from the edge or center of this plate. (Sometimes two or more plates gave rise to the same maximum or minimum values. All plate numbers are shown for these cases).

On the chart particular attention should be given to those minimums and maximums that fall considerably beyond the limits of plus and minus two standard deviations. For the B

Table A-3. B Steel

Plate numbers and the maximum and minimum values among 12 plates are shown above and below the vertical line crossing the horizontal line for each property. E and C refer to edge and center of plate.

Property	Minimum value plate No.	Minimum value	-2s.d.	Avg	+2s.d.	Maximum value	Maximum value plate No.
YP(psi)	208E	31,200	32,542	33,808	35,074	40,000	211C
TS(psi)	207E	58,400	61,208	62,992	64,776	72,800	211C
Elong.(%)	206C,212E	28.5	28.6	31.1	33.5	36.5	211E
GS(ASTM No.)	207	7.1	7.26	7.67	8.07	8.0	202,209
C(%)	207C	.18	.188	.198	.207	.22	201C
Mn(%)	207C	.70	.740	.770	.800	.82	209E, 209C, 212E
P(%)	204C	.010	.0137	.0145	.0153	.017	207E, 207C, 208E, 208C
Si(%)	205C	.041	.0428	.0475	.0522	.053	209E
T_{V15}	204	14	18.6	27.9	37.2	42	211
T_{V25}	204	32	35.2	47.3	59.3	67	211

Table A-4. C Steel

Plate numbers and the maximum and minimum values among 12 plates are shown above and below the vertical line crossing the horizontal line for each property. E and C refer to edge and center of plate.

Property	Minimum value and plate No.	-2s.d.	Avg	+2s.d.	Maximum value and plate No.
YP(psi)	216E 28,300	29,662	30,488	31,314	217C,219C,221C 32,800
TS(psi)	218C 55,900	57,724	58,504	59,284	219C 61,700
Elong.(%)	217C 32,	32.44	34.10	35.76,	218C 36
GS(ASTM No.)	223 6.6,	6.62	7.08	7.54,	218 7.6
C(%)	218C 222C 224C .12	.124	.140	.156	219C .17
Mn(%)	216C .636	.65	.708	.769	224E .770
P(%)	213E,216C,216E .006	.0091	.0108	.0125	223C .016
Si(%)	215C .17	.205	.213	.222	221C .24
T_{V15}	216,218,220 -39.9	-34	-22.6	-9	223 -5.3
T_{V25}	218,220 -24.9	-17	-7.3	10	224 10.4

steel extreme values are equally divided between edge and center specimens, whereas center specimens predominate among the maximums for the C steel. Plates from the top of the ingot furnish most of these extremely high or low values. Either center or bottom plates run more true to form. One might conclude that plates from the middle or bottom of the ingot would be more representative in the sense of approximating the heat. Equally, if it is desired to detect a lack of uniformity in the product, the top plates are more likely to serve as indicators. Therefore, two plates--one of them from the top and the other from either the center or bottom--would reveal by their disparity the lack of uniformity.

The two charts are shown facing to facilitate cross comparison of the steels. It is instructive to note, for example, that silicon is much more uniform in the B steel than in the C steel. A very large number of such comparisons can be made, many of which may be of no particular metallurgical improtance. The attempt has been made to present the data in such a way that answers can be found to many inquiries that might be proposed.

DETERMINATION OF TRANSITION TEMPERATURES

One of the by-products of the study was a comparison of various methods of interpolation to get transition temperature, as shown in Table A-5. Given reasonably smooth data, simple

Methods for Transition Temperatures Determination:

Method P--temperature read from straight line connecting the two points closest to required energy level

Method Q--temperature read from least squares quadratic fitted to all points

Method L--temperature read from least squares quadratic fitted to logarithms of original observations

TABLE A-5

Steel	Plate No.	Transition Temperatures, F: 15 ft-lb P	15 ft-lb Q	15 ft-lb L	25 ft-lb P	25 ft-lb Q	25 ft-lb L
B	201	21	22		46	44	
B	202	32	30		46	47	
B	203	17	19		45	40	
B	204	19	14		32	32	
B	205	36	32		48	48	
B	206	34	29		46	48	
B	207	26	30		45	46	
B	208	38	37		54	54	
B	209	31	27		44	48	
B	210	29	26		46	47	
B	211	42	42		65	67	
B	212	26	27		44	46	
C	213	-23	-22	-22	-15	-11	- 8
C	214	-16	-20	-16	- 9	- 9	- 2
C	215	-14	-15	-11	- 5	- 2	+ 3
C	216	-18*	-34	-23	-13	-15	- 7
C	217	-19	-20	-15	- 6	- 5	+ 2
C	218	-32	-34	-28	-13	-17	-11
C	219	-26	-30	-26	- 9	-12	- 8
C	220	-30	-34	-27	-20	-17	-12
C	221	-25	-28	-23	-16	-15	-10
C	222	- 9	-15	- 7	+10	0	+20
C	223	-13	- 9	- 9	-3 +18**	+6	+10
C	224	- 2	-10	0	+ 9	+10	+18

*Indicates poor agreement among methods.
**Range of transition temperature at 25 ft-lb level as a result of curve reversal.

linear interpolation is satisfactory. In certain cases it appears desirable to fit a curve and make use of points other than those immediately adjacent to the interpolated value. The methods are usually in good agreement, but occasionally the linear interpolation gives rise to difficulty.

CONCLUSIONS

Finally, the remarks below should provide a guide for future sampling of heats. Ingot identity is unimportant (with the possible exception of first and last ingots, which were not included in the scope of this sampling program). Plate position within the ingot is important. The general level of a property is well represented by a plate from the center of an ingot. Extreme values, if present, occur chiefly in top plates. The inclusion of a top plate in sampling a heat depends on the importance attached to detecting the existence of plates most divergent from the general average.

The sampling scheme used in the work thus far was planned to serve as a guide for sampling additional heats and plates. The statistical analysis points to less variation between plates from comparable positions in <u>different</u> ingots than is found between plates from different positions in the <u>same</u> ingot. Visual observation of segregation confirms this view. It was found that, for the B steel, segregation was present in all top and center plates and very slightly in one bottom plate. Faint segregation was observed in two of the three heats of C steel and then only in the top and center plates.

Not less than two plates should be taken to characterize a heat of steel. They should be from the same ingot. A pair of locations such as top and center (or top and bottom) of the ingot will be most likely to bring to light lack of uniformity in the product. Uniformity is as important as the average in evaluating the product. Three plates, rather than two, from the same ingot would double the information on uniformity. If the scope of the investigation permits, three plates are recommended to characterize a heat of steel.

APPENDIX B

NIL-DUCTILITY TRANSITIONS OF SELECT ABS-B AND ABS-C STEELS

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The subject investigation (SR-139, "Joint AISI-SSC Study") was established as the first stage of a broad program to study the quality of mill-production American Bureau of Shipping (ABS)-grade steels. The principal feature was the testing of numerous samples from relatively few heats in order to determine the minimum number and location of test samples required to describe adequately the characteristics of a given heat. Various plates from three heats each of ABS Class B and Class C steels were investigated; all plates were in the as-rolled condition. The U. S. Naval Research Laboratory (NRL) was requested to conduct crack-starter drop-weight tests on the same materials received at NBS for this project. Identical steel numbers and code designations as established by NBS were used to identify these plates.

Detailed procedures for drop-weight tests have been described[1, 2]. Briefly, test conditions are adjusted so as to normalize variables involving steel strengths, specimen thickness, dimensions, etc., and thus permit the measurement of the same parameter (i.e., ductility in the presence of a crack) for all steels. The nil-ductility transition (NDT) temperatures determined in the standard drop-weight test have been related to the temperatures at and below which brittle-fracture initiation becomes potentially possible in conventional engineering structures. This relationship has been established by comparison of test results with service performance.

The NDT temperature was also found to correlate with the temperatures for Charpy V energies of 3 to 10 ft-lb (usually within the range 5 to 7 ft-lb) for World War II ship plate steels[2, 3, 4]. Similar studies for fully killed and medium-alloy steels indicated that 10 ft-lb index was not general[4, 5, 6]; such steels were found to correlate with index values of 20 ft-lb or higher. These predictions have since been corroborated by investigations of service-failure material for three low alloy steels where the failure initiation temperatures corresponded to approximately the Charpy V 20 ft-lb temperatures of all three steels involved.

Correlations of NDT with Charpy V results have been predicated upon relationships to the average (faired-position) Charpy transition curves. The inherent variations observed in tests of different grades of steels have demonstrated that the determination of the complete Charpy V transition curve is preferable to the use of single-temperature or limited-temperature tests[6]. With the use of well-defined average Charpy V curves (2 or more specimens tested at each 20 F interval in the transition region) the NDT temperatures established for a particular grade of steel are observed to correspond to a range of Charpy values.

Normally, 6 to 8 drop-weight specimens are required to establish the nil-ductility transition (NDT) temperature to an accuracy of $\pm$ 10 F. However, it was believed that NDT temperatures could be established reliably with the aid of Charpy V correlations and only 4 specimens from the edge and center regions of each plate. Accordingly, drop-weight tests of these plates were not started until Charpy V data were obtained from the NBS.

For all except one (No. 225) of the ABS-B steels, the NBS Charpy tests were conducted over a temperature range sufficient to develop complete transition curves for these steels. From the average (faired-position) curves drawn with the NBS data, the range of temperatures correlating approximately with the 10 ft-lb Charpy V temperatures was chosen for the drop-weight tests conducted for each ABS-B steel. As shown in Table 1, such procedures resulted in establishing the NDT temperatures with drop-weight tests conducted over the extremely narrow temperature span of 30 F or less. The numbers shown in parentheses after each NDT temperature listed in Table 1 represent the energy of the average Charpy V curve at the NDT temperature.

Differences of only 10 F between NDT of edge and center region material observed for five of these plates are considered to be within the limits of accuracy of the drop-weight tests. Thus, the results of Table 1 indicate that no significant general variation in NDT characteristics exists within any one plate of the ABS-B steels investigated. In addition, little or no variation is observed in notch-toughness characteristics of all the Class-B plates studied. Such consistency is generally not expected among plates of three different heats; it is believed that this consistency is a reflection of the almost identical chemical compositions and mill practices employed for these three heats.

Charpy V tests for all ABS Class-C steels were conducted by NBS over the temperature range of -50 to 30 F. The complete transition curve was not established, and well-defined average curves could not be drawn because of excessive scatter obtained in Charpy tests of these steels. NDT temperatures for the Class-C steels, Table 2, were established with the limited samples available by commencing tests of each steel at temperatures corresponding approximately to the 20 to 25 ft-lb Charpy V temperatures. The NDT values shown in parentheses in Table 2 are not considered to be definitely established by the limited tests employed. For these steels, the NDT temperatures are at least as high as those shown; however, it is possible that some would be raised approximately 10 F by results of additional tests.

TABLE 1. Drop-Weight Test Results of ABS Class-B Steels

Test Temperature and Result

X = Break
0 = No Break

Steel No.	Code	0 F	10 F	20 F	30 F	40 F	NDT (Edge)	NDT (Center)
201 Edge	B1ST	X	00		0		0 F (7)	
Center		X	XX	0				10 F (10)
202 Edge	B1SC	X	00		0		0 F (9)	
Center		X	XX	0				10 F (9)
203 Edge	B1MT	X	X	0	0		10 F (12)	
Center		XX	00					0 F (8)
204 Edge	B1MB	XX	0	0			0 F (9)	
Center		XX	00					0 F (9)
225 Edge	B1LT	XX	0	0			0 F (8)	
Center			X00	0				10 F (10)
205 Edge	B2SC		X	00	0		10 F (7)	
Center			X	X0	0			20 F (9)
206 Edge	B2SB	X	00		0		0 F (7)	
Center		XX	00					0 F (7)
207 Edge	B2LT		XX	0	0		10 F (10)	
Center			XX	00				10 F (10)
208 Edge	B2LC	X	X0		0		10 F (8)	
Center			XX	00				10 F (8)
209 Edge	B3MC		X0	0	0		10 F (9)	
Center			XX	00				10 F (9)
210 Edge	B3MB	X	00		0		0 F (9)	
Center		XXX	0					0 F (9)
211 Edge	B3LT	X	X	0		0	10 F (8)	
Center			XX	00				10 F (8)
212 Edge	B3LB	X	00		0		0 F (9)	
Center		XX	00					0 F (9)

TABLE 2. Drop-Weight Test Results of ABS Class-C Steels

Test Temperature and Result

X = Break
0 = No Break

Steel No.	Code	-20 F	-10 F	0 F	10 F	20 F	30 F	NDT (Edge)	NDT (Center)
213 Edge	C1ST	X	X0	0				-10 F	
Center			X0	X	0				(0 F)
214 Edge	C1SC	XX	00					-20 F	
Center			XX	00					-10 F
215 Edge	C1MT		X	X0	0			0 F	
Center				XX	X0				10 F
216 Edge	C1MB	XX	00					-20 F	
Center			XX	00					-10 F
217 Edge	C2SC		XX	00				-10 F	
Center			0*	X0	0				(0 F)
218 Edge	C2SB	XX	00					-20 F	
Center			XX	X0					0 F
219 Edge	C2LT		XX	00				-10 F	
Center			X	X0	0				0 F
220 Edge	C2LC		X	XX	0			0 F	
Center				X0	X0				(10 F)
221 Edge	C3MC	X	X0	0				-10 F	
Center			X	XX	0				0 F
222 Edge	C3MB			XX	00			0 F	
Center				X	XX0				10 F
223 Edge	C3LT	X	XX	0				-10 F	
Center			X	X	X	X	0**		20 F
224 Edge	C3LB				X0	X0		(20 F)	
Center						X0	00		20 F

* One edge of specimen was flame cut.
** Extension welded test specimen.
(--F) NDT temperature not definite.

As shown by the NDT range of -20 to 20 F for edge-of-plate specimens and -10 to 20 F for center-of-plate specimens, the Class-C steels do exhibit variations in notch toughness among plates of the three different heats. In addition, the results for two plates (Nos. 218 and 223) revealed a significant difference (20 and 30 F respectively) in NDT between the edge and center regions of each plate. From the available data, it was not possible to ascertain whether such differences were readily apparent in the Charpy V tests conducted by NBS. Accordingly, Charpy V specimens were machined from the drop-weight samples of plate No. 223. From 2 to 5 Charpy specimens were tested at various temperatures ranging from -40 to 100 F in order to establish the complete transition curves of each respective area. As shown in Fig. 1, the average (faired-position) curves corroborate drop-weight results in that at least a 20 F displacement is shown between the average Charpy curves of the two areas. The results of chemical analyses of drillings taken from the drop-weight specimens, Table 3, indicate that the variation in notch toughness between the edge and center regions of this plate is not due to assignable variations in chemical composition.

TABLE 3

CHEMICAL COMPOSITION OF ABS CLASS-C STEEL NO. 223

Location	%C	%Mn	%P	%S	%Si	%Cr	%Mo	%Ni	%Cu	%Ti	%V
Edge (NRL)	.15	.67	.010	.030	.20	.04	.01	.07	.10	Nil	.02
Center (NRL)	.16	.67	.010	.033	.20	.05	.01	.07	.10	Nil	.01
Edge (NBS)	.13	.75	.015	.029	.22	---	---	---	---	---	---
Center (NBS)	.13	.72	.016	.030	.22	---	---	---	---	---	---

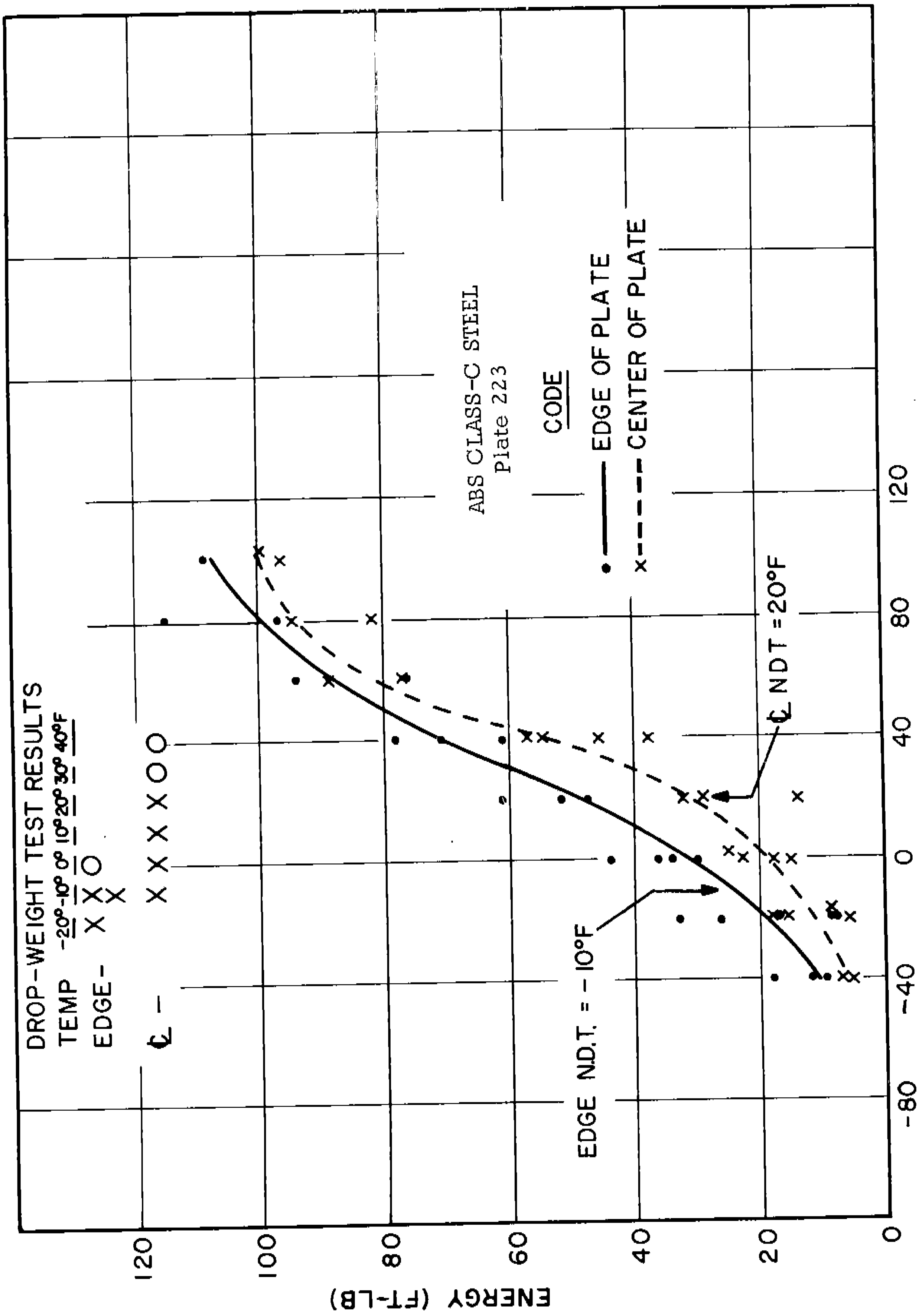
DROP-WEIGHT TEST RESULTS
TEMP -20° -10° 0° 10° 20° 30° 40°F
EDGE- X X O
℄ - X X X X X O O
ABS CLASS-C STEEL
Plate 223
CODE
EDGE OF PLATE
CENTER OF PLATE
EDGE N.D.T. = -10°F
℄ NDT = 20°F
ENERGY (FT-LB)
TEMPERATURE (°F)
0
20
40
60
80
100
120
-80
-40
0
40
80
120

FIG. 1

REFERENCES

1. Pellini, W. S., Puzak, P. P., and Eschbacher, E. W., "Procedures for NRL Drop-Weight Test," NRL MEMO Report No. 316, June 1954.

2. Puzak, P. P., Schuster, M. E., and Pellini, W. S., "Cracker-Starter Tests of Ship Fracture and Project Steels", The Welding Journal, Res. Suppl., October 1954, p. 481-s. See also Puzak, P. P., Schuster, M. E., and Pellini, W. S., "Part I: Crack-Starter Tests of Ship Fracture and Project Steels", Final Report, Ship Structure Committee Report, Serial No. SSC-77, June 18, 1954.

3. Puzak, P. P., Eschbacher, E. W., and Pellini, W. S., "Initiation and Propagation of Brittle Fracture in Structural Steels," The Welding Journal, Res. Suppl., December 1952, p. 561-s.

4. Puzak, P. P., Schuster, M. E., and Pellini, W. S., "Applicability of Charpy Test Data," The Welding Journal, Res. Suppl., September 1954, p. 433-s.

5. Puzak, P. P. and Pellini, W. S., "Effect of Temperature on the Ductility of High Strength Structural Steels Loaded in the Presence of Sharp Cracks," NRL Report No. 4545, June 1955.

6. Puzak, P. P. and Pellini, W. S., "Evaluation of the Significance of Charpy Tests for Quenched and Tempered Steels," The Welding Journal, Res. Suppl., June 1956, p. 275-s.

APPENDIX C

TABULATION OF CHARPY V-NOTCH ENERGY ABSORPTION AND PER CENT CLEAVAGE FRACTURE AREA

The following tables consist of a comprehensive tabulation of data obtained for each Charpy V-notch specimen tested parallel to the direction of rolling. It is offered as information to future investigators to obviate duplication of these tests.

For statistical purposes the location of each specimen has been noted. The specimens were cut from blanks shown with an "N" designation on the template in Fig. 1 (See page 7). Each specimen, beginning with the first one at the edge, of the plate was numbered consecutively toward the center of the plate. The key to the numbered specimens tested for each plate is given at the beginning of each group of specimens.

The location of each specimen in its respective plate with reference to edge (Blank N 1), next to edge (Blank N 2), next to center (Blank N 3), or center (Blank N 4), is shown at the bottom of each sheet together with each plate's chemical composition. Each value shown for the chemical composition is the average of two analyses.

The following example illustrates how to obtain information for a given specimen. The third test at 10 F for Plate 228 of ABS Class B steel can be found first by locating the plate number in the first column of each sheet. Plate 228 is on page 43. The third test is in the third row down. At 10 F the specimen broke under 6.2 ft-lb of energy and had 90 per cent cleavage area. Referring to the specimen key at the top of the 10 F column for this group, the number designating specimen position, which is in the third row down, is 28. To determine the approximate position in the plate that this number 28 represents, one refers to the plate listing at the bottom of the page. Reading across the line for Plate 228, specimen location 28 is found in the column under Blank N 3. Thus this specimen, the third test at 10 F for Plate 228, was obtained from the next-to-center blank in the plate. The location of number 28 within the blank can be inferred from the fact that, within this blank, specimen location 25 was on the "edge" side and specimen location 37 was on the "center" side. The chemical composition as determined for the total plate is also given on the same line.

3/4-in. ABS-B STEEL CHARPY V-NOTCH ENERGY ABSORPTION (ft-lb, left columns) and PER CENT CLEAVAGE FRACTURE AREA (right columns)

	Test Temperatures -- F									
	0	10	20	30	40	50	60	70	100	130
Key to NBS Plate Specimens 201--212	7 22 37 29 26	5 20 35 38 27	10 25 40 14 27	[illegible] [illegible] 32 [illegible] 43	9 24 39 13 27	4 19 34 41 26	15 30 45 8 --	1 16 31 11 44	6 21 36 28 46	3 18 33 42 27
201	7.5 90	11.8 88	9.6 85	24.2 75	29.8 85	32.1 70	39.1 65	*47.4 55	68.2 20	*75.8 0
	7.1 100	14.6 95	*12.4 85	*19.5 75	*13.5 85	18.2 85	34.3 80	*46.6 65	69.1 30	66.3 30
	7.1 90	9.1 90	12.4 80	*30.6 70	15.2 80	26.3 75	40.7 70	*43.2 60	64.4 35	*83.6 10
	5.7 90	11.3 90	9.6 90	23.5 85	18.2 85	35.1 80	24.2 90	30.6 55	60.7 35	78.7 10
	-- --	12.9 90	-- --	15.2 85	-- --	-- --	-- --	44.0 60	-- --	-- --
202	9.1 90	10.7 85	10.2 83	16.4 83	16.4 85	*45.7 65	47.4 50	55.3 45	69.1 30	*78.7 10
	10.2 90	7.5 90	10.2 85	15.2 85	30.6 75	18.8 --	22.8 75	35.9 75	58.0 45	74.8 20
	8.5 90	12.4 85	9.6 95	15.2 80	16.4 80	39.1 75	35.9 55	53.5 50	65.3 45	69.1 20
	7.1 95	10.7 85	9.6 85	9.1 75	14.6 80	27.6 70	27.6 70	54.4 45	63.4 40	74.8 10
	-- --	-- --	-- --	18.8 80	17.6 80	27.6 75	-- --	40.7 75	-- --	-- --
203	6.6 85	16.4 95	12.4 80	*39.1 65	32.1 70	29.1 75	43.2 60	*57.1 25	63.4 45	*69.1 30
	7.5 90	9.6 88	14.6 85	20.8 75	10.7 80	43.2 73	36.7 70	35.9 80	66.3 45	66.3 40
	12.9 90	9.6 90	15.8 90	22.8 80	35.9 75	26.3 85	15.8 75	49.1 70	58.9 50	50.8 15
	6.2 90	23.5 85	14.6 90	15.8 85	36.7 80	14.0 80	43.2 70	44.9 63	51.7 75	78.7 15
	-- --	-- --	-- --	25.6 80	17.0 80	-- --	-- --	42.3 73	-- --	-- --
204	9.1 90	10.7 93	13.5 85	30.6 70	32.1 85	39.1 80	50.8 60	88.5 20	65.3 35	77.7 10
	9.6 95	11.3 95	*22.8 60	28.3 85	19.5 85	35.1 --	32.8 75	49.1 55	77.7 20	*82.6 0
	7.5 95	10.7 85	11.3 90	*41.5 65	29.8 85	42.3 70	44.0 60	45.7 70	*80.6 5	*87.5 0
	12.9 88	11.3 90	-- --	18.8 90	24.9 80	31.3 70	55.3 50	47.4 65	-- --	83.6 5
	-- --	-- --	24.2 75	34.1 75	-- --	-- --	-- --	57.1 45	60.7 83	-- --
205	7.5 90	6.6 93	10.7 90	14.6 80	15.8 90	34.3 85	20.8 85	45.7 80	70.1 35	72.0 35
	6.6 93	9.1 95	8.5 95	11.8 90	17.6 90	31.3 85	37.5 75	36.7 80	56.2 50	68.2 30
	5.3 100	7.1 98	8.5 93	12.4 90	12.9 90	35.9 80	30.6 80	35.9 85	69.1 45	80.6 15
	9.1 90	10.7 90	8.5 90	12.9 90	18.8 83	32.8 75	38.3 78	47.4 68	47.4 75	66.3 45
	-- --	-- --	-- --	15.2 90	13.5 83	-- --	-- --	42.3 50	-- --	-- --
206	5.7 95	12.4 90	11.3 95	30.6 80	14.6 90	41.5 85	58.0 40	67.2 30	*72.0 30	-- --
	7.1 95	8.5 100	9.6 95	11.8 85	14.0 90	35.1 80	35.9 70	50.8 60	61.6 60	82.6 5
	7.1 90	8.0 90	9.6 90	12.4 90	12.9 90	22.1 90	29.1 65	24.2 85	61.6 35	*72.9 10
	7.1 90	10.2 90	12.9 93	15.8 90	-- --	28.3 80	40.7 65	44.9 70	-- --	66.3 30
	-- --	-- --	-- --	10.7 90	25.6 85	-- --	-- --	36.7 78	67.2 85	-- --
207	6.6 95	*6.6 90	10.2 85	11.3 78	22.1 85	*33.6 75	40.7 55	68.2 30	45.7 55	85.6 15
	7.1 90	12.9 85	12.4 90	11.8 80	29.8 75	29.1 75	45.7 40	59.8 50	*82.6 25	81.6 20
	7.1 88	*12.4 85	11.8 80	16.4 90	33.6 75	31.3 80	-- --	62.5 45	*76.7 30	97.5 10
	6.6 88	10.7 90	15.8 85	14.0 83	35.1 73	35.9 68	29.8 75	44.9 63	68.2 35	87.5 15
	-- --	11.8 85	-- --	24.2 65	-- --	-- --	-- --	36.7 60	-- --	-- --
208	6.6 90	8.5 90	6.6 85	15.8 77	11.3 85	24.2 80	15.2 65	52.6 --	54.4 35	71.0 20
	6.2 98	8.0 90	9.1 90	11.3 95	17.0 78	17.6 75	32.8 65	34.3 75	39.9 60	65.3 25
	7.5 95	10.2 95	10.2 85	11.3 80	12.9 90	20.1 65	29.8 70	42.3 --	48.3 35	*75.8 20
	6.6 90	18.8 85	9.6 88	14.0 70	17.6 88	34.3 78	37.5 65	39.1 60	60.7 40	54.4 30
	-- --	-- --	-- --	11.8 88	14.6 10	35.9 70	-- --	29.1 60	-- --	74.8 10
209	5.7 95	10.7 85	10.2 88	22.8 70	28.3 75	26.3 75	29.8 75	*58.9 25	55.3 35	81.6 0
	8.0 95	10.7 90	7.1 98	13.5 75	22.1 75	30.6 75	37.5 63	28.3 65	57.1 45	71.0 25
	7.1 90	8.5 90	11.8 90	14.0 75	12.4 90	26.9 70	18.2 70	39.9 70	42.3 55	72.9 15
	10.2 90	8.5 80	8.5 88	21.4 75	-- --	31.3 85	35.9 72	47.4 50	-- --	63.4 30
	-- --	-- --	9.6 90	12.9 83	-- --	-- --	-- --	32.1 60	58.0 45	-- --
210	8.0 83	9.6 75	12.4 90	18.2 65	15.8 75	25.6 68	21.4 85	49.1 --	54.4 35	70.1 15
	8.0 90	8.5 85	14.0 70	16.4 85	12.4 75	26.9 80	35.9 65	44.9 60	68.2 25	80.6 10
	12.4 90	12.4 78	10.7 80	14.0 70	17.0 85	37.5 85	37.5 55	32.1 --	60.7 25	*76.7 5
	10.7 85	7.5 90	12.4 85	15.2 85	20.1 65	31.3 75	49.1 63	50.8 40	54.4 40	83.6 5
211	7.1 90	11.3 88	13.5 78	*33.6 60	16.4 80	*39.1 60	26.3 75	58.0 50	55.3 30	76.7 10
	7.1 95	8.0 80	5.7 90	10.7 80	8.5 88	45.7 68	11.8 75	35.9 73	48.3 45	71.0 15
	7.5 90	6.6 90	7.5 90	9.6 88	8.5 93	12.4 80	17.0 80	14.0 --	24.2 70	39.9 30
	4.8 93	5.7 90	9.6 85	15.8 80	-- --	15.2 80	27.6 60	45.7 40	-- --	27.6 55
	-- --	-- --	9.1 90	9.1 93	-- --	16.4 90	-- --	17.0 75	20.1 75	-- --
212	6.2 90	12.4 80	11.8 80	20.8 60	16.4 70	37.5 55	39.1 50	*80.6 15	*62.5 30	80.6 5
	13.5 80	11.8 88	7.1 90	24.9 70	17.0 78	36.7 60	22.8 55	50.8 40	63.4 20	78.7 10
	7.5 90	7.5 90	12.9 75	14.0 75	15.2 88	27.6 75	38.3 60	49.1 50	74.8 20	*87.5 0
	8.5 88	10.2 80	14.0 83	15.8 70	17.6 68	33.6 70	29.8 60	39.1 45	-- --	69.1 15
	8.0 90	-- --	10.7 85	15.2 80	-- --	-- --	-- --	40.7 45	54.4 45	-- --

*Lamination

LOCATION OF 3/4-in. ABS-B STEEL CHARPY V-NOTCH SPECIMENS AND CHEMICAL COMPOSITION OF EACH STEEL PLATE

NBS No.	Blank N1	2½-in. between N1 and N2	Blank N2	7--10-in. between N2 ans N3	Blank N3	2½-in. between N3 and N4	Blank N4	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	Al	Ti	As	Sn	N
201	1--11		12--22		23--34		35--45	.21	.74	.013	.027	.051	.06	.10	.02	.01	.006	.01	.003	.02	.004	.006
202	1--12		13--23		24--35		36--45	.21	.76	.013	.027	.050	.06	.10	.02	.01	.006	.01	.003	.02	.004	.006
203	1--12		13--23		24--35		36--46	.21	.77	.013	.028	.050	.06	.11	.02	.01	.006	.01	.003	.02	.004	.005
204	1--13		14--24		25--36		37--47	.20	.76	.011	.026	.048	.057	.11	.022	.01	.005	.008	.01	.02	.004	.005
205	1--12		13--23		24--35		36--46	.20	.74	.015	.029	.042	.035	.029	.031	.01	.004	.008	.01	.02	.004	.005
206	1--13		14--24		25--36		37--47	.20	.74	.015	.029	.044	.035	.029	.030	.01	.004	.011	.01	.02	.004	.006
207	1--12		13--23		24--34		35--44	.19	.72	.017	.028	.045	.036	.032	.032	.003	.004	.01	.01	.02	.01	.005
208	1--12		13--23		24--35		36--46	.19	.76	.017	.028	.044	.034	.033	.031	.003	.004	.01	.01	.02	.01	.005
209	1--13		14--24		25--36		37--46	.20	.82	.015	.029	.051	.070	.082	.036	.003	.040	.01	.01	.02	.01	.004
210	1--13		14--23		24--35		36--45	.19	.79	.014	.026	.051	.070	.084	.036	.003	.039	.01	.01	.02	.01	.004
211	1--13		14--24		25--36		37--47	.20	.81	.015	.028	.048	.070	.083	.037	.003	.039	.01	.01	.02	.009	.004
212	1--13		14--24		25--36		37--46	.19	.81	.015	.027	.047	.071	.086	.036	.003	.038	.01	.01	.02	.009	.004

3/4-in. ABS-B STEEL CHARPY V-NOTCH ENERGY ABSORPTION (ft-lb, left columns) and PER CENT CLEAVAGE FRACTURE AREA (right columns)

	Test Temperatures — F									
	-10	0	10	20	30	40	50	60	70	80
Key to NBS Plate Specimens 207A, 211A, 225	-- -- -- --	8 18 26 44	9 21 29 38	4 14 25 37	6 20 31 43	7 15 32 41	5 17 28 40	10 16 30 45	11 19 33 39	12 22 27 42
207A	-- -- -- --	5.7 90 7.5 88 7.5 90 7.1 90	10.2 88 12.4 88 9.1 90 9.1 88	12.4 85 8.5 90 13.5 90 16.4 90	13.5 88 12.9 80 26.3 75 11.8 88	18.8 78 17.0 70 21.4 75 28.3 75	17.0 65 22.1 60 54.4 50 19.5 70	30.6 75 33.6 75 21.4 75 54.4 50	29.1 50 47.4 55 70.1 30 52.6 60	69.1 90 56.2 40 65.3 35 58.0 48
211A	-- -- -- --	6.6 88 7.1 90 3.9 90 5.7 90	7.5 85 7.1 88 6.2 90 6.6 88	10.7 85 8.5 90 9.1 90 6.6 90	12.4 83 9.1 88 8.0 80 8.0 90	14.6 75 11.3 88 12.4 90 9.6 80	26.3 70 30.6 75 17.6 85 12.9 80	28.3 70 26.9 73 10.7 75 14.6 75	39.1 55 *32.8 60 29.1 65 16.4 73	36.7 60 39.1 55 19.5 65 29.1 65
225	-- -- -- --	6.6 88 8.5 90 9.1 90 5.3 90	15.2 85 11.3 90 8.0 90 14.0 88	13.5 80 *17.0 65 8.0 88 16.4 85	14.0 80 15.8 78 18.8 75 18.2 75	35.9 68 *40.7 53 *20.8 70 23.5 75	32.8 65 35.9 67 *34.3 65 *46.6 50	40.7 58 *56.2 38 *44.0 63 22.1 65	41.5 55 50.8 50 43.2 55 64.4 40	53.5 40 50.8 40 *72.9 20 52.6 35
Key to NBS Plate Specimens 226—229	12 23 29 43	5 18 30 41	8 19 28 45	10 17 32 46	4 15 27 38	7 16 34 42	9 22 31 39	11 20 35 40	6 21 33 44	12 23 29 43
226	8.0 90 8.5 95 9.1 90 9.6 90	13.5 85 8.5 95 13.5 85 9.1 90	12.4 85 8.0 90 10.7 85 14.0 90	10.2 85 10.2 87 30.6 75 13.5 85	9.6 90 23.5 85 29.8 80 14.0 85	26.9 90 23.5 80 15.8 80 36.7 70	31.3 80 20.8 85 37.5 60 39.1 60	35.9 65 42.3 65 34.3 65 34.3 58	42.3 60 47.4 40 39.1 55 32.8 60	-- -- -- -- -- -- -- --
227	6.6 95 4.8 95 6.2 95 6.2 90	5.7 90 14.0 90 7.1 90 *9.1 87	9.1 90 7.1 90 8.5 90 *8.5 85	9.6 80 12.9 82 12.4 90 17.0 80	13.5 62 *20.1 80 11.8 80 *15.2 80	15.2 80 *18.8 70 20.1 80 24.2 75	35.9 80 42.3 70 44.0 60 54.4 70	24.9 65 35.9 65 34.3 65 31.3 77	44.9 60 31.3 60 34.3 60 55.3 40	-- -- -- -- -- -- -- --
228	-- -- -- -- -- -- -- --	8.0 90 4.8 90 6.6 95 6.6 90	6.6 92 6.6 90 6.2 90 10.2 90	12.4 85 8.5 90 12.9 85 10.7 90	9.6 85 8.0 90 9.6 90 13.5 85	23.5 70 12.4 80 15.2 85 15.2 80	29.1 85 20.8 80 18.8 70 15.2 70	34.3 65 36.7 62 20.8 75 24.9 70	43.2 70 49.1 50 34.3 60 27.6 65	48.3 45 34.3 65 33.6 70 44.0 55
229	-- -- -- -- -- -- -- --	5.7 95 8.5 90 9.1 90 6.6 90	8.0 90 6.6 95 6.6 87 10.2 90	10.7 90 9.1 90 12.9 80 10.7 90	10.2 85 24.2 85 9.6 90 11.8 90	15.8 77 17.0 85 16.4 80 22.8 80	17.0 80 15.8 70 29.1 75 17.0 75	27.6 70 37.5 60 22.8 65 20.1 65	34.3 75 33.6 55 25.6 70 39.9 60	40.7 50 58.9 50 45.7 50 40.7 50

*Lamination

LOCATION OF 3/4-in. ABS-B STEEL CHARPY V-NOTCH SPECIMENS AND CHEMICAL COMPOSITION OF EACH STEEL PLATE

NBS No.	Blank N1		Blank N2		Blank N3		Blank N4	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	Al	Ti	As	Sn	N
207A	1--12	2½-in. between N1 and N2	13--22	7--10-in. between N2 and N3	23--34	2½-in. between N3 and N4	35--45	.15	.68	.015	.021	.044	.033	.034	.030	.003	.004	.01	.01	.02	.01	.004
211A	1--12		13--23		24--35		36--46	.30	.91	.024	.049	.047	.077	.091	.036	.003	.037	.01	.01	.02	.019	.005
225	1--12		13--23		24--35		36--46	.20	.75	.013	.026	.05	.063	.11	.024	.01	.005	.01	.01	.02	.005	.005
226	1--12		13--23		24--36		37--46	.22	.80	.014	.030	.053	.059	.094	.026	.005	.008	.01	.005	.02	.007	.006
227	1--13		14--24		25--36		37--46	.20	.79	.017	.029	.052	.038	.027	.034	.005	.007	.01	.005	.02	.007	.006
228	1--13		14--24		25--37		38--48	.20	.76	.017	.030	.051	.039	.024	.033	.005	.007	.01	.005	.02	.007	.006
229	1--13		14--24		25--36		37--47	.21	.85	.016	.029	.049	.074	.066	.039	.005	.040	.01	.005	.02	.009	.005

1 1/4-in. ABS-C STEEL CHARPY V-NOTCH ENERGY ABSORPTION (ft-lb, left columns) and PER CENT CLEAVAGE FRACTURE AREA (right columns)

Test Temperatures — F

	-50		-40		-30		-20		-10		0		10		20		30	
Key to NBS Plate Specimens 213—218	12		4		9		10		7		8		11		—		6	
	22		14		21		16		15		18		19		—		20	
	27		25		29		30		[illegible]		26		33		—		31	
	41		36		38		44		40		43		38		—		42	
213	6.2	95	9.1	95	7.5	98	31.5	93	9.6	90	50.0	80	50.8	70	—		87.5	40
	5.7	95	6.6	98	6.6	95	24.9	90	35.9	80	24.2	80	19.5	90	—		74.8	55
	6.2	98	3.9	98	10.2	93	15.2	93	29.1	90	35.9	80	41.5	80	—		103.6	15
	4.4	95	7.1	98	8.5	95	19.5	90	55.3	75	45.7	80	28.3	90	—		110.6	10
214	4.8	93	9.1	95	—	—	17.0	90	32.8	80	15.2	90	70.1	55	—		90.5	35
	5.7	90	5.3	95	—	—	10.2	95	10.7	90	44.9	80	55.3	70	—		84.6	45
	4.8	93	9.6	95	—	—	7.1	95	28.3	88	49.1	80	41.5	80	—		88.5	35
	7.5	90	5.7	90	—	—	5.3	90	48.3	80	31.3	88	13.5	90	—		32.8	85
215	3.9	93	6.2	93	—	—	6.6	90	20.1	88	66.3	55	35.9	80	—		25.6	90
	4.8	98	7.5	95	—	—	7.5	90	14.0	80	22.1	90	27.6	88	—		73.9	45
	5.7	95	3.0	93	—	—	22.1	90	10.2	90	35.9	80	67.2	50	—		109.6	10
	3.5	90	4.4	93	—	—	8.5	95	8.5	85	19.5	90	40.7	80	—		72.9	55
216	6.2	95	7.5	93	—	—	10.2	90	12.4	90	34.3	85	22.1	85	—		52.6	80
	8.0	90	10.7	93	—	—	12.4	95	16.4	93	101.6	25	78.7	35	—		68.2	70
	4.8	98	10.7	90	—	—	7.1	88	56.2	75	24.2	90	54.4	75	—		72.9	60
	5.7	93	8.0	100	—	—	9.1	90	35.1	83	63.4	75	45.7	80	—		69.1	75
217	7.5	90	4.8	100	28.3	85	26.9	82	43.2	75	16.4	90	59.8	70	—		78.7	45
	5.3	93	7.5	90	8.0	98	8.0	88	8.5	88	10.2	90	58.0	70	—		67.2	60
	5.3	98	9.6	88	20.1	90	10.7	85	21.4	85	31.3	85	42.3	80	—		46.6	80
	3.9	90	5.3	93	9.6	90	11.3	90	10.7	90	10.7	95	9.1	90	—		35.1	85
218	4.8	95	22.1	88	26.9	85	15.2	85	12.9	90	25.6	90	74.8	85	—		44.0	85
	9.1	93	18.8	90	26.9	90	33.6	90	48.3	80	54.4	65	47.4	65	—		90.5	25
	4.8	90	3.9	93	9.6	90	14.6	93	32.8	85	18.8	85	32.8	80	—		82.6	40
	5.3	95	5.7	95	8.5	85	5.3	85	16.4	90	78.7	65	54.4	65	—		76.7	50
Key to NBS Plate Specimens 219—221	11		9		4		10		5		8		12		7		6	
	19		21		14		16		17		18		22		15		20	
	33		29		25		30		28		26		27		32		31	
	39		38		37		45		40		44		42		41		43	
219	6.2	97	7.5	82	8.0	93	30.6	92	20.5	92	47.4	80	29.8	83	54.4	40	44.0	70
	7.1	100	24.2	92	10.7	98	11.3	95	12.4	88	13.5	88	42.3	82	28.3	70	56.2	70
	6.2	95	5.7	95	7.5	98	12.4	93	35.9	85	50.0	80	39.9	80	34.3	75	79.7	65
	4.4	98	12.4	90	26.9	92	14.6	93	29.8	90	26.3	80	35.1	82	31.3	82	47.4	77
220	4.8	93	4.8	100	24.2	97	9.6	90	40.7	98	34.3	90	*41.5	80	49.1	80	59.8	64
	4.8	95	7.1	92	9.1	98	24.9	88	45.7	80	12.9	87	11.8	87	53.5	70	52.6	65
	3.9	93	6.2	90	20.1	93	40.7	83	37.5	80	35.1	83	36.7	80	60.7	78	58.0	65
	7.5	98	9.6	94	6.6	96	24.2	90	37.5	80	42.3	83	*44.9	80	61.6	70	41.5	83
221	4.4	96	7.1	95	7.5	96	8.5	93	57.1	65	40.7	83	70.1	50	44.0	71	59.8	50
	6.6	98	5.7	91	30.6	83	15.2	93	21.4	89	53.5	68	17.0	85	110.6	5	80.6	40
	6.6	95	7.5	96	4.8	95	12.9	95	44.0	83	23.5	85	92.5	28	68.2	48	58.0	60
	5.7	93	3.5	96	10.7	90	22.1	90	28.3	88	51.7	70	50.0	75	74.8	39	102.6	0
Key to NBS Plate Specimens 222—224	12		4		9		11		8		6		10		5		7	
	19		16		22		23		18		20		17		21		15	
	33		35		30		36		37		31		29		32		34	
	40		42		41		47		44		48		43		45		46	
222	4.8	95	6.6	98	5.3	95	14.6	92	9.6	82	20.1	88	95.5	30	64.4	55	38.3	80
	5.3	98	3.9	96	9.6	98	3.9	90	12.9	88	39.1	80	10.7	85	14.6	83	75.8	35
	3.5	82	8.0	45	10.2	93	12.9	90	17.6	90	6.6	92	14.0	83	32.1	80	72.9	45
	6.2	95	8.5	90	6.6	92	14.0	90	18.8	90	8.5	83	21.4	83	18.8	85	11.3	83
223	3.9	94	12.9	95	11.8	90	8.5	92	18.8	90	46.6	70	21.4	87	31.3	77	76.7	43
	4.8	93	6.6	97	11.8	97	7.1	97	21.4	67	16.4	93	10.7	90	11.3	93	59.8	67
	3.5	90	5.3	93	3.9	95	9.6	85	9.6	85	32.8	80	32.8	83	14.6	83	75.8	55
	5.3	97	7.1	93	12.9	87	10.2	90	21.4	82	18.8	93	16.4	80	15.2	83	35.9	73
224	4.4	98	6.2	92	5.3	90	11.3	88	20.1	87	20.1	87	22.8	83	100.5	27	25.6	80
	4.4	95	6.2	88	10.2	92	10.2	90	7.1	86	8.0	90	27.6	80	39.9	80	21.4	80
	5.7	87	7.1	97	4.8	93	6.6	97	26.9	97	12.9	88	30.6	82	32.8	80	29.1	83
	6.2	95	3.0	96	3.9	93	11.8	97	8.5	90	7.1	93	14.0	88	36.7	75	19.5	80

*Lamination

LOCATION OF 1 1/4-in. ABS-C STEEL CHARPY V-NOTCH SPECIMENS AND CHEMICAL COMPOSITION OF EACH STEEL PLATE

NBS No.	Blank N1	Blank N2	Blank N3	Blank N4	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	Al	Ti	As	Sn	N
213	1--13	14--24	25--36	37--46	.15	.72	.006	.022	.21	.059	.022	.018	.004	.005	.046	.004	.02	.004	.005
214	1--13	14--23	24--35	36--46	.15	.73	.007	.020	.20	.059	.023	.018	.004	.005	.045	.004	.02	.005	.005
215	1--13	14--23	24--35	36--45	.15	.72	.008	.021	.20	.057	.023	.018	.004	.005	.045	.004	.02	.004	.005
216	1--12	13--22	23--34	35--45	.14	.68	.006	.019	.20	.052	.023	.018	.004	.005	.044	.004	.02	.004	.004
217	1--12	13--22	23--34	35--44	.15	.71	.009	.022	.22	.11	.034	.024	.004	.005	.057	.004	.02	.008	.005
218	1--12	13--22	23--33	34--43	.13	.67	.008	.019	.22	.091	.032	.022	.004	.005	.060	.004	.02	.007	.005
219	1--13	14--24	25--36	37--46	.16	.69	.014	.024	.21	.10	.034	.023	.004	.005	.047	.004	.02	.009	.007
220	1--13	14--23	24--35	36--46	.15	.69	.014	.023	.22	.103	.034	.022	.004	.005	.050	.004	.02	.009	.006
221	1--13	14--24	25--36	37--47	.14	.71	.014	.031	.23	.082	.044	.026	.004	.005	.054	.004	.02	.009	.006
222	1--14	15--25	26--39	40--50	.13	.73	.012	.027	.22	.089	.042	.026	.004	.005	.060	.004	.02	.008	.005
223	1--12	13--23	24--37	38--48	.13	.74	.015	.029	.22	.096	.043	.028	.004	.005	.049	.004	.02	.009	.006
224	1--13	14--24	25--38	39--49	.13	.71	.014	.027	.21	.084	.044	.028	.004	.005	.052	.004	.02	.008	.006

2½-in. between N1 and N2; 7--10-in. between N2 and N3; 2½-in. between N3 and N4