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SSC-141

MILL SAMPLING TECHNIQUES FOR QUALITY DETERMINATION OF SHIP STEEL PLATE

by

Charles L. Staugaitis

SHIP STRUCTURE COMMITTEE

SHIP STRUCTURE COMMITTEE

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ADDRESS CORRESPONDENCE TO:

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

February 28, 1962

Dear Sir:

The Ship Structure Committee and the American Iron and Steel Institute sponsored jointly a study at the National Bureau of Standards to determine the notch toughness of currently produced ship plate steels.

Herewith is a copy of the final report of this investigation, Serial No. SSC-141, entitled Mill Sampling Techniques for Quality Determination of Ship Steel Plate by Charles L. Staugaitis.

The project was conducted under the advisory guidance of the Committee on Ship Steel of the National Academy of Sciences-National Research Council.

Please address any comments concerning this report to the Secretary, Ship Structure Committee.

Yours sincerely,

J. A. Alger Jr.

J. A. Alger, Jr.
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

Serial No. SSC-141

Final Report
of
Project SR-139

to the

SHIP STRUCTURE COMMITTEE

on

MILL SAMPLING TECHNIQUES FOR QUALITY DETERMINATION OF SHIP STEEL PLATE

by

Charles L. Staugaitis

National Bureau of Standards

under

Treasury Department
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transmitted through

Committee on Ship Steel
Division of Engineering and Industrial Research
National Academy of Sciences-National Research Council

under

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Washington, D. C.
National Academy of Sciences-National Research Council
February 28, 1962

ABSTRACT

In order to evaluate the variation in notch toughness of currently produced ship plate steel, studies were made of 105 plates submitted by five producers. The plates were selected to give statistical information regarding the variation in composition, mechanical properties and microstructure that might be expected within heats, within ingots, and with position in the plate, and complete information regarding the processing of the plates was obtained from the producers.

The notch toughness was evaluated primarily by the Charpy V-notch impact test, although two cooperating laboratories tested many of the plates with the drop weight and van der Veen slow bend tests. The results showed somewhat different patterns for the fully killed and semikilled grades, and sampling plans for each grade are suggested. Because of the marked uniformity of the mill practices of the producers, it was not possible to assess the separate effects of processing variables on notch toughness.

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for the

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INTRODUCTION

This investigation, initiated as a result of a survey of the ship steel research program made in 1953,[1] was directed at determining the notch toughness of currently produced steel plate used in merchant ship construction and to evaluate, if possible, those mill practice variables which may significantly influence this property. The project received joint support from the Ship Structure Committee and the American Iron and Steel Institute, and was under the guidance of a project advisory committee of the Committee on Ship Steel of the National Academy of Sciences-National Research Council.

MATERIAL

Arrangements were made by the Committee on Ship Steel to have steel plates together with data sheets containing extensive information on the manufacturing and processing history of each plate delivered directly from five participating mills. The material for the experimental work consisted of two grades of steel; 3/4 in. ABS-Class B steel and 1 1/4 in. ABS-Class C steel (as-rolled). Table 1 summarizes the individual mill contributions for both grades of steel.

Ladle analyses for the individual heats are presented in Tables 2 and 3. Note that samples obtained from the first three heats of each grade of steel are made to pre-1956 ABS requirements while the remaining steels conform to current ABS Rules presented in Appendix II.

To facilitate the identification of each ingot and plate received, the following designation is used throughout this report unless otherwise noted:

	S - Second		T - Top
INGOT	M - Middle	PLATE	C - Center
	L - Next to last		B - Bottom

Generally, the as-received plates were at least three-feet long in the rolling direction by the full plate width which usually ranged from six to eight feet. In a few cases where the full width of the plate was less than five feet,

Table 1

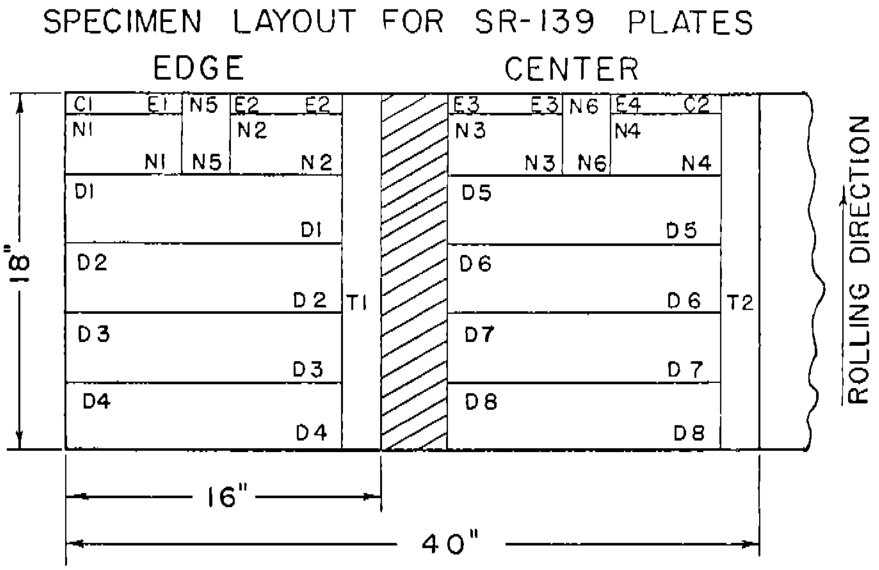
Number of Mill Contributions and Samples Tested

Manufacturer	Heats	Sample Plates Received	Sample Plates Tested
3/4 in. ABS-Class B Steel			
1†	3	27	17
1	3	9	9
2	6	18	15
3	4	18	15
TOTAL	16	72	56
1 1/4 in. ABS-Class C Steel (as-rolled)			
1	3	9	9
2†	3	27	12
2	3	12	12
4	3	9	7*
5	3	9	9
TOTAL	15	66	49

†Steel made to 1954 ABS requirements.
*Two plates could not be properly identified.

a corresponding increase in the length dimension was made to accommodate a minimum of thirty square feet of material. Subsequently, a piece 18 in. long by half-plate width (usually 40 in. to 50 in. wide) was removed by flame-cutting. Two sections 18 in. by 16 in. were then cut from this piece, one adjacent to the edge and the other nearest the center of the original plate.

Figures 1 and 2 show respectively the complete specimen layout and sheet metal template used to maintain the location and orientation of each test blank. The small holes in the template provide reference points for punch marks indicating where blanks should be sawed while the larger holes locate the position where identification numbers are to be



Specimen Code

N1 to N4	Long. Impact Blanks	T1, T2	Tensile Coupons (8)
N5 & N6	Transv. Impact Blanks	C1, C2	Chemical Samples
E1 to E4	Macro-etch Blanks	▨	Surplus Material
D1 to D8	Drop Weight Blanks		

FIG. 1. COMPLETE SPECIMEN BLANK LAYOUT.

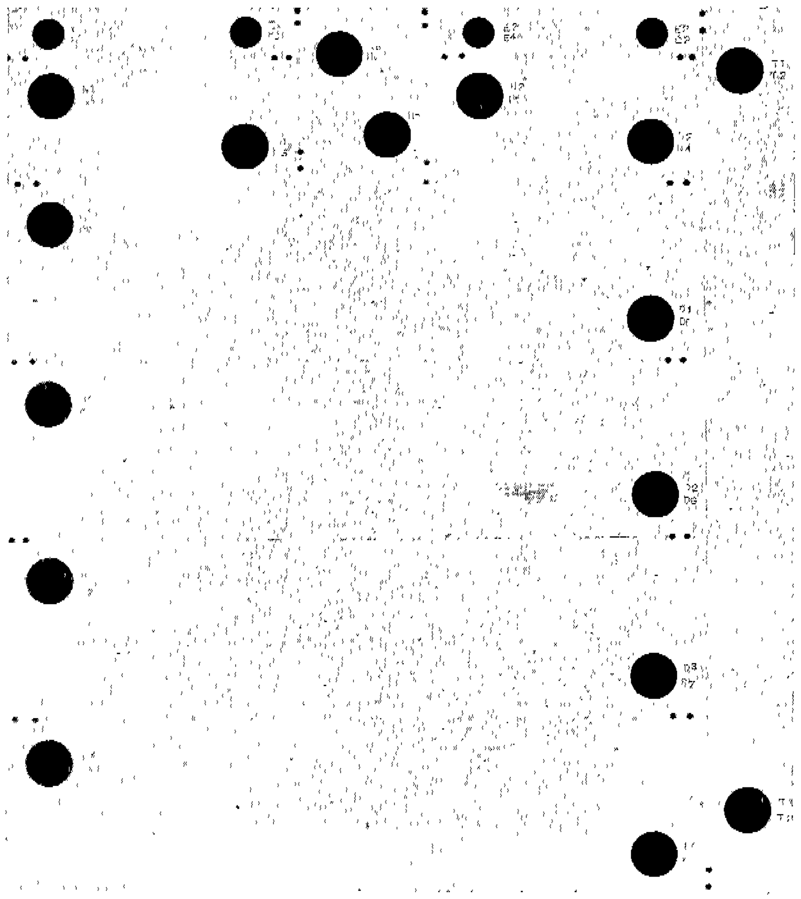


FIG. 2. SHEET METAL TEMPLATE FOR SPECIMEN LAYOUT. THE SMALL HOLES ORIENT THE VARIOUS TEST BLANKS WHILE THE LARGER HOLES SERVE TO LOCATE THE SAME AREAS FOR STAMPING OF IDENTIFICATION SYMBOLS.

Table 2

Ladle Analysis for 3/4 in. ABS-Class B Steel

Mfg.	Heat Code	C	Mn	P	S	Si	Cu	Ni	Sn
1	B1*	.20	.78	.016	.028	.047	.07	.12	
	B2*	.19	.74	.017	.032	.039	.03	.03	
	B3*	.20	.82	.019	.026	.046	.09	.07	
	B11	.16	.90	.018	.023	.014	.04	.04	
	B12	.16	.93	.012	.025	.034	.04	.04	
	B13	.17	.95	.016	.029	.040	.04	.04	
2	B4	.15	1.05	.010	.020	.04			
	B5	.15	.94	.008	.020	.03			
	B6	.17	.98	.010	.025	.03			
	B14	.17	.95	.008	.024	.05	.07	.04	
	B15	.21	1.04	.009	.021	.05	.06	.03	
	B16	.18	.98	.010	.022	.03	.05	.02	
3	B7	.19	.94	.027	.016	.06	.06		
	B8	.19	.95	.010	.029	.06	.04		.01
	B9	.18	.90	.015	.037	.07			
	B10	.19	.88	.013	.025	.06	.07		.01

ABS Requirements

	C	Mn	P	S
Pre-1956	.23 max.	.60/.90	.04 max.	.05 max.
1956	.21 max.	.80/1.10	"	"

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*Pre-1956 practice

stamped thus insuring consistency in specimen orientation.

A complementary investigation at the New York Naval Shipyard on a limited number of these steels necessitated altering the layout plan to accommodate an additional 22 unnotched van der Veen blanks. The modified specimen layout and the template for marking off the van der Veen blanks are illustrated in Figs. 3 and 4.

Table 3

Ladle Analysis for 1 1/4 in. ABS-C Steel (as-rolled)

Mfg.	Heat Code	C	Mn	P	S	Si	Cu	Ni	Cr	Sn	Al	Mo
1	C4	.16	.71	.012	.032	.17	.05	.04				
	C5	.18	.65	.013	.026	.21	.07	.06				
	C6	.17	.72	.019	.035	.22	.07	.03				
2	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	
	C13	.18	.82	.009	.036	.25	.09	.04				
	C14	.16	.61	.009	.028	.20	.07	.03	.02	.002		.003
	C15	.18	.70	.010	.024	.23	.03	.03	.02	.002		.003
4	C7	.16	.71	.016	.043	.23						
	C8	.17	.70	.025	.032	.23						
	C9	.17	.77	.013	.037	.22						
5	C10	.17	.82	.018	.040	.27	.20	.09				
	C11	.17	.74	.021	.025	.30	.24	.11				
	C12	.17	.74	.012	.028	.28	.17	.13				

ABS Requirements

	C	Mn	P	S	Si
Pre-1956	.25†	.60/.90	.04†	.05†	.15/.30
1956	.24†	.60/.90	.04†	.05†	.15/.30

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*Pre-1956 practice
†Max.

TESTING PROCEDURE

A preliminary study^2 utilized a sampling plan devised by Dr. W. J. Youden, Statistical Consultant of the NBS Statistical Engineering Section, that permitted proper comparisons to be made between plates rolled from the same ingot, between ingots poured from the same heat and between

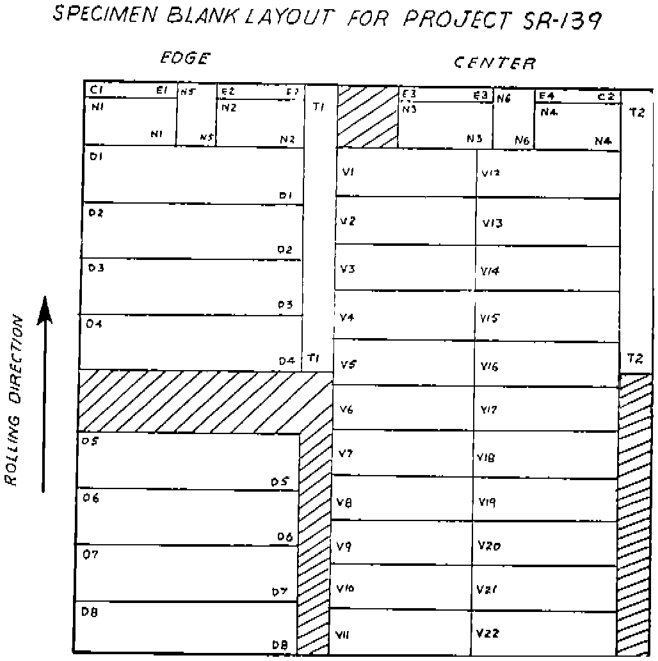


FIG. 3. MODIFIED SPECIMEN BLANK LAYOUT. THE BLANKS MARKED BY LETTER V REPRESENT THE LOCATION OF VAN DER VEEN TEST SPECIMENS. THE REMAINING DESIGNATIONS ARE THE SAME AS IN FIG. 1.

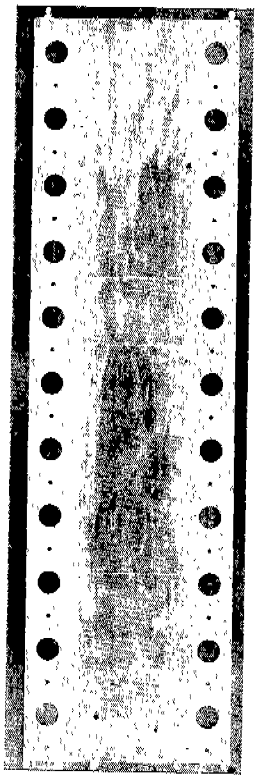


FIG. 4. SHEET METAL TEMPLATE FOR VAN DER VEEN UNNOTCHED TEST BLANKS. THE SMALL HOLES ORIENT THE VARIOUS TEST BLANKS WHILE THE LARGER ONES SERVE TO LOCATE THE SAME AREAS FOR STAMPING OF IDENTIFICATION SYMBOLS.

heats using similarly located ingot and plate positions. In addition, Dr. Youden designed a specimen selection scheme that was used to provide a more accurate distinction of Charpy behavior from one plate to another and in particular to allow a more precise statistical treatment of the data. Basically, the plan involved the testing of four Charpy bars at each selected temperature and chosen in such a way that four different regions of the plate width running from edge to center were always represented. Both sampling schemes and the statistical methods employed are more fully described in Appendix I. Statistical analysis of the experimental data was largely performed by personnel of the Statistical Engineering Section on the NBS 704 computer.

Tensile Tests

The tensile results (Table 4) are reported as the average of two full-plate thickness tension coupons (8 in. gage length) located in the test plate as shown in Fig. 1. The loading rates for the determination of yield point and tensile strength were well below the levels specified for the room temperature testing of structural steels. All tests were carried out on a 200,000-lb capacity Riehle Hydraulic Testing Machine using an averaging extensometer (microformer type) to record the stress-strain curves of each tension specimen.

Chemical and Spectrochemical Analysis

Two chemical samples marked C1 and C2 (Fig. 1) representing the edge and center of the plate width respectively were removed from each steel plate and analyzed. The elements C, P, S and N were determined by chemical analysis and the Mn, Si, Cu, Ni, Cr, V, Mo, Al, Sn, Ti and As content was determined by spectrochemical methods. Table 5 presents the average composition for the cross section of the plate thickness except in plates 207, 211 and 227 (pre-1956 steels from mill 1) where C2 was divided into two sections as indicated in Figs. 5 and 6 and designated C3 and C4. The former represents the composition of the normal material while the latter

Table 4

Physical Properties of ABS-Class B and C Steel

MFG.	HEAT CODE	NBS NO.	INGOT & PLATE	YIELD POINT	TENSILE STRENGTH	ELONG. (8 in.)	FINISH TEMP.	FERRITE GRAIN SIZE	C	Mn	P	Si	S	T_{v10}	T_{v15}	T_{v25}	NIL DUCTILITY TEMPERATURE		TEMP. 50% FIBROUS	TEMP. 10% FIBROUS
																	Edge	Center		
				KSI	KSI	%	°F	No.	%	%	%	%	%	°F	°F	°F	°F	°F	°F	°F
									3/4-in. ABS-Class B Steel											
1'		201	TS	33.1	63.1	31.0	1800	7.7	.21	.74	.013	.051	.027	6	21	46	0	10	84	17
		202	CS	33.8	63.2	31.5	1810	8.0	.21	.76	.014	.051	.027	7	32	46	0	10	84	0
	B1	203	TM	32.9	63.0	31.0	1795	7.8	.21	.77	.014	.050	.028	4	17	45	10	0	94	1
		204	BM	33.4	61.0	31.0	1820	7.8	.20	.76	.011	.048	.026	5	19	32	0	0	73	11
		225	TL	33.4	63.4	32.0	1745	7.9	.20	.76	.013	.050	.026	5	24	37	0	10	64	0
		226	CM	34.8	64.1	32.0	1830	7.6	.22	.80	.014	.053	.030	-5	18	39	0	0	71	0
		205	CS	32.8	61.2	30.0	1895	7.2	.20	.75	.015	.041	.029	21	36	48	10	20	98	35
		206	BS	32.8	60.5	29.0	1860	7.5	.20	.74	.016	.044	.028	12	34	46	0	0	93	26
	B2	207	TL	31.8	58.9	30.5	1895	7.1	.17	.72	.016	.045	.025	8	26	38	10	10	82	0
		208	CL	32.2	62.0	30.5	1910	7.7	.19	.77	.017	.044	.028	23	38	54	10	10	89	15
		227	TS	32.0	59.8	33.0	1885	7.4	.19	.79	.016	.052	.028	10	-29	41	0	0	72	2
		228	CM	31.5	62.5	32.0	1770	7.2	.20	.77	.018	.051	.030	15	38	55	0	0	82	17
		209	CM	35.5	65.1	30.5	1800	8.0	.20	.82	.015	.051	.028	12	31	44	10	10	83	17
		210	BM	33.8	62.9	31.5	1880	7.6	.19	.79	.014	.050	.025	10	29	46	0	0	78	-1
	B3	211	TL	39.0	71.4	22.2	1890	7.9	.25	.84	.020	.048	.039	31	41	64	10	10	88	13
		212	BL	34.4	63.5	30.5	1870	7.7	.19	.81	.015	.047	.027	3	26	44	0	0	69	-2
		229	CL	36.2	64.7	29.5	1855	7.3	.21	.85	.016	.050	.029	17	32	57	0	0	80	8
			Avg	33.7	63.0	30.5	1842	7.6	.20	.78	.015	.049	.028	10.8	28.9	46.1	3.5	5.3	81.4	9.7
1		276	TL	32.1	56.9	32.0	1880	7.2	.14	.93	.010	<.015	.019	10	27	34	0	-	73	-7
	B11	277	CL	33.1	60.5	32.5	1885	7.2	.17	.98	.012	<.015	.026	9	27	38	0	-	75	7
		278	BL	32.2	58.7	33.0	1880	7.5	.17	.96	.012	<.015	.024	5	23	38	0	-	75	5
		279	TM	34.1	61.1	32.5	1830	7.8	.18	.99	.010	.034	.024	0	13	23	0	-	61	4
	B12	280	CM	34.1	62.8	29.0	1855	7.5	.19	.99	.010	.034	.025	4	15	30	0	-	69	-2
		281	BM	34.0	61.5	32.0	1810	7.8	.17	.96	.009	.034	.024	0	14	28	0	-	60	-8
		282	TS	38.0	66.8	29.0	NR	7.6	.19	1.10	.013	.044	.028	-24	-18	7	-10	-	54	-12
	B13	283	CS	35.7	64.2	31.5	NR	7.1	.19	1.12	.013	.046	.027	-14	-5	16	0	-	55	-14
		284	BS	33.6	59.6	32.5	NR	7.5	.16	1.09	.011	.061	.024	-3	6	15	-10	-	32	-12
			Avg	34.1	61.3	31.5	1857	7.5	.17	1.01	.011	.033	.024	-1.4	11.3	25.4	-2.2		61.5	-4.3
2	B4	230	CL	35.4	61.0	31.0	1600	8.0	.16	1.06	.012	.050	.019	-30	-24	-13	-20	-20	24	-22
		231	BL	35.7	59.8	32.0	1600	8.1	.15	1.05	.011	.053	.019	-11	2	+11	-10	-10	28	-15
	B5	232	TL	32.6	57.9	32.0	1725	7.8	.16	.94	.010	.043	.027	-9	-1	+13	-20	-20	35	-14
		233	BL	33.8	58.4	33.0	1640	7.8	.15	.93	.009	.049	.025	-5	6	+18	-10	-10	37	-14
	B6	234	TL	34.7	62.9	33.0	1665	8.2	.18	1.02	.012	.045	.022	-15	-11	+8	0	-10	38	-10
		235	CL	34.9	63.9	31.0	1665	8.1	.18	1.04	.012	.045	.020	-14	-5	+13	-10	0	39	-10
		285	TS	33.2	64.1	31.0	1695	7.9	.19	1.02	.008	.032	.023	3	17	28	NT	NT	64	3
	B14	286	CS	34.1	62.4	31.5	1675	8.1	.19	1.01	.008	.032	.023	-7	-2	10	NT	NT	44	-8
		287	BS	33.3	59.3	32.0	1675	7.6	.17	1.01	.007	.044	.020	-4	7	25	NT	NT	46	-7
		288	TM	37.7	68.1	30.5	1695	7.7	.22	1.13	.008	.049	.019	-19	-15	-9	NT	NT	42	-20
	B15	289	CM	37.0	68.8	30.5	1695	7.8	.22	1.16	.008	.048	.019	-25	-12	1	NT	NT	57	-14
		290	BM	36.2	65.8	31.5	1680	7.8	.20	1.09	.007	.048	.018	-5	-1	8	NT	NT	41	-10
		291	TL	34.0	62.5	31.0	1690	7.7	.19	1.05	.009	.048	.018	-5	0	11	NT	NT	48	-12
	B16	292	CL	35.0	64.3	32.0	1710	7.4	.20	1.04	.009	.043	.018	-12	8	20	NT	NT	49	-6
		293	BL	33.2	62.1	33.0	1710	7.9	.20	1.04	.009	.046	.017	-6	9	21	NT	NT	48	-15
			Avg	34.7	62.7	31.7	1675	7.9	.18	1.04	.009	.045	.022	-10.9	-1.5	11	-11.7	-11.7	42.7	-11.6
3		236	CS	37.8	65.9	29.5	1690	8.1	.20	1.00	.011	.074	.023	-4	12	21	-10	-10	42	2
		237	BS	35.9	63.4	33.0	1700	8.0	.18	.95	.011	.075	.024	8	15	23	0	-10	49	-3
	B7	238	TM	36.2	63.2	32.0	1750	7.9	.18	.96	.011	.069	.023	-1	7	20	0	-10	49	0
		239	BM	34.8	62.6	33.0	1720	8.0	.18	.94	.011	.066	.024	2	11	23	-10	-10	47	-5
		240	TL	35.3	62.6	33.0	1725	8.2	.18	.95	.012	.064	.025	7	9	14	-10	0	43	0
		241	CL	36.1	64.4	32.0	1720	8.0	.19	.96	.011	.062	.025	-1	8	27	0	0	51	-3
		267	TL	36.3	63.7	32.0	1800	7.9	.19	1.00	.010	.079	.027	14	22	33	0	-	64	-10
	B8	268	CL	34.4	63.5	31.5	1745	8.0	.19	.99	.009	.081	.027	-1	6	20	0	-	58	-2
		269	BL	34.1	60.3	33.5	1765	7.5	.18	1.01	.009	.090	.026	15	27	40	-10	-	43	-7
		270	TM	33.9	61.0	31.5	1975	8.0	.17	.97	.012	.071	.034	-11	-3	10	0	-	44	-12
	B9	271	CM	34.9	62.9	31.5	1960	7.8	.18	1.03	.011	.074	.037	-10	-4	6	0	-	45	-9
		272	BM	33.5	58.5	33.5	1985	7.8	.16	.97	.011	.075	.033	6	10	20	0	-	39	-9
		273	TS	37.6	64.9	31.5	1920	7.6	.21	.94	.011	.096	.023	9	18	38	0	-	60	-7
	B10	274	CS	35.7	65.6	31.5	1890	7.5	.21	.98	.010	.093	.023	11	20	40	0	-	72	-9
		275	BS	35.1	64.4	31.0	1950	7.9	.20	.94	.010	.093	.022	16	25	34	0	-	68	-7
			Avg	35.4	63.1	32.0	1820	7.9	.19	.97	.011	.077	.026	4.0	12.2	24.6	-2.7	-6.7	51.6	-5.4

NR - Denotes Not Reported
NT - Denotes Not Tested
1' - Pre-1956 ABS Steel

Table 4
(Continued)

MFG.	HEAT CODE	NBS NO.	INGOT & PLATE	YIELD POINT	TENSILE STRENGTH	ELONG. (8 in.)	FINISH TEMP.	FERRITE GRAIN SIZE	C	Mn	P	Si	S	T_{v10}	T_{v15}	T_{v25}	NIL DUCTILITY TEMPERATURE Edge	Center	TEMP. 50% FIBROUS	TEMP. 10% FIBROUS
				KSI	KSI	%	°F	No.	%	%	%	%	%	°F	°F	°F	°F	°F	°F	°F
								1 1/4-in ABS-Class C Steel (As-Rolled)												
1		242	TL	32.2	62.3	32.5	1840	7.6	.16	.73	.011	.23	.032	-6	-1	+10	20	20**	58	-7
	C4	243	CL	32.9	61.8	32.0	1890	7.1	.16	.73	.011	.22	.031	-18	-10	+12	20	20	54	-11
		244	BL	33.0	59.3	30.5	1910	7.5	.14	.71	.010	.22	.028	-18	-12	+2	10	20**	37	-26
		245	TL	32.3	61.3	33.0	2000	7.5	.16	.68	.011	.22	.028	-7	+7	+19	30	10	52	+5
	C5	246	CL	32.0	61.3	31.0	1950	7.2	.15	.68	.010	.23	.027	-6	0	+18	10	10	57	-3
		247	BL	33.1	59.4	33.0	1950	7.6	.14	.66	.010	.21	.026	-25	-13	0	30	10	42	-17
		248	TL	34.3	63.3	31.0	1900	7.3	.16	.73	.021	.21	.034	-11	+5	+19	20	10	62	-13
	C6	249	CL	34.7	62.7	32.0	1870	7.5	.15	.73	.020	.23	.034	-16	-9	+8	20**	30*	60	-18
		250	BL	33.5	60.9	32.0	1860	7.1	.15	.74	.024	.24	.031	-12	-2	+11	20	10	45	-7
			Avg	33.1	61.4	32.0	1907	7.4	.15	.71	.014	.22	.030	-13.2	-3.9	+11	20	16.7	51.9	-10.8
2'		213	TS	29.3	58.1	35.0	1800	7.3	.15	.73	.007	.21	.022	-30	-23	-15	-10	0	24	-18
	C1	214	CS	29.8	58.1	34.0	1800	7.1	.15	.73	.008	.20	.020	-27	-16	-9	-20	-10	29	-14
		215	TM	28.9	58.1	34.0	1775	6.9	.15	.72	.008	.20	.021	-23	-14	-5	0	+10	30	-21
		216	BM	28.7	56.5	33.0	1790	7.5	.14	.68	.006	.20	.019	-36	-18	-13	-20	-10	58	-32
		217	CS	32.5	60.7	33.0	1775	7.3	.15	.71	.010	.22	.022	-32	-19	-6	-10	0	50	-10
	C2	218	BS	29.2	56.1	36.0	1790	7.6	.13	.67	.008	.22	.019	-44	-32	-13	-20	0	27	-27
		219	TL	32.2	61.1	33.5	1775	6.8	.16	.69	.015	.21	.024	-43	-26	-9	-10	0	67	-18
		220	CL	31.1	59.7	33.5	1790	6.8	.15	.69	.014	.22	.023	-36	-30	-20	0	+10	55	-14
		221	CM	32.2	59.5	33.5	1800	7.0	.14	.71	.014	.24	.030	-36	-25	-16	-10	0	22	-26
	C3	222	BM	30.5	57.5	34.0	1810	7.3	.13	.73	.012	.23	.027	-24	-9	+10	0	+10	55	-17
		223	TL	31.3	59.7	33.5	1800	6.6	.13	.73	.016	.22	.029	-30	-13	+10	-10	+20	34	-19
		224	BL	30.0	56.6	35.0	1800	6.7	.13	.71	.014	.21	.029	-20	-2	+9	+20**	+20	65	-20
			Avg	30.5	58.5	34.0	1792	7.1	.14	.71	.011	.22	.024	-31.7	-18.9	-6.4	-7.5	+4.2	43.0	-19.7
2		294	CL	34.7	63.3	32.0	1890	7.0	.19	.79	.011	.25	.035	-25	-12	6			28	-8
	C13	295	BL	32.3	60.1	35.0	1858	7.4	.17	.75	.010	.24	.033	-32	-14	9			38	-14
		296	TM	34.9	64.4	31.5	1850	7.2	.19	.80	.010	.24	.035	-33	-25	3			37	-8
		297	CM	35.7	64.5	31.0	1850	7.2	.19	.81	.010	.26	.036	-34	-19	-3			46	-18
		298	TM	31.8	58.6	35.0	1775	7.1	.16	.66	.012	.23	.025	-21	-9	7			49	1
	C14	299	BM	32.3	57.0	36.0	1779	7.4	.14	.63	.010	.21	.023	-25	-16	1			41	-5
		300	TS	32.1	59.4	31.0	1787	6.7	.16	.67	.012	.22	.025	-23	-17	5			40	-2
		301	CS	32.0	58.2	34.5	1787	6.7	.16	.68	.010	.23	.024	-32	-20	-3			33	-11
		302	TL	34.1	63.2	33.0	1795	7.1	.18	.73	.010	.23	.022	-40	-28	7			36	-7
	C15	303	BL	32.8	59.4	33.0	1795	6.7	.16	.70	.010	.23	.018	-40	-31	2			41	-9
		304	BS	32.7	60.9	32.0	1795	7.3	.17	.72	.008	.25	.019	-33	-22	-9			45	-13
		305	CS	35.3	63.5	33.0	1795	7.2	.19	.75	.008	.28	.021	-24	-16	-3			49	-2
			Avg	33.4	61.0	33.1	1813	7.1	.17	.72	.010	.24	.026	-30.2	-19.1	1.8			40	-8
4		251	TL	36.2	64.9	29.5	1500	7.7	.15	.74	.012	.27	.034	-20	-9	+22	10	0	69	-20
	C7	252	CL	36.7	65.0	30.5	1500	7.2	.15	.74	.008	.25	.035	-24	-10	+17	0	-10*	77	-13
		253	BL	37.5	65.1	30.0	1500	7.3	.16	.74	.013	.26	.036	-25	-11	+29	10	-10*	75	-4
		254	TL	40.9	68.0	29.5	1400	7.3	.16	.76	.031	.24	.037	-26	-3	+24	30	10	83	-1
	C8	255	CL	39.2	66.3	30.5	1400	7.1	.16	.75	.032	.23	.036	-18	+11	+32	0	10	93	-2
		256	BL	38.2	65.3	30.5	1400	7.1	.15	.73	.031	.23	.035	-24	-13	+15	10	-10	76	-7
	C9	257	BL	38.8	67.8	30.5	1450	7.5	.18	.79	.015	.24	.037	-30	-16	+22	0	10	54	-21
			Avg	38.2	66.1	30.0	1450	7.3	.16	.75	.020	.25	.036	-23.8	-7.3	+23	8.6	0	75.3	-9.7
5		258	TL	37.9	67.3	29.5	1740	7.5	.16	.84	.026	.29	.042	-20	-7	+22	0**	10	51	-6
	C10	259	CL	38.9	67.1	30.5	1740	7.8	.16	.85	.026	.31	.042	-31	-14	+22	10	10	42	-19
		260	BL	38.5	66.1	31.5	1740	7.3	.16	.82	.025	.29	.041	-32	-17	+15	0	0	31	-30
		261	TL	38.8	67.0	28.5	1930	7.5	.16	.79	.013	.32	.027	-39	-30	+4	0	-20	65	-16
	C11	262	CL	36.9	66.4	31.5	1930	7.1	.16	.79	.014	.31	.026	-40	-26	+9	-10	-20	51	-12
		263	BL	36.9	65.4	30.5	1930	7.7	.16	.78	.013	.30	.025	-52	-37	+2	-20	-10	48	-22
		264	TL	36.7	64.6	31.0	1760	7.8	.15	.70	.013	.28	.030	-23	-10	+12	-10**	0	62	-17
	C12	265	CL	37.2	64.4	32.5	1760	7.4	.17	.72	.015	.28	.029	-26	-4	+15	-20	-20	53	-4
		266	BL	35.7	63.5	32.0	1760	7.4	.15	.71	.015	.27	.029	-27	-12	+17	10	-10	63	-13
			Avg	37.5	65.8	30.8	1810	7.5	.16	.78	.018	.29	.032	-32.2	-17.4	+13.1	-4.4	-6.7	51.8	-15.4

* - Probably higher
** - Probably lower
2' - Pre-1956 ABS Steel

Table 5

Composition of ABS-Class B and C Steel

MFG.	HEAT CODE	NBS NO.	SAMPLE IDENT. (1)	C	Mn*	P	S	Si*	Ni*	Cu*	Cr*	V*	Mo*	Al*	Sn*	Ti*	As*	N
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
									Composition of 3/4-in. ABS-Class B Steel									
1'	B1	201	C1	.21	.74	.013	.029	.052	.10	.06	.02	<.01	.006	<.01	.004	<.003	<.02	.006
			C2	.20	.74	.013	.026	.049	.10	.06	.02	<.01	.006	<.01	.004	<.003	<.02	.006
	B1	202	C1	.20	.77	.013	.027	.051	.10	.06	.02	<.01	.006	<.01	.004	<.003	<.02	.005
			C2	.21	.75	.014	.027	.050	.10	.06	.02	<.01	.006	<.01	.004	<.003	<.02	.006
	B1	203	C1	.21	.78	.013	.028	.050	.11	.06	.02	<.01	.006	<.01	.004	<.003	<.02	.005
			C2	.21	.76	.014	.028	.049	.11	.06	.02	<.01	.006	<.01	.004	<.003	<.02	.005
	B1	204	C1	.20	.75	.011	.027	.046	.11	.058	.022	<.01	.005	<.007	.004	<.01	<.02	.005
			C2	.19	.75	.010	.025	.051	.11	.056	.023	<.01	.005	.009	.004	<.01	<.02	.005
	B1	225	C1	.20	.75	.013	.027	.05	.11	.063	.024	<.01	.005	<.01	.004	<.01	<.02	.005
			C2	.20	.76	.012	.025	.05	.12	.063	.024	<.01	.005	<.01	.005	<.01	<.02	.005
	B1	226	C1	.22	.80	.014	.031	.052	.094	.059	.026	<.005	.008	<.01	<.007	<.005	<.02	.005
			C2	.22	.80	.014	.030	.054	.094	.059	.026	<.005	.008	<.01	<.007	<.005	<.02	.007
	B2	205	C1	.20	.74	.015	.030	.042	.028	.035	.031	<.01	.004	.009	.004	<.01	<.02	.005
			C2	.20	.75	.015	.029	.041	.030	.035	.030	<.01	.004	.007	.004	<.01	<.02	.004
	B2	206	C1	.20	.75	.016	.030	.042	.029	.035	.030	<.01	.004	.009	.004	<.01	<.02	.006
			C2	.19	.73	.015	.027	.046	.030	.034	.030	<.01	.004	.013	.004	<.01	<.02	.006
	B2	207	C1	.19	.74	.017	.028	.046	.032	.036	.032	<.003	.004	<.01	<.01	<.01	<.02	.005
			C3	.18	.70	.017	.027	.044	.034	.033	.030	<.003	.004	<.01	<.01	<.01	<.02	.005
			C4	.12	.66	.012	.015	.043	.033	.033	.030	<.003	.004	<.01	<.01	<.01	<.02	.004
	B2	208	C1	.19	.75	.017	.028	.043	.030	.035	.031	<.003	.004	<.01	<.01	<.01	<.02	.005
			C2	.19	.78	.017	.029	.045	.035	.034	.032	<.003	.004	<.01	<.01	<.01	<.02	.005
	B2	227	C1	.20	.78	.017	.031	.051	.024	.037	.033	<.003	.007	.02	<.007	<.005	<.02	.007
			C3	.20	.80	.017	.028	.054	.028	.039	.034	<.003	.007	.005	<.007	<.005	<.02	.006
			C4	.14	.80	.012	.020	.051	.029	.039	.035	<.003	.007	.005	<.007	<.005	<.02	.006
	B2	228	C1	.20	.77	.017	.029	.053	.024	.012	.033	<.003	.007	.01	<.007	<.005	<.02	.006
			C2	.20	.76	.018	.031	.048	.021	.037	.034	<.003	.007	.01	<.007	<.005	<.02	.006
	B3	209	C1	.20	.82	.015	.029	.053	.081	.071	.037	<.003	.038	<.01	.010	<.01	<.02	.004
			C2	.20	.82	.015	.028	.050	.063	.068	.036	<.003	.041	<.01	.009	<.01	<.02	.004
	B3	210	C1	.19	.78	.014	.027	.047	.083	.070	.036	<.003	.040	<.01	.010	<.01	<.02	.004
			C2	.19	.80	.014	.024	.054	.084	.070	.036	<.003	.039	<.01	.010	<.01	<.02	.004
	B3	211	C1	.20	.81	.015	.028	.049	.083	.070	.037	<.003	.039	<.01	.009	<.01	<.02	.004
			C3	.20	.80	.015	.026	.047	.089	.072	.036	<.003	.038	<.01	.011	<.01	<.02	.004
			C4	.40	.92	.034	.070	.047	.092	.083	.037	<.003	.035	<.01	.028	<.01	<.02	.006
	B3	212	C1	.19	.82	.015	.028	.016	.086	.072	.036	<.003	.039	<.01	.009	<.01	<.02	.004
			C2	.19	.80	.015	.027	.047	.086	.071	.036	<.003	.038	<.01	.009	<.01	<.02	.003
	B3	229	C1	.21	.86	.016	.029	.050	.066	.073	.039	<.005	.040	.01	.009	<.005	<.02	.005
			C2	.21	.81	.016	.030	.049	.066	.074	.040	<.005	.039	.01	.009	<.005	<.02	.004
1	B11	276	C1	.14	.94	.010	.019	<.015	.025	.019	.029	.005	.006	.01	<.010	<.004	-	.005
			C2	.15	.93	.010	.020	<.015	.029	.047	.029	.005	.006	.01	<.010	<.004	-	.005
	B11	277	C1	.17	.96	.012	.025	<.015	.021	.044	.030	.005	.006	.01	<.010	<.004	-	.005
			C2	.17	1.00	.012	.027	<.015	.025	.046	.032	.005	.006	.01	<.010	<.004	-	.006
	B11	278	C1	.17	.96	.012	.024	<.015	.023	.048	.030	.005	.006	.01	<.010	<.004	-	.006
			C2	.17	.96	.012	.025	<.015	.028	.047	.028	.006	.006	.01	<.010	<.004	-	.005
	B12	279	C1	.19	1.01	.010	.027	.034	.021	.046	.041	.005	.005	.01	<.010	<.004	-	.006
			C2	.17	.97	.010	.022	.034	.022	.044	.041	.005	.006	.01	<.010	<.004	-	.006
	B12	280	C1	.19	.99	.011	.026	.035	.022	.045	.043	.005	.006	.01	<.010	<.004	-	.007
			C2	.19	1.00	.010	.025	.033	.022	.047	.042	.005	.006	.01	<.010	<.004	-	.007
	B12	281	C1	.18	.96	.009	.021	.034	.023	.045	.038	.006	.006	.01	<.010	<.004	-	.007
			C2	.17	.96	.009	.024	.035	.022	.043	.038	.005	.006	.01	<.010	<.004	-	.006
	B13	282	C1	.19	1.10	.013	.028	.044	.030	.047	.037	.006	.005	.01	<.010	<.004	-	.006
			C2	.19	1.10	.014	.029	.045	.034	.051	.041	.005	.006	.01	<.010	<.004	-	.006
	B13	283	C1	.19	1.11	.013	.027	.046	.033	.045	.038	.005	.006	.01	<.010	<.004	-	.006
			C2	.19	1.13	.013	.028	.046	.033	.052	.037	.005	.006	.01	<.010	<.004	-	.006
	B13	284	C1	.17	1.10	.012	.026	.048	.033	.049	.038	.005	.005	.01	<.010	<.004	-	.005
			C2	.16	1.09	.011	.022	.074	.034	.049	.035	.008	.006	.025	<.010	<.004	-	.004
2	B4	230	C1	.16	1.05	.012	.019	.049	.023	.085	.025	<.005	.005	.02	.007	<.005	<.02	.005
			C2	.16	1.07	.012	.020	.050	.023	.088	.023	<.005	.005	.02	.007	<.005	<.02	.004
	B4	231	C1	.15	1.05	.011	.021	.050	.023	.085	.029	<.005	.005	.02	.007	<.005	<.02	.004
			C2	.14	1.04	.011	.018	.056	.023	.083	.031	<.005	.005	.02	.007	<.005	<.02	.004
	B5	232	C1	.16	.94	.010	.028	.041	.036	.096	.023	<.005	.008	.02	.008	<.005	<.02	.004
			C2	.15	.94	.009	.027	.046	.040	.094	.023	<.005	.008	.02	.008	<.005	<.02	.005
	B5	233	C1	.15	.91	.009	.026	.044	.040	.090	.022	<.005	.008	.02	.008	<.005	<.02	.005
			C2	.14	.94	.008	.024	.055	.039	.090	.025	<.005	.007	.03	.008	<.005	<.02	.004
	B6	234	C1	.18	1.04	.011	.022	.047	.022	.053	.026	<.005	<.005	.02	.007	<.005	<.02	.006
			C2	.17	1.00	.012	.022	.044	.021	.051	.026	<.005	<.005	.02	.007	<.005	<.02	.005
	B6	235	C1	.18	1.03	.012	.021	.047	.022	.053	.024	<.005	<.005	.01	.007	<.005	<.02	.006
			C2	.18	1.04	.012	.019	.047	.020	.050	.025	<.005	<.005	.01	.007	<.005	<.02	.005

Table 5
(Continued)

MFG.	HEAT CODE	NBS NO.	SAMPLE IDENT. (1)	C	Mn*	P	S	Si*	Ni*	Cu*	Cr*	V*	Mo*	Al*	Sn*	Ti*	As*	N
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Composition of 3/4-in. ABS-Class B Steel (Continued)																		
2	B14	285	C1	.19	1.01	.008	.023	.031	.030	.064	.017	.006	<.005	<.01	<.01	<.004	-	.004
			C2	.20	1.04	.009	.024	.033	.028	.072	.021	.006	<.005	<.01	<.01	<.004	-	.005
	B14	286	C1	.19	1.01	.008	.023	.034	.027	.071	.020	.006	.005	<.01	<.01	<.004	-	.005
			C2	.19	1.01	.008	.024	.031	.028	.062	.020	.006	<.005	<.01	<.01	<.004	-	.005
	B14	287	C1	.17	1.01	.007	.020	.035	.028	.060	.017	.006	.005	<.01	<.01	<.004	-	.004
			C2	.17	1.01	.007	.020	.053	.025	.067	.016	.007	<.005	<.01	<.01	<.004	-	.004
	B15	288	C1	.22	1.11	.008	.019	.047	.017	.061	.024	.007	<.005	.01	<.01	<.004	-	.005
			C2	.22	1.15	.009	.019	.051	.017	.063	.022	.006	.005	.01	<.01	<.004	-	.005
	B15	289	C1	.22	1.17	.008	.020	.050	.019	.060	.023	.005	.005	.01	<.01	<.004	-	.005
			C2	.23	1.16	.008	.019	.047	.018	.067	.020	.006	<.005	.01	<.01	<.001	-	.005
	B15	290	C1	.20	1.09	.007	.018	.016	.017	.062	.018	.007	<.005	.01	<.01	<.001	-	.004
			C2	.20	1.09	.007	.018	.050	.016	.056	.022	.006	<.005	.01	<.01	<.004	-	.005
	B16	291	C1	.20	1.06	.009	.019	.047	.018	.063	.018	.007	<.005	<.01	<.01	<.001	-	.007
			C2	.19	1.05	.009	.017	.049	.017	.052	.019	.007	<.005	<.01	<.01	<.001	-	.005
	B16	292	C1	.20	1.06	.009	.019	.046	.015	.057	.019	.006	<.005	<.01	<.01	<.004	-	.004
			C2	.20	1.03	.009	.018	.041	.015	.048	.018	.006	<.005	<.01	<.01	<.004	-	.004
	B16	293	C1	.21	1.04	.010	.018	.043	.016	.055	.019	.006	<.005	<.01	<.01	<.004	-	.003
			C2	.18	1.05	.009	.017	.050	.015	.054	.017	.006	<.005	<.01	<.01	<.004	-	.003
3	B7	236	C1	.19	.98	.011	.023	.078	.024	.048	.015	<.005	.006	.01	<.007	<.005	<.02	.007
			C2	.20	1.02	.011	.023	.078	.024	.049	.014	<.005	.005	.01	<.007	<.005	<.02	.008
	B7	237	C1	.18	.94	.011	.026	.072	.024	.047	.014	<.005	.005	.01	<.007	<.005	<.02	.007
			C2	.17	.96	.010	.022	.078	.024	.049	.015	<.005	.005	.01	<.007	<.005	<.02	.007
	B7	238	C1	.18	.97	.010	.024	.075	.021	.049	.014	<.005	.005	.03	<.007	<.005	<.02	.006
			C2	.18	.94	.011	.023	.062	.020	.010	.010	<.005	.005	.02	<.007	<.005	<.02	.005
	B7	239	C1	.19	.94	.011	.024	.066	.021	.040	.010	<.005	.005	.02	<.007	<.005	<.02	.005
			C2	.17	.93	.011	.024	.066	.020	.040	.010	<.005	.005	.02	<.007	<.005	<.02	.005
	B7	240	C1	.18	.96	.012	.026	.063	.020	.040	.010	<.005	.005	.02	<.007	<.005	<.02	.005
			C2	.18	.94	.011	.025	.066	.022	.044	.010	<.005	.005	.02	<.007	<.005	<.02	.006
	B7	241	C1	.19	.96	.010	.024	.059	.019	.039	.010	<.005	.005	.02	<.007	<.005	<.02	.006
			C2	.19	.96	.011	.026	.064	.022	.041	.010	<.005	.005	.02	<.007	<.005	<.02	.005
	B8	267	C1	.18	1.00	.010	.027	.080	.015	.039	.015	<.004	.006	<.01	<.010	<.004	-	.004
			C2	.20	1.00	.010	.027	.078	.015	.039	.011	<.004	.006	<.01	<.010	<.004	-	.005
	B8	268	C1	.19	1.01	.009	.027	.082	.016	.039	.013	<.004	.006	<.01	<.010	<.004	-	.004
			C2	.19	.98	.009	.027	.081	.014	.038	.014	<.004	.006	<.01	<.010	<.004	-	.004
	B8	269	C1	.19	1.00	.009	.027	.085	.015	.039	.016	.004	.005	.01	<.010	<.004	-	.004
			C2	.17	1.02	.009	.025	.095	.015	.038	.012	<.004	.006	.02	<.010	<.004	-	.004
	B9	270	C1	.17	.99	.013	.035	.072	.022	.043	.018	<.004	.005	<.01	<.010	<.004	-	.004
			C2	.17	.96	.012	.034	.071	.020	.041	.020	<.004	.005	<.01	<.010	<.004	-	.005
	B9	271	C1	.18	1.01	.011	.035	.075	.021	.045	.018	<.004	.005	<.01	<.010	<.001	-	.004
			C2	.19	1.05	.011	.039	.074	.020	.044	.022	<.004	.005	<.01	<.010	<.004	-	.005
	B9	272	C1	.18	1.03	.012	.036	.077	.020	.051	.022	<.004	.005	<.01	<.010	<.004	-	.004
			C2	.15	.92	.010	.030	.073	.019	.044	.020	<.004	.005	<.01	<.010	<.004	-	.004
	B10	273	C1	.21	.94	.012	.023	.096	.022	.056	.015	<.001	.005	<.01	<.010	<.004	-	.004
			C2	.22	.95	.011	.023	.097	.022	.056	.016	<.004	.005	<.01	<.010	<.004	-	.004
	B10	274	C1	.21	.95	.011	.023	.096	.026	.065	.024	<.004	.006	<.01	<.010	<.004	-	.004
			C2	.22	1.01	.010	.023	.091	.024	.059	.020	<.004	.006	<.01	<.010	<.004	-	.004
	B10	275	C1	.21	.95	.011	.022	.095	.024	.056	.016	<.004	.005	<.01	<.010	<.004	-	.004
			C2	.20	.94	.009	.022	.091	.023	.061	.016	<.004	.005	<.01	<.010	<.004	-	.004
Composition of 1 1/4-in. ABS-Class C Steel (As-Rolled)																		
1	C4	242	C1	.16	.72	.011	.031	.23	.034	.051	.030	<.004	<.01	.03	<.010	<.004	<.03	.007
			C2	.17	.73	.012	.033	.22	.032	.051	.032	<.004	<.01	.03	<.010	<.004	<.03	.007
	C4	243	C1	.16	.72	.011	.031	.22	.036	.049	.033	<.004	<.01	.03	<.010	<.004	<.03	.004
			C2	.16	.74	.011	.032	.22	.036	.050	.032	<.004	<.01	.03	<.010	<.004	<.03	.005
	C4	244	C1	.14	.70	.010	.029	.21	.035	.050	.032	<.004	<.01	.03	<.010	<.004	<.03	.006
			C2	.14	.71	.010	.028	.22	.035	.050	.031	<.004	<.01	.03	<.010	<.004	<.03	.007
	C5	245	C1	.16	.67	.011	.028	.22	.054	.070	.046	<.004	<.01	.03	.010	<.004	<.03	.007
			C2	.17	.69	.011	.029	.21	.054	.070	.049	<.004	<.01	.03	.011	<.004	<.03	.009
	C5	246	C1	.16	.68	.010	.027	.23	.053	.071	.048	<.004	<.01	.03	.010	<.004	<.03	.006
			C2	.15	.68	.011	.027	.22	.056	.069	.047	<.004	<.01	.03	.010	<.004	<.03	.005
	C5	247	C1	.14	.66	.010	.026	.23	.050	.069	.044	<.004	<.01	.03	.010	<.004	<.03	.008
			C2	.14	.66	.010	.027	.20	.052	.071	.046	<.004	<.01	.03	.010	<.004	<.03	.008
	C6	248	C1	.16	.72	.021	.033	.21	.029	.078	.034	<.004	<.01	.03	<.010	<.004	<.03	.007
			C2	.16	.74	.021	.035	.21	.031	.078	.034	<.004	<.01	.03	<.010	<.004	<.03	.007
	C6	249	C1	.16	.73	.021	.035	.22	.031	.082	.034	<.004	<.01	.03	<.010	<.004	<.03	.007
			C2	.15	.73	.019	.033	.24	.029	.078	.035	<.004	<.01	.03	<.010	<.004	<.03	.007
	C6	250	C1	.15	.73	.025	.032	.24	.030	.080	.036	<.004	<.01	.03	<.010	<.004	<.03	.004
			C2	.15	.74	.023	.031	.24	.030	.080	.034	<.004	<.01	.03	<.010	<.004	<.03	.004
2'	C1	213	C1	.15	.71	.006	.022	.21	.022	.059	.018	<.004	<.005	.047	.004	<.004	<.02	.005
			C2	.15	.74	.007	.022	.20	.022	.060	.018	<.004	<.005	.045	.004	<.004	<.02	.005
	C1	211	C1	.14	.75	.008	.019	.20	.023	.064	.018	<.004	<.005	.047	.005	<.004	<.02	.005
			C2	.15	.70	.007	.021	.20	.024	.053	.018	<.004	<.005	.043	.005	<.004	<.02	.005

Table 5

Composition of 1 1/4-in. ABS-Class C Steel (AS-Rolled) (Continued)

MFG.	HEAT CODE	NBS NO.	SAMPLE IDENT. (1)	C	Mn*	P	S	Si*	Ni*	Cu*	Cr*	V*	Mo*	Al*	Sn*	Ti*	As*	N
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
2'	C1	215	C1	.14	.72	.008	.021	.20	.023	.057	.018	<.004	<.005	.046	.004	<.004	<.02	.004
			C2	.15	.72	.008	.022	.19	.024	.058	.017	<.004	<.005	.044	.005	<.004	<.02	.004
	C1	216	C1	.14	.71	.006	.020	.20	.022	.054	.018	<.004	<.005	.044	.004	<.004	<.02	.005
			C2	.13	.65	.006	.018	.20	.023	.050	.017	<.004	<.005	.044	.004	<.004	<.02	.005
	C2	217	C1	.15	.75	.009	.022	.22	.034	.11	.024	<.004	<.005	.058	.008	<.004	<.02	.005
			C2	.15	.67	.010	.022	.22	.034	.10	.023	<.004	<.005	.056	.008	<.004	<.02	.006
	C2	218	C1	.13	.68	.009	.020	.22	.032	.092	.022	<.004	<.005	.054	.008	<.004	<.02	.005
			C2	.12	.66	.007	.018	.22	.033	.090	.023	<.004	<.005	.066	.007	<.004	<.02	.005
	C2	219	C1	.15	.68	.014	.024	.21	.033	.10	.023	<.004	<.005	.049	.008	<.004	<.02	.007
			C2	.17	.70	.015	.025	.21	.035	.10	.024	<.004	<.005	.046	.010	<.004	<.02	.008
	C2	220	C1	.15	.70	.014	.023	.22	.033	.11	.023	<.004	<.005	.051	.008	<.004	<.02	.006
			C2	.14	.68	.014	.023	.22	.034	.097	.023	<.004	<.005	.048	.009	<.004	<.02	.006
	C3	221	C1	.14	.69	.014	.030	.23	.044	.078	.026	<.004	<.005	.055	.008	<.004	<.02	.006
			C2	.14	.72	.014	.031	.24	.044	.086	.026	<.004	<.005	.054	.009	<.004	<.02	.006
	C3	222	C1	.13	.75	.013	.028	.23	.043	.092	.027	<.004	<.005	.059	.008	<.004	<.02	.005
			C2	.12	.71	.011	.026	.22	.041	.086	.025	<.004	<.005	.060	.007	<.004	<.02	.005
	C3	223	C1	.13	.75	.015	.029	.22	.042	.098	.028	<.004	<.005	.049	.009	<.004	<.02	.005
			C2	.13	.72	.016	.030	.22	.043	.094	.028	<.004	<.005	.049	.010	<.004	<.02	.006
	C3	224	C1	.14	.72	.015	.029	.21	.045	.094	.028	<.004	<.005	.052	.008	<.004	<.02	.006
			C2	.12	.66	.013	.026	.21	.044	.073	.027	<.004	<.005	.052	.008	<.004	<.02	.005
2	C13	294	C1	.19	.78	.010	.035	.25	.029	.087	.030	<.006	<.006	.05	<.01	<.004	-	.004
			C2	.19	.81	.011	.035	.25	.027	.095	.026	<.006	<.006	.05	<.01	<.004	-	.004
	C13	295	C1	.18	.75	.010	.034	.24	.027	.081	.027	<.006	<.006	.05	<.01	<.004	-	.004
			C2	.16	.74	.009	.031	.23	.029	.090	.028	<.006	<.006	.05	<.01	<.004	-	.004
	C13	296	C1	.19	.79	.010	.035	.25	.027	.076	.028	<.006	<.006	.05	<.01	<.004	-	.004
			C2	.19	.80	.009	.035	.22	.028	.090	.028	<.006	<.006	.05	<.01	<.004	-	.004
	C13	297	C1	.19	.80	.009	.035	.25	.027	.081	.028	<.006	<.006	.05	<.01	<.004	-	.004
			C2	.19	.81	.011	.037	.26	.027	.089	.031	<.006	<.006	.05	<.01	<.004	-	.005
	C14	298	C1	.15	.65	.012	.024	.22	.020	.057	.022	<.006	<.006	.05	<.01	<.004	-	.004
			C2	.16	.67	.012	.025	.23	.021	.059	.025	<.006	<.006	.05	<.01	<.004	-	.005
	C14	299	C1	.14	.62	.010	.022	.21	.020	.059	.022	<.006	<.006	.05	<.01	<.004	-	.004
			C2	.14	.64	.010	.023	.21	.019	.058	.021	<.006	<.006	.05	<.01	<.004	-	.005
	C14	300	C1	.15	.67	.010	.024	.22	.019	.052	.024	<.006	<.006	.05	<.01	<.004	-	.004
			C2	.16	.66	.013	.025	.19	.020	.061	.022	<.006	<.006	.05	<.01	<.004	-	.005
	C14	301	C1	.16	.67	.010	.024	.23	.020	.061	.022	<.006	<.006	.05	<.01	<.004	-	.005
			C2	.15	.68	.010	.023	.23	.019	.059	.021	<.006	<.006	.05	<.01	<.004	-	.005
	C15	302	C1	.18	.74	.009	.021	.25	.017	.062	.017	<.006	<.006	.06	<.01	<.004	-	.006
			C2	.18	.72	.011	.022	.20	.018	.064	.018	<.006	<.006	.06	<.01	<.004	-	.006
	C15	303	C1	.17	.71	.010	.019	.25	.018	.056	.018	<.006	<.006	.06	<.01	<.004	-	.006
			C2	.15	.69	.009	.016	.22	.018	.065	.018	<.006	<.006	.07	<.01	<.004	-	.005
	C15	304	C1	.18	.74	.009	.020	.26	.019	.063	.018	<.006	<.006	.05	<.01	<.004	-	.007
			C2	.16	.70	.007	.018	.24	.017	.060	.018	<.006	<.006	.05	<.01	<.004	-	.006
	C15	305	C1	.18	.74	.008	.020	.28	.070	.056	.018	<.006	<.006	.05	<.01	<.004	-	.007
			C2	.19	.75	.008	.021	.27	.019	.058	.018	<.006	<.006	.05	<.01	<.004	-	.007
4	C7	251	C1	.15	.74	.013	.034	.27	.13	.37	.066	<.004	.02	.02	.039	<.004	<.03	.007
			C2	.16	.74	.012	.035	.27	.13	.36	.064	<.004	.02	.02	.039	<.004	<.03	.006
	C7	252	C1	.15	.73	.009	.035	.24	.14	.37	.069	<.004	.02	.02	.038	<.004	<.03	.004
			C2	.15	.74	.008	.036	.25	.13	.35	.068	<.004	.02	.02	.037	<.004	<.03	.004
	C7	253	C1	.16	.73	.013	.035	.26	.13	.36	.068	<.004	.02	.02	.038	<.004	<.03	.004
			C2	.16	.75	.014	.037	.26	.13	.37	.074	<.004	.02	.02	.039	<.004	<.03	.005
	C8	254	C1	.15	.75	.031	.037	.24	.14	.30	.11	<.004	.02	.03	.028	<.004	<.03	.006
			C2	.17	.76	.031	.037	.23	.14	.30	.11	<.004	.02	.03	.027	<.004	<.03	.007
	C8	255	C1	.16	.74	.032	.036	.23	.14	.30	.11	<.004	.02	.03	.026	<.004	<.03	.005
			C2	.16	.76	.032	.036	.22	.14	.31	.11	<.004	.02	.03	.025	<.004	<.03	.005
	C8	256	C1	.16	.75	.033	.036	.24	.15	.30	.11	<.004	.02	.03	.027	<.004	<.03	.005
			C2	.15	.71	.030	.034	.22	.14	.28	.11	<.004	.02	.03	.025	<.004	<.03	.003
	C9	257	C1	.18	.78	.015	.037	.24	.16	.29	.098	<.004	.04	.03	.031	<.004	<.03	.005
			C2	.18	.79	.015	.037	.24	.16	.30	.098	<.004	.04	.03	.029	<.004	<.03	.005
5	C10	258	C1	.16	.83	.026	.043	.28	.094	.20	.10	<.004	.04	.05	.023	<.004	<.03	.004
			C2	.16	.85	.026	.041	.29	.094	.20	.10	<.004	.04	.05	.023	<.004	<.03	.004
	C10	259	C1	.16	.83	.027	.041	.30	.092	.20	.10	<.004	.04	.05	.021	<.004	<.03	.004
			C2	.16	.86	.026	.043	.31	.092	.19	.10	<.004	.04	.05	.021	<.004	<.03	.004
	C10	260	C1	.16	.82	.025	.041	.28	.092	.20	.10	<.004	.04	.05	.022	<.004	<.03	.005
			C2	.17	.82	.025	.041	.29	.090	.20	.10	<.004	.04	.05	.020	<.004	<.03	.004
	C11	261	C1	.16	.78	.013	.027	.31	.094	.22	.063	<.004	.02	.04	.019	<.004	<.03	.005
			C2	.16	.79	.013	.027	.32	.092	.23	.065	<.004	.02	.04	.017	<.004	<.03	.005
	C11	262	C1	.16	.79	.014	.026	.31	.090	.23	.063	<.004	.02	.04	.017	<.004	<.03	.005
			C2	.16	.79	.015	.026	.31	.093	.23	.062	<.004	.02	.04	.017	<.004	<.03	.004
	C11	263	C1	.16	.77	.014	.025	.29	.095	.23	.067	<.004	.02	.04	.017	<.004	<.03	.004
			C2	.17	.78	.013	.025	.30	.094	.22	.068	<.004	.02	.04	.019	<.004	<.03	.004
	C12	264	C1	.15	.72	.013	.031	.28	.098	.19	.065	<.004	.04	.04	.017	<.004	<.03	.004
			C2	.16	.68	.013	.030	.27	.098	.18	.064	<.004	.04	.04	.017	<.004	<.03	.004
	C12	265	C1	.17	.72	.015	.030	.28	.098	.18	.059	<.004	.04	.04	.016	<.004	<.03	.004
			C2	.17	.72	.016	.029	.28	.10	.18	.064	<.004	.04	.04	.018	<.004	<.03	.005
	C12	266	C1	.15	.70	.015	.030	.28	.098	.17	.065	<.004	.04	.04	.018	<.004	<.03	.005
			C2	.15	.71	.016	.028	.26	.096	.18	.060	<.004	.04	.04	.018	<.004	<.03	.005

(1) C1 and C2 are samples removed from edge and center of each plate respectively

* Spectrochemical Analysis

2' & 1' Pre-1956 ABS Steel

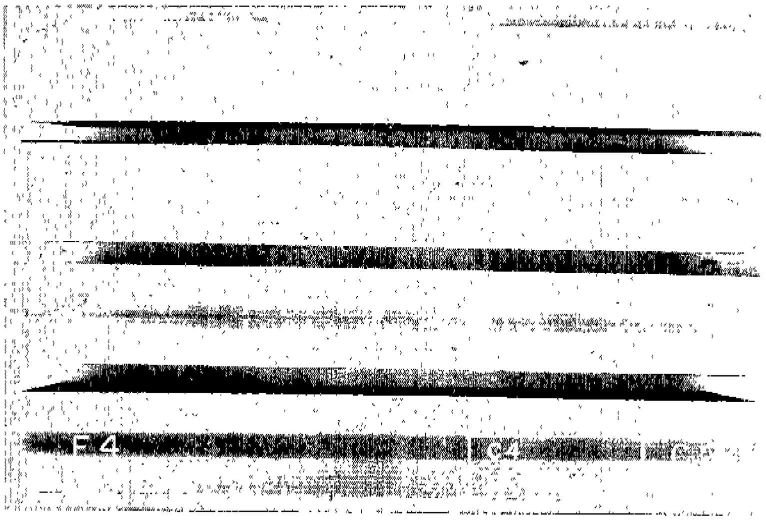


FIG. 5. SEGREGATION ZONES PRESENT IN 4 SELECTED CROSS SECTIONS REMOVED FROM PLATE NO. 211, OF ABS CLASS B STEEL. ETCH BLANK (E1) AT TOP IS FROM THE EDGE OF PLATE, AND ETCH BLANK (E4) AT BOTTOM IS FROM THE CENTER OF PLATE. CHEMICAL ANALYSIS MADE ON SECTIONS OUTLINED.

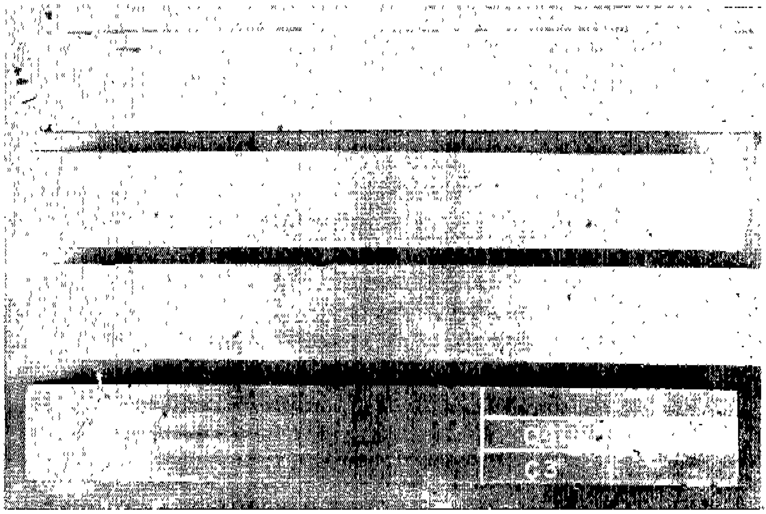


FIG. 6. INVERSE SEGREGATION OF ETCH BLANKS FROM 4 LOCATIONS ACROSS PLATE 207, OF ABS CLASS B STEEL. CROSS SECTION (E1) AT TOP IS FROM EDGE OF PLATE AND CROSS SECTION AT BOTTOM (E4) IS FROM CENTER OF PLATE. CHEMICAL ANALYSIS MADE ON SECTIONS OUTLINED.

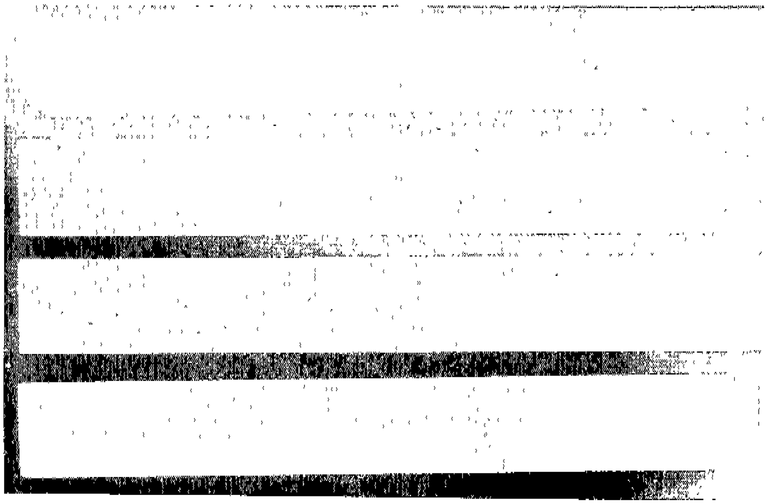


FIG. 7. SEGREGATION IN ETCH BLANKS FROM 4 LOCATIONS ACROSS PLATE 203 OF ABS CLASS B STEEL. THE ORIENTATION OF ETCH BLANKS SAME AS SHOWN IN PREVIOUS FIGURES.

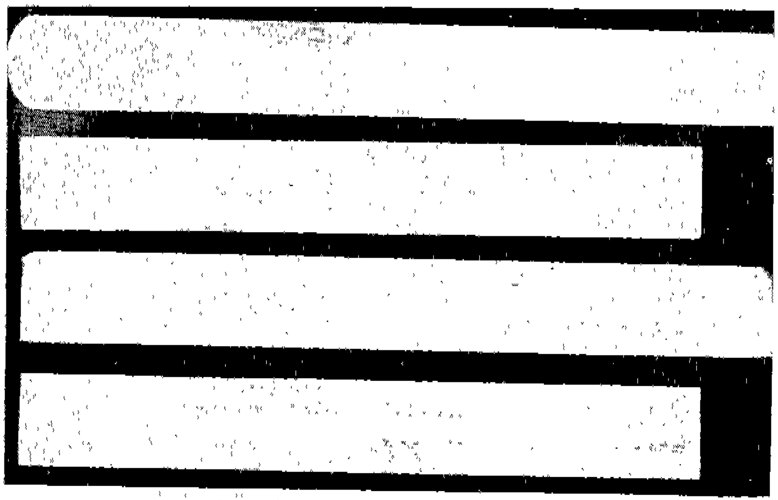


FIG. 8. SEGREGATION IS ETCH BLANKS FROM 4 LOCATIONS ACROSS PLATE 205 OF ABS CLASS B STEEL. THE ORIENTATION OF ETCH BLANKS SAME AS IN PREVIOUS FIGURES.

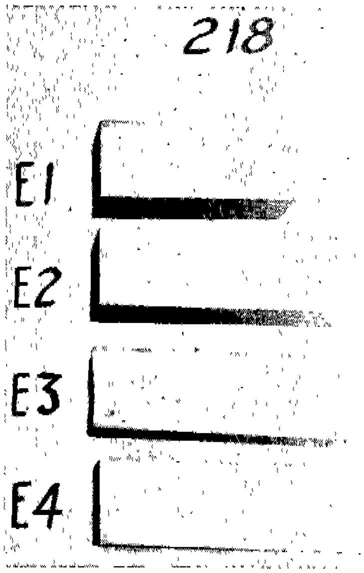


FIG. 9. CROSS SECTIONS OF ETCH BLANKS FROM 4 LOCATIONS ACROSS PLATE 218 OF ABS CLASS C STEEL (AS-ROLLED). THE ORIENTATION OF ETCH BLANKS SAME AS IN PREVIOUS FIGURES.

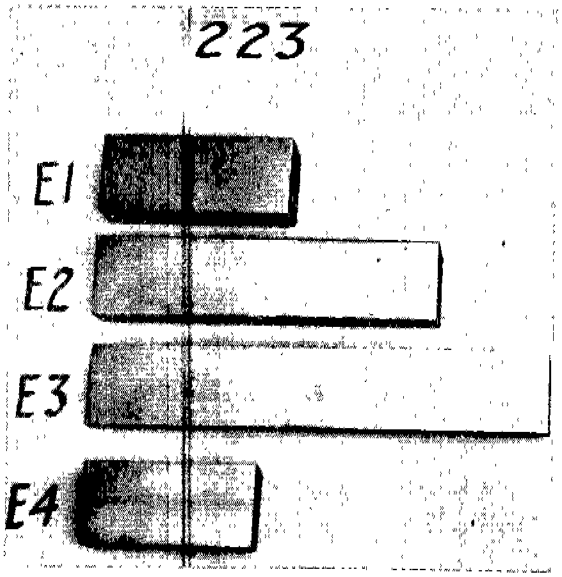


FIG. 10. CROSS SECTIONS OF ETCH BLANKS FROM 4 LOCATIONS ACROSS PLATE 223 OF ABS CLASS C STEEL (AS-ROLLED). SAME SEGREGATION IS VISIBLE IN ETCH BLANK E4. THE ORIENTATION OF ETCH BLANKS SAME AS IN PREVIOUS FIGURES.

that of the segregated zone located in the center of the plate thickness. Examples of segregation observed are illustrated in Figs. 5-10.

Metallographic Examination

Ferrite grain size measurements were made of every plate using the Heyn Intercept Method (ASTM Recommended Practice E89-52). In addition, a cross section of every plate from edge to center was etched in 5% Nital and examined visually to determine the extent of segregation. These etched blanks marked consecutively E1-E4 were adjacent to the Charpy impact blanks (Fig. 1) and consequently represented accurately the degree of segregation of these specimens.

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 fps. The Charpy bars were cut parallel to the rolling direction with the notches always cut perpendicular to the plate surface.

In the preliminary study a limited number of transverse impact specimens were also machined from blanks marked N5 and N6 located as shown in Fig. 1. The specimen dimensions were in accordance with the ASTM Specifications E23-47T for type A. All specimens were immersed in a bath prepared in the following manner for at least 20 minutes before testing:

for temperature above 40°F - a water bath cooled with chipped ice

for temperature below 40°F - a mixture of 50/50 glycol and water cooled with dry ice

for temperature below -30°F - a mixture of 50/50 CC14 and chloroform cooled with dry ice.

The temperatures were carefully controlled within ± 1 F. Tests were carried out at intervals of 10 F over a temperature range that included energy values from 10 to 50 ft-lb.

Typical Charpy energy curves are illustrated in Figs. 11 and 12. The transition temperatures were obtained by connecting the mid-points of the straight lines shown and then reading off the temperature values at the corresponding 15 and 25 ft-lb energy levels. The ability of this simple graphical connected point method to satisfactorily interpolate transition temperature was initially questioned but subsequent comparison of these results with the more statistically rigorous but time consuming fitted quad-

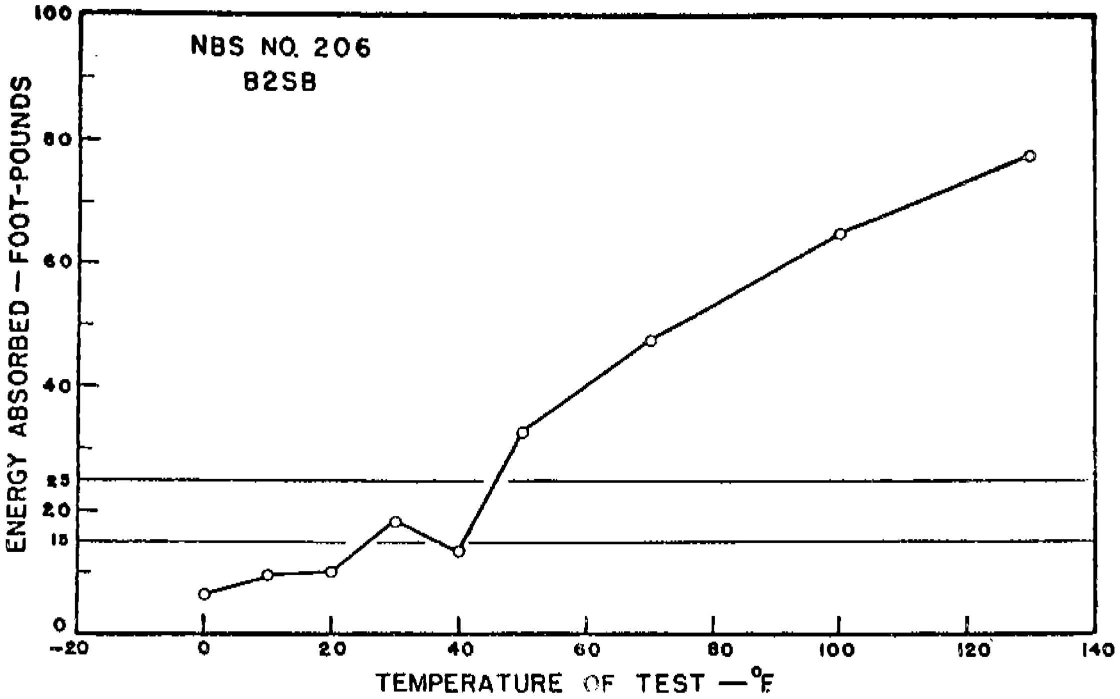


FIG. 11. CHARPY V-NOTCH IMPACT CURVE OF PLATE NO. 206, 3/4 IN. PRE-1956 ABS CLASS B STEEL. AVERAGE OF AT LEAST 3 SPECIMENS AT EACH TEST TEMPERATURE.

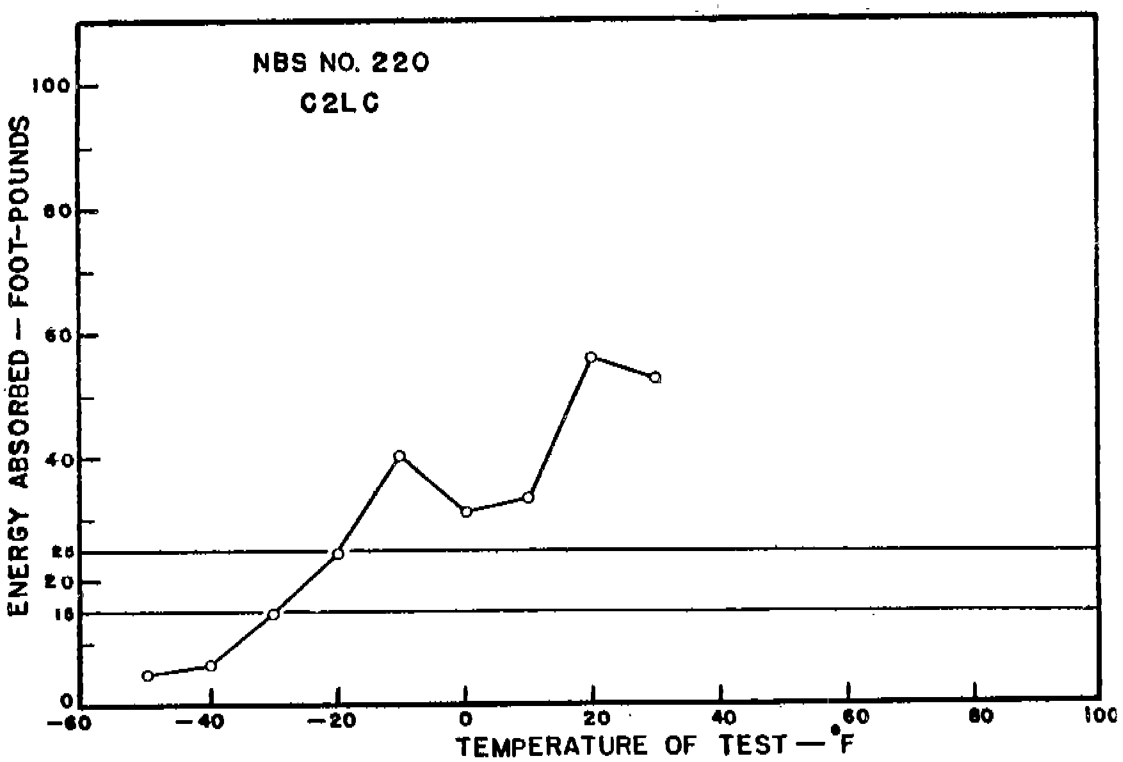


FIG. 12. CHARPY V-NOTCH IMPACT CURVE OF PLATE NO. 220, 1 1/4 IN. ABS CLASS C STEEL (AS-ROLLED). AVERAGE OF 4 SPECIMENS AT EACH TEST TEMPERATURE.

ratic method indicated such good agreement that this technique was used throughout the Charpy test program.

Full Plate Thickness Test for Notch Toughness Properties

Through the cooperation of the Naval Research Laboratory and the New York Naval Shipyard, full plate thickness tests also were performed. They represented two widely known but different test methods namely, drop-weight crack starter tests and the van der Veen notched slow bend test.

In the initial phase of this investigation the drop-weight blanks were located as shown in Fig. 1, but with the introduction of the van der Veen tests in the second phase of this work the drop-weight blanks were all located along the plate edge as shown in Fig. 3.

A detailed description of the procedures for performing drop-weight tests have been previously reported in the literature.[3-5] Briefly, this particular test evaluates the behavior of a test blank in bending in the presence of a very sharp notch originating in a weld bead previously deposited on the plate surface. When a weight is dropped from a given height, the specimens susceptibility toward brittleness is determined by the extent to which it deforms plastically in bending without fracturing completely. The Naval Research Laboratory's nil ductility transition temperature (NDT) as presented in this report is defined as the highest temperature at which a brittle fracture will occur i.e., no significant amount of plastic deformation will develop at or below the stated NDT temperature in the presence of a sharp notch.

The New York Naval Shipyard evaluated the toughness performance of a limited number of steel plates and reported the results in terms of a fracture appearance transition temperature. The VDV transition temperature is directly related to the depth of fibrous area developed beneath a previously pressed-in notch. As reported,[6,7] the intersection of the 32 mm line with the resultant depth of fibrous vs. temperature curve defines the fracture transition temperature. The test blank is 2 3/4 in. by 9 in., with the larger dimension taken perpendicular to the rolling direction.

DISCUSSION OF EXPERIMENTAL RESULTS

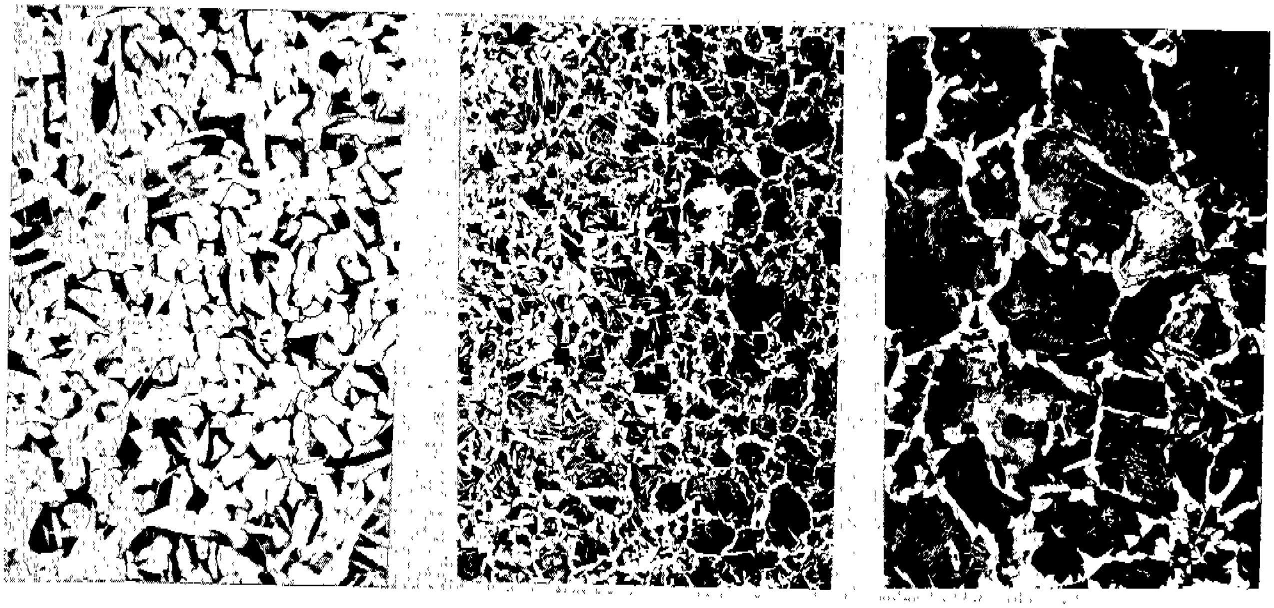
Tensile Properties

Every plate satisfied the ABS per cent elongation requirement and most conformed to the specified limits for yield point and tensile strength. The following table indicates the proportion of the steel samples failing to comply with these latter requirements:

Steel	Mill	Number of Plates	Not Passing	Per Cent
Class B (pre-1956)	1'	17	3	18
Class B (current)	1, 2, 3	39	2	5
Class C (pre-1956)	2'	12	9	75
Class C (current)	1, 2, 4, 5	37	2	5

The high proportion of pre-1956 Class C steels failing to meet the ABS tensile requirements is partly attributable to their lower average carbon level and probably to the relatively low cross-head speeds that were used, each of which can have a measurable effect. The deviations from acceptable limits for these nine plates ranged from about 2 to 10%, whereas the remainder registered departures of less than 2%.

The widest spread in properties were found to occur in the Class B steels, notably producer 1 (pre-1956 steel) where the extremes in macrosegregation were also observed. The highest yield point and tensile strength with a corresponding low per cent elongation was exhibited by plate No. 211. The deviations from the mill averages were 16, 13 and 27% respectively. The explanation for this was found in the relatively high carbon content of the dark zone (Fig. 5) located in the center of the plate thickness. Chemical analysis of this zone, the microstructure of which is more clearly seen in Fig. 13, indicated an average carbon level of 0.40% in contrast to 0.20% for the remaining cross section of normal carbon content. The inverse condition is shown by Fig. 6 and also emphasized in Fig. 14 of plate 207. Here the

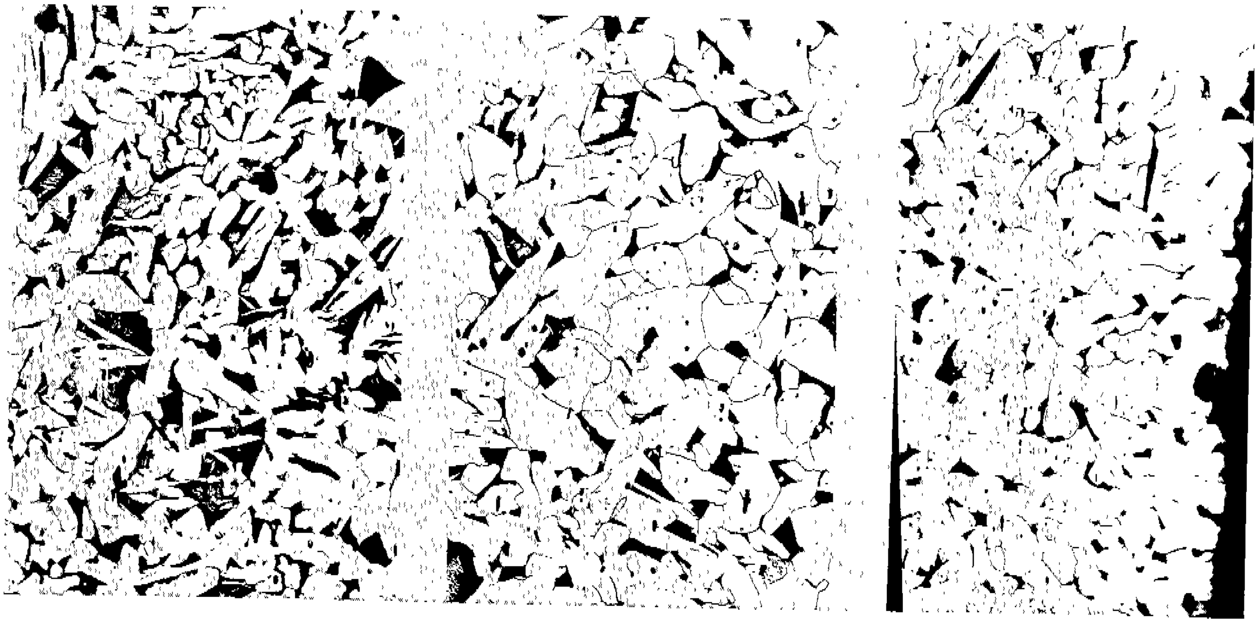


a) Normal carbon content. X 250

b) Boundary between normal and segregated areas. X 100

c) Segregated area. X 250

FIG. 13. PHOTOMICROGRAPHS REPRESENTING THE CROSS SECTION OF PLATE 211 (FIG. 5). X 1/2



a) Area near plate surface. X 250

b) Area of negative segregation. X 250

c) Normal carbon content. X 250

FIG. 14. PHOTOMICROGRAPHS REPRESENTING THE CROSS SECTION OF PLATE 207 (FIG. 6). X 1/2

central zone etched out light in appearance with a corresponding average carbon content of 0.12% compared to the parent metal of 0.19%. Hardness measurements made on these areas of segregation and compared with the values obtained on adjacent areas of normal carbon content are reported below:

Plate	Segregated Zone		Zone of Normal Carbon Content	
	%C	R_B	%C	R_B
207	.12	56	.19	68
211	.40	92	.20	71

The largest differences occurred between the two different types of segregation with little variation noted in the two zones representing normal carbon levels. While various shades of these two extreme conditions were observed in other plates of Class B quality, none ever developed appearances which exceeded those just described. No similar situation was observed in the Class C material.

In general, the tensile properties of currently produced steels were not considered to be materially effected by segregation except in those few cases (particularly pre-1956 Class B steel) where this heterogeneous condition was exceptionally severe.

Segregation

Segregation is an inherent feature of differential solidification and therefore its occurrence cannot be prevented but to some extent this undesirable condition can be controlled. This problem has received the attention of many investigators both from the point of view of the basic mechanism involved as well as obtaining information which could be directed towards improving the quality of the final steel product. Some of these studies[7-12] have indicated that the majority of elements do segregate to some extent and will usually be located in the same general area of the poured ingot. The present study supports this view to the extent that a relationship between different levels in an ingot and macrosegregation was observed. The following table summarizes this relationship:

Steel	Plate Location	Total Plates	Plates Segregated	Per Cent of Total
B	T	19	18	95
B	C	20	19	95
B	B	17	5	29
		56	42	
C	T	16	12	75
C	C	16	10	63
C	B	17	2	12
		49	24	

The marked susceptibility of top and center plates toward segregation is in general agreement with previous metallurgical experience. In most cases, segregation became most noticeable in the two etch blanks (E3 and E4, Figs. 1, 5, 6) nearest the plate center regardless of the appearance of the zone.

Examination of the etched cross sections of all plates exhibiting segregation indicated that the different types observed can be represented reasonably well by the five macrophotographs of Figs. 5-8 and 10 mentioned previously. By classifying the appearance of each segregated plate's cross section under one of these five general types the following table was prepared

Steel	Plate Location	Plates Segregation	Type of Segregation Observed				
			Figure 5	Figure 6	Figure 7	Figure 8	Figure 10
B	T	18	2	3	4	9	0
B	C	19	1	0	8	10	0
B	B	5	0	1	1	1	2
		42	3	4	13	20	2
C	T	12	0	0	5	3	4
C	C	10	0	0	4	4	2
C	B	2	0	0	1	0	1
		24	0	0	10	7	7

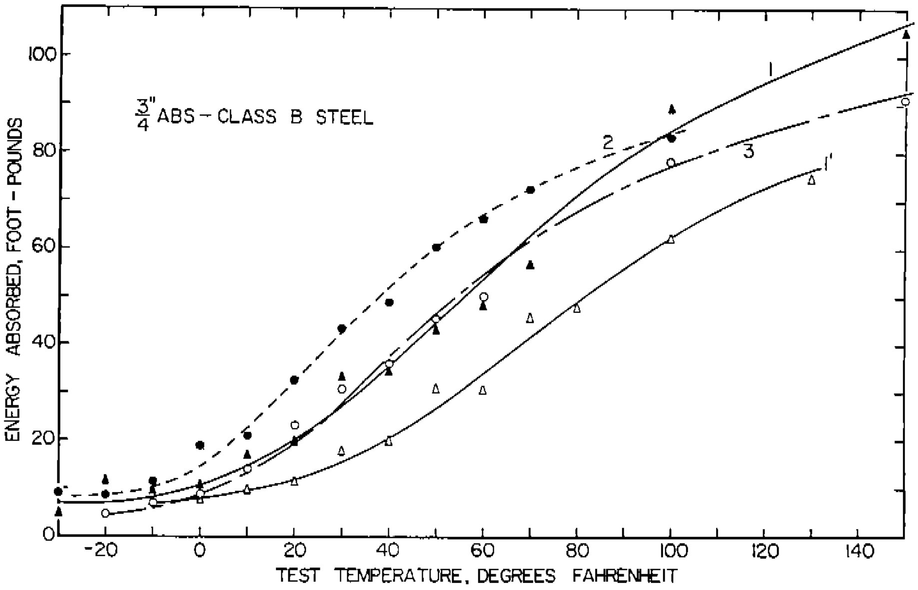


FIG. 15. CHARPY V-NOTCH IMPACT RESULTS OF 3/4 IN. ABS CLASS B STEEL FOR DIFFERENT MANUFACTURERS.

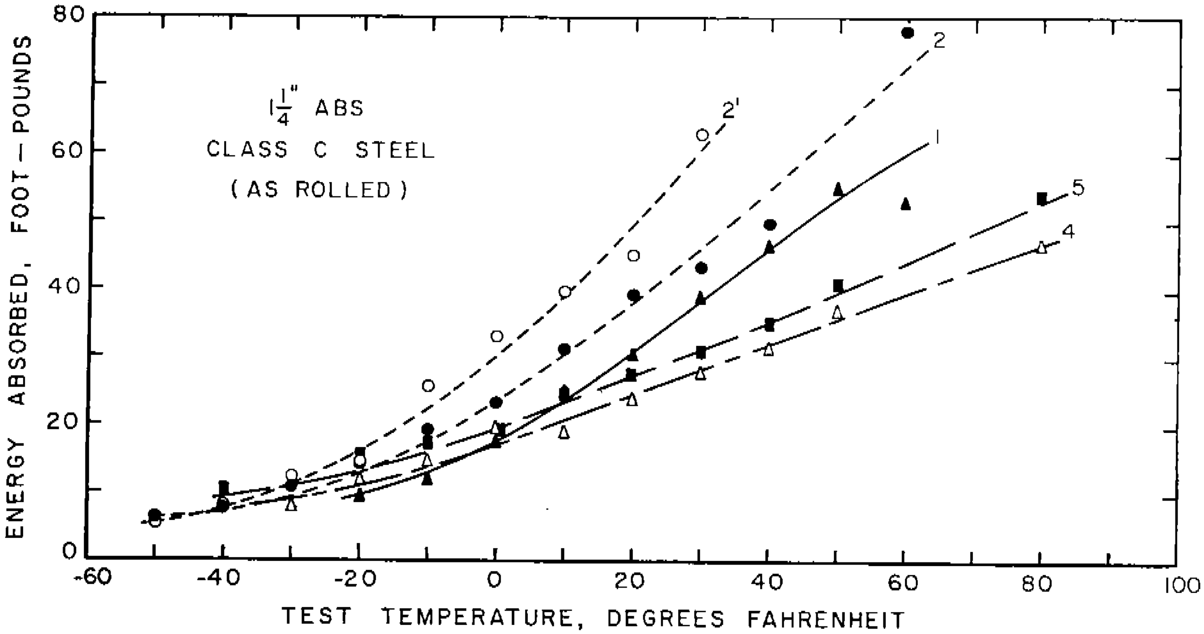


FIG. 16. CHARPY V-NOTCH IMPACT RESULTS OF 1 1/4 IN. ABS CLASS C STEEL (AS-ROLLED) FOR DIFFERENT MANUFACTURERS.

These results indicate that the majority of segregated plates exhibited cross sections which closely resembled the etched surfaces of Figs. 7 and 8. In the case of the Class C steel, a good proportion of the plates also displayed a surface condition very similar to the one shown in Fig. 10.

Though recognizing the importance of segregation on steel quality, it was decided early in this investigation, to defer any detailed study of this problem to a later date, after it became evident that Charpy V-notch bar properties were sensitive to the extent and type of segregation present in the plate.

Notch Toughness

Charpy Impact Test (longitudinal). The Charpy V-notch data provided the primary source of information used in evaluating and interpreting the toughness characteristics of these steels. The general performance of both grades of steel on an individual mill basis is graphically summarized in Figs. 15 and 16. The variety of slopes assumed by the individual Charpy curves in Fig. 16 is attributable in large part to the substantially different mill practices represented in this graph. Figure 17 gives the distribution of T_V-15 values for both grades of steel made to current ABS requirements. For the Class C steel the distribution is approximately normal, however, for the Class B steel the curve is incomplete. The lower portion of the latter curve is almost entirely represented by a single producer. Obviously a much larger sampling is required if an accurate description of the B steel distribution is to be obtained.

The relationship between energy absorption and fracture appearance at a particular temperature is presented in Fig. 18. Although the tensile strengths were about the same, significant differences in performance are exhibited by the steels made to pre-1956 requirements compared to current ABS Rules.

Based on a Charpy V transition temperature at the 15 ft-lb level the overall quality of each class of steel is presented in terms of a mean and

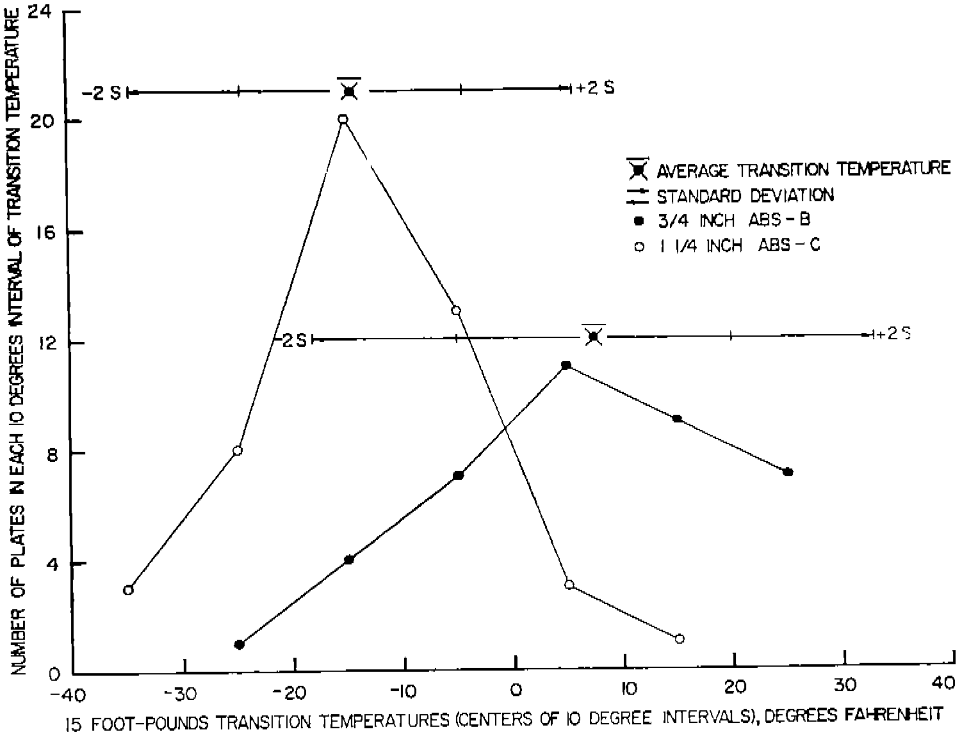


FIG. 17. DISTRIBUTION OF TRANSITION TEMPERATURE OF CURRENTLY PRODUCED 3/4 IN. ABS-B AND 1 1/4 IN. ABS-C (AS-ROLLED) STEELS.

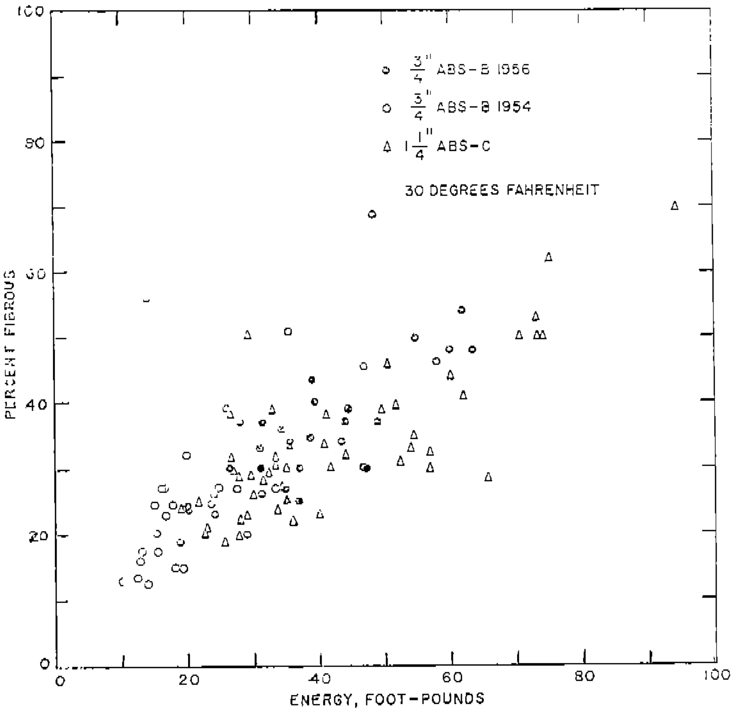


FIG. 18. CORRELATION OF CHARPY V-ENERGY ABSORPTION AND CHARPY V-FRACTURE APPEARANCE AT 30 F.

standard deviation:

Steel (Current)	Mill	Heats	T_V-15 (°F)		
			n	$\bar{x}$	sd*
3/4 in. ABS-B	1, 2, 3	13	39	6.7	12.8
1 1/4 in. ABS-C (as-rolled)	1, 2, 4, 5	15	49	-14.3	10.0
(pre-1956)					
3/4 in. ABS-B	1	3	17	28.9	7.4

---

*Standard deviation is a measure of dispersion and depending on whether sd is low or high the corresponding scatter is small or large.

The relatively lower scatter revealed by Mill 1 (pre-1956 steel) can be explained by the fact that usually within an individual producer the processing variables were found to be very uniform whereas appreciable differences were observed between the various mills. The standard deviation for the current steels is the product of samples from three different sources, consequently its higher dispersion is not unusual.

The relationship between energy absorption and specimen locations across a plate is demonstrated in Figs. 19 and 20. These impact curves, established for the two top plates discussed previously, display the extremes in segregation. It is readily evident that depending on the kind of segregation encountered (see Figs. 5 and 6) the specimens nearest the center of the plate width will, on the average, absorb either more or less energy than those adjacent to the edge. It is precisely for this reason that the previously mentioned specimen selection scheme was designed.

From the point of view of Charpy energy it would seem reasonable to expect a more uniform behavior in the Class C steels compared to the Class B steels since the latter exhibited appreciably more segregation. However, an analysis of the Charpy data for all the samples of both grades of steel does not support this view. Normalizing the data for comparison purposes, these results are presented graphically in Figs. 21 and 22. In Fig. 21, the overall

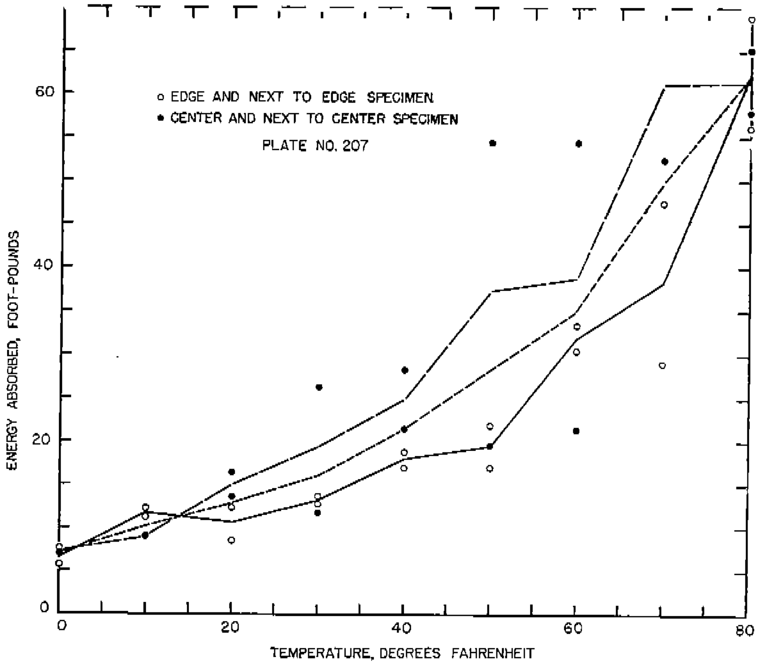


FIG. 19. INFLUENCE OF SPECIMEN LOCATION IN PLATE NO. 207 ON CHARPY V-ENERGY ABSORPTION.

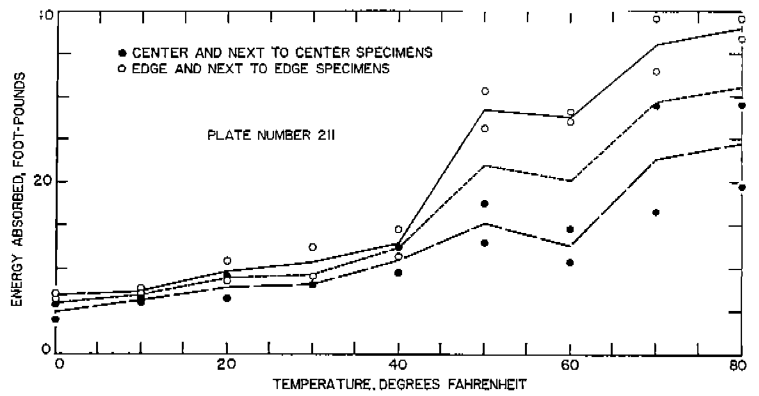


FIG. 20. INFLUENCE OF SPECIMEN LOCATION IN PLATE NO. 211 ON CHARPY V-ENERGY ABSORPTION.

scatter appears to be about the same for all three mills but in Fig. 22 the scatter in energy absorption is significantly different for each mill.

A limited metallographic study of these Class C steels did not result in any information that would satisfactorily explain this abnormal behavior. It will be noted however, that the lower two curves represent mills of substantially lower production capacity than the upper two mills and of markedly different practices.

Charpy Impact (transverse): During the early phase of this work, some transverse impact tests were made involving 24 steel samples equally divided between both classes of steel representing only pre-1956 practice. The Charpy V transition temperatures thus determined are compared below with the values for the longitudinally oriented Charpy bars:

	3/4 in. ABS-B			1 1/4 in. ABS-C		
(°F)	Long.	Transverse	Difference	Long.	Transverse	Difference
$T_V 15$	29.1	45.5	16.4	-18.9	13.4	32.3
$T_V 25$	46.1	79.8	33.7	- 6.4	54.5	60.9

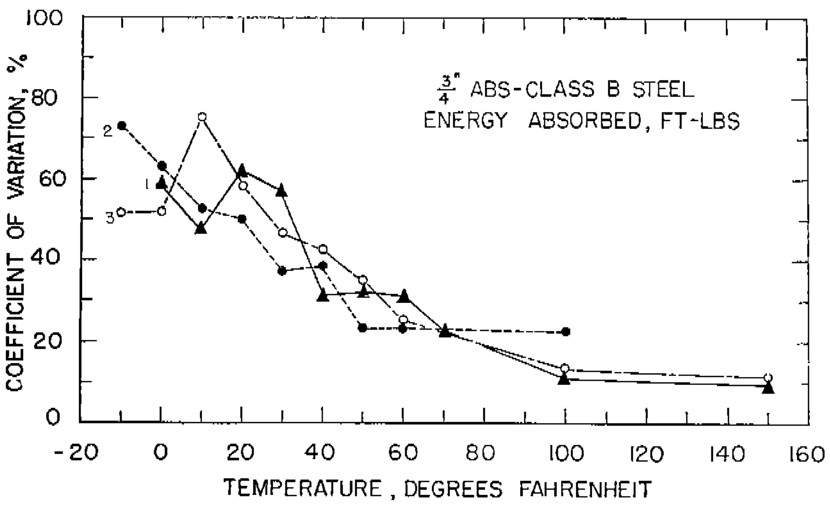


FIG. 21. DISPERSION OF CHARPY V-ENERGY WITH TEMPERATURE OF 3/4 IN. ABS-CLASS B STEELS.

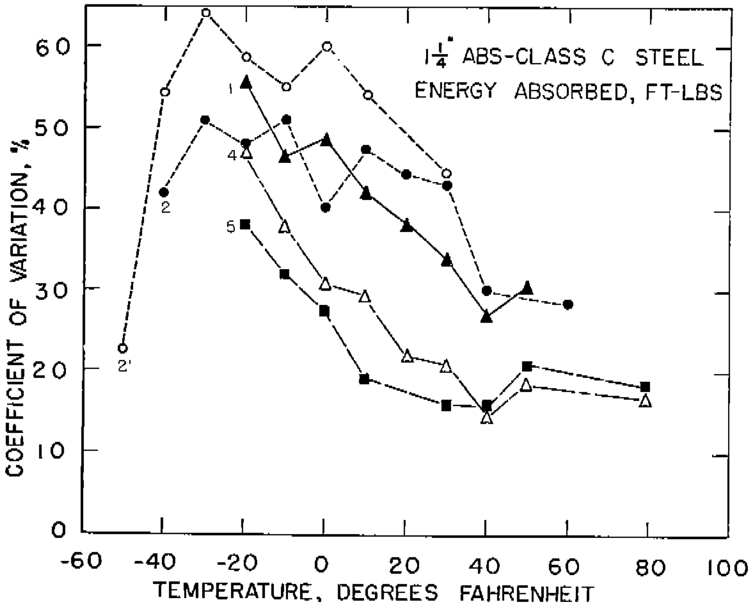


FIG. 22. DISPERSION OF CHARPY V-ENERGY WITH TEMPERATURE OF 1 1/4 IN. ABS-CLASS C STEELS.

The transverse transitions for both grades of steel are decidedly higher with the largest deviations observed for the Class C steels.

Drop-Weight Tests: The Naval Research Laboratory reported drop-weight transitions (Table 4) on 47 of the 56 B samples and 37 of 49 C samples. These results are summarized in the following table together with the corresponding Charpy energy values:

Mill	Class	No. of Plates	NDT (°F)		Charpy Energy at NDT Temp. (ft-lb)	
			Edge	Center	Edge	Center
1'	B	17	4	5	9	9
1	B	9	- 2	-	11	-
2	B	6	-12	-12	13	12
3	B	15	- 3	- 7*	9	7*
		30	- 5	-10	11	10
2'	C	12	20	20	38	38
1'	C	9	20	17	31	28
4	C	7	9	0	20	17
5	C	9	- 4	- 7	19	19
		25	8	3	23	21

1' and 2' - pre-1956 steel.
*Represents only 6 steel samples.

The results indicate that at the NDT transition the average Charpy V-impact energy for edge and center are 10 and 22 ft-lbs for the B and C steels respectively. An analysis of the NRL data permits the following observations:

1. No correlation across the plate width was noted for the B steel but in 20% of the C steels differences larger than 10 F were observed between edge and center regions.

2. Only relatively small variations in NDT values were noted for both grades of steel although the variation was slightly larger for the C material.

3. The remarkable consistency of NDT transitions generally observed within each mill is largely attributed to the marked uniformity in chemistry and mill practices employed.

4. The NDT values were about the same for the two grades of steel.

Table 6

VAN DER VEEN Fracture Transition Temperature (32 mm)

Mfg.	Class	No.	$\bar{x}$ °F	Std. Deviation
1*	ABS-B	6	73.5	13.9
1	ABS-B	9	74.3	32.9
2	ABS-B	9	63.7	16.8
3	ABS-B	9	51.5	20.7
	(exclude 1*)	27	63.4	25.2
2*	ABS-C	6	48.8	10.2
2	ABS-C	12	41.1	23.8

---

*Pre-1956 steel.

Van der Veen Notched Slow Bend Tests The fracture transition temperatures based on the 32 mm fibrous depth below the notch are summarized in Table 6 for the individual producers. These results indicate about the same level of improvement of the fully killed steel to the semi-killed as did the Charpy V transition data reported earlier. The degree of improvement is approximately 20 F. An analysis of the VDV data failed to indicate any consistent correlations with ingot and plate location or mill practice variables. A graphical plot of the test data relating two different fracture transitions is shown in Fig. 23.

STATISTICAL ANALYSIS OF DATA

Influence of Mill Processing Variables on Notch Bar Toughness

As explained earlier the interpretation of the test results were based largely on the Charpy V impact data that were accumulated although several other notch toughness parameters (NDT and VDV transitions) were also included in this analysis.

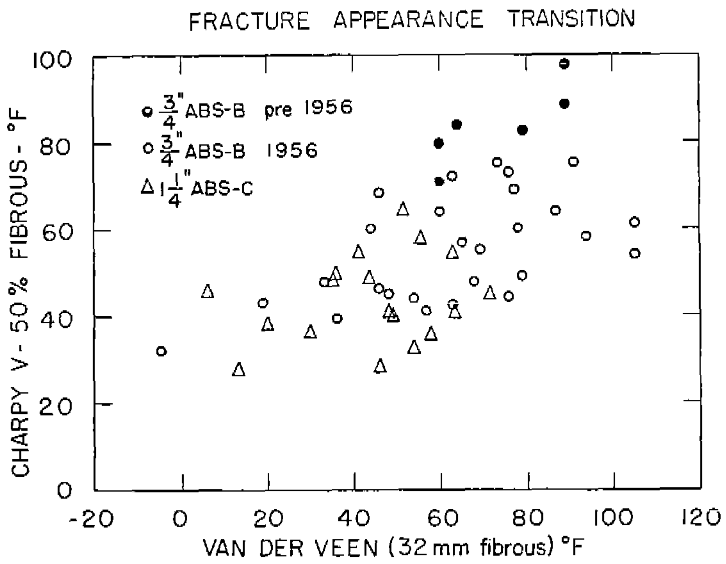


FIG. 23. CORRELATION OF FRACTURE TRANSITION TEMPERATURES FOR CHARPY V AND VAN DER VEEN NOTCHED SLOW BEND TEST.

At several stages in this investigation, the possibility of determining the relationship between a number of the more important mill practice variables and toughness performance was explored although this was not considered to be the primary objective. Previous attempts to detect the effects of such factors as finishing temperature, grain size, carbon, manganese, phosphorus and silicon proved fruitless. In order to complete this phase of work a final study was made with the restriction that only data representing currently produced steels would be analyzed.

The independent variables selected for study were finishing temperature, carbon, manganese, phosphorus, silicon, sulfur and aluminum. Ferrite grain size data was omitted because its variation within individual mills was usually less than one ASTM grain size number and statistically never appeared to be significant. The calculated regression equations for predicting Charpy V transition temperature as a linear function of mill processing variables are listed in Tables 7 and 8. A study of these coefficients and the standard errors associated with them indicates that these equations are not quantitatively meaningful, although in some cases individual coefficients appear to be statistically important. The negligible effects observed for the very important elements carbon and silicon is interpreted to mean that their separate effects could not be statistically ascertained owing to the narrowness of their variation within individual mills. Manganese and sulfur show up as important for both steels but the pronounced effect of the latter is puzzling because its range in variations is in the order of thousands of one per cent and its content was always less than .05%. Previous studies[14] on laboratory heats indicated that sulfur contents up

Table 7

Regression Coefficients Fitted to Elements and Finishing Temperature for 3/4 in. ABS B Steel

	T_V 15		T_V 25	
	Coefficient	sd	Coefficient	sd
Constant	+ 106.7	49	93.4	5.3
Finishing Temperature (per 100 F)	+ 5.7**	2.1	5.41**	2.2
Carbon (per 1%)	- 53.7	110	37.5	118
Manganese	- 144.9*	28	- 143.0*	30
Phosphorus	-1440	1025	- 386.6	1110
Silicon	71.5	82	35.6	88
Sulfur	-1186**	453	-1043.7**	486
Aluminum	- 463	413	- 432	443
Standard Deviation about fitted line		8.39		9.01

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*Significant at 1% level
**Significant at 5% level

Table 8

Regression Coefficients Fitted to Elements and Finishing Temperature for 1 1/4 in. ABS C Steel (as-rolled)

	T_V 15		T_V 25	
	Coefficient	sd	Coefficient	sd
Constant	+ 17.5	24	+ 19.3	25
Finishing Temperature (per 100 F)	+ 1.2	0.86	- 0.8	0.88
Carbon (per 1%)	+ 47.2	86	+ 105.2	88
Manganese	- 80.7***	42	- 81.1***	43
Phosphorus	+400.4	242	+ 327	247
Silicon	- 84.6***	47	+ 98.8***	48
Sulfur	+889.9*	314	+1008*	320
Aluminum	-298.3**	114	- 294.8**	116
Standard Deviation about fitted line		7.49		7.66

---

*Significant at 1% level
**Significant at 5% level
***Significant at 10% level

to .06% did not significantly effect Charpy transition temperature. Finishing temperature appeared important only in the B steel whereas aluminum registered a significant effect only on the C steel.

From these results very little information of a quantitative nature can be gleaned. The difficulty stems partly from the very narrow range in composition that was prevalent and partly to the limited sampling that was involved in this analysis. In addition, the assumption that the separate effects behaved linearly and were completely independent of each other was not necessarily correct, and hence may also have contributed in producing the spurious results.

Variation Within Plates

To assess the spread in Charpy V bar properties across the plate width an analysis was made on 39 plates of B steel and 49 plates of C steel. Each plate was divided into four regions; namely: edge, next to edge, next to center and center, represented by test blanks N1, N2, N3 and N4, Fig. 1. Each region supplied one impact specimen for each test temperature that was common to all plates from one mill (usually 5 to 7 temperatures at 10 F intervals). The sum of the energies absorbed for these specimens was used to characterize each of the four plate locations. An analysis of variance was performed and it was concluded that there was no consistent correlation between the capacity for energy absorption and location of specimens in the plate, although in individual cases marked variation in Charpy V properties was observed.

Variation Between Plates, Ingots and Heats

The degree of variation existing among different levels within an ingot, between different ingots within a heat and between the various heats from a given mill was examined.

For the C steel, 24 samples representing 6 heats, 3 ingot locations and 3 plate positions were used in the analysis. Mill 2 was the only mill that provided a sufficient number of samples suitably arranged to permit such a study. It was concluded that differences between heats constituted the primary source of variation and that plate positions and ingot locations were not statistically important.

A similar analysis was performed on 15 plates of B steel from the same producer, however, in this instance, coefficients were fitted only to the heat and plate classifications because several of the heats were represented by a single ingot category and thus did not permit the statistical separation of the ingot effect from the heat effect. The results indicated that variations between heats and between plates were significant. Previously, it was shown on pre-1956 B steel[2] that ingot variation was markedly less than either plate or heat variations.

The relationship between Charpy V transition and plate location is graphically summarized in Figs. 24 and 25. The mean T_V-15 value and estimated standard deviation are plotted for the various plate positions within each producer. For the B steel the bottom plates appear to exhibit higher average Charpy V transitions than either the top or center positions. Compared to the bottom plates, the largest dispersion in results is associated with the top plates. No trend was noted for the C steel. Although these observations are based on a relatively small sampling, the graphical evidence appears convincing.

Sampling

The previous sections have indicated where the most important variations in properties develop. For both grades of steel, heat differences are the principle source of variation although plate positions assume equal importance for the B steel. In both cases however, the evidence indicates that the effect of ingot locations can be considered negligible.

An estimate of the spread in Charpy V transition within individual heats for each grade of steel is calculated to be:

	n	df*	sd
ABS-B	39	26	7.44 F
ABS-C	49	34	6.62 F

*Degrees of Freedom

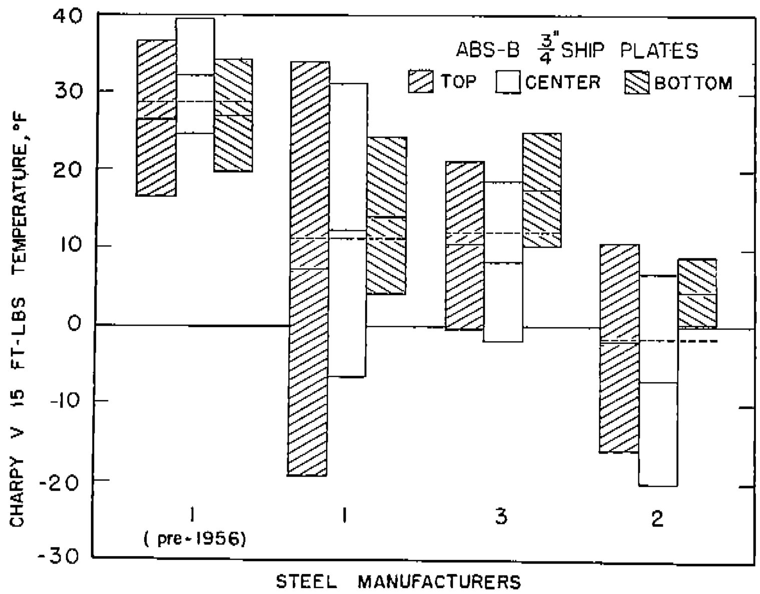

FIG. 24. DISPERSION OF TRANSITION TEMPERATURES FOR DIFFERENT PLATE POSITIONS OF 3/4 IN. ABS-B STEELS IN TERMS OF A MEAN AND ONE STANDARD DEVIATION. THE DASHED LINE REPRESENTS AVERAGE OF ALL PLATES OF AN INDIVIDUAL PRODUCER.

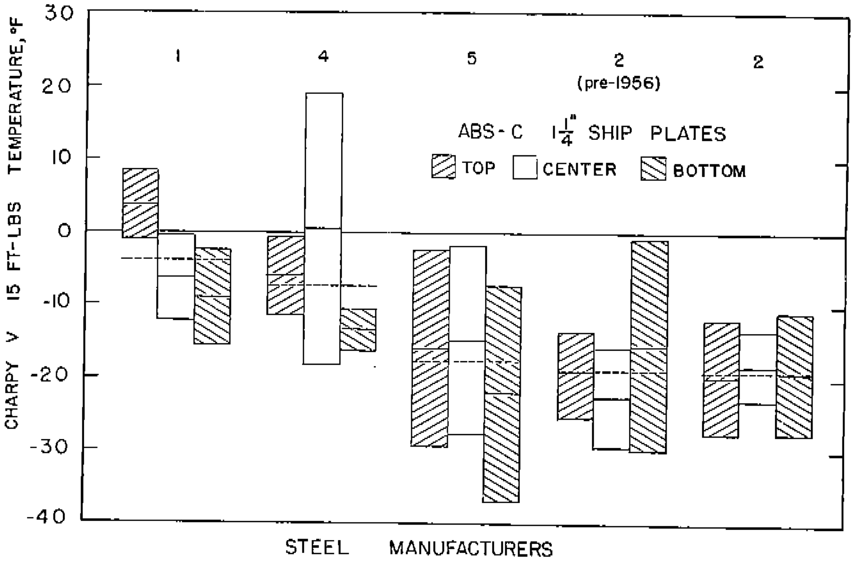

FIG. 25. DISPERSION OF TRANSITION TEMPERATURES FOR DIFFERENT PLATE POSITIONS OF 1 1/4 IN. ABS-C STEELS (AS-ROLLED) IN TERMS OF A MEAN AND ONE STANDARD DEVIATION. THE DASHED LINE REPRESENTS AVERAGE OF ALL PLATES WITHIN AN INDIVIDUAL PRODUCER.

These figures represent the estimated average for all the heats without regard to manufacturer. Consequently, they are more likely to be representative of the producer having the largest number of heats. By assuming a normal distribution and testing four impact specimens per temperature, the 95% confidence levels for a random sampling of four plates from a single heat are:

$$\text{ABS-B} \pm 2.056\,(7.44/\sqrt{4}) = \pm 7.65\text{ F}$$

$$\text{ABS-C} \pm 2.034\,(6.62/\sqrt{4}) = \pm 6.73\text{ F}$$

By placing these limits about the mean of four samples we should expect to find that 95% of the time this spread will include the grand average for the entire heat if all the plates had actually been tested.

Assuming that the analysis of the data has satisfactorily represented the behavior of the current production steels, no distinction as to plates or ingots need be given for the sampling of C steel except that it be done in a random fashion.

For the B steel the data indicates that the bottom plates will provide a reasonably stable Charpy V transition value but will be biased on the high side by about 4 to 5 F from the mean of a heat. If interest is centered on the spread in transition temperature values then samples selected from tops of ingots are to be preferred because of their more erratic behavior resulting in a much larger dispersion of results.

SUMMARY AND CONCLUSIONS

The principle objective of this study was to investigate currently produced 3/4-in. ABS-B and 1-1/4-in. ABS-C ship plate steel as obtained from mills in order to determine its notch toughness and to evaluate those mill factors that may significantly influence this property.

The generally stable character of these steels in terms of mechanical properties is largely attributed to the remarkable uniformity in mill practices as revealed by the data sheets of each manufacturer. It was this uniformity that rendered statistical treatment of the data ineffective for determining the separate effects of mill variables on toughness quality. However, much information has been obtained and an analysis of the results does permit the following conclusions to be made:

1. The mill practices associated with each manufacturer reflected very close control.

2. As a consequence of this marked uniformity, it was not possible to determine the extent to which processing variables influence notch toughness performance.

3. The negative findings of the regression analysis do not refute any previous results regarding the influence of mill factors inasmuch as interactions and non-linearity of behavior can blot out specific effects.

4. Ninety-two per cent of the plates exhibited static tensile variations of less than 8% from their mill averages.

5. Macrosegregation was observed in both grades of steel. However, the extremes of this condition were confined to the Class B steel.

6. Ninety-five per cent of the top and center plates of ABS-B steel showed segregation compared to 29% of the bottom plates, more than half of which exhibited only an extremely faint zone.

7. Seventy-five per cent and 62% of the top and center plates of C steel were segregated compared to 12% of the bottom plates. However, all zones were extremely faint and difficult to define.

8. In the majority of plates the two etch blanks nearest the center of the plate width exhibited the most pronounced segregation regardless of its type.

9. The effect of carbon segregation on Charpy V bar properties was significant.

10. No consistent correlation was found between Charpy V behavior and location of specimens in the plate although in individual cases pronounced variation in properties was observed.

11. A statistical analysis of 24 samples of Class C steel indicates that differences between heats constitute the primary source of variation and that no particular significance should be attached to ingot or plate locations.

12. A similar analysis performed on 15 plates of B steel indicated that variations between heats as well as plates were equally important.

13. Bottom plates of B steel display slightly higher T_V-15 values than either top or center plates but the largest dispersions were associated with the top plate positions. No trend was noted for the Class C steel.

14. The mean and standard deviation of T_V-15 in degress Fahrenheit for each grade of steel made to current ABS Rules are:

	$\bar{x}$ °F	sd	n
3/4 in. ABS-B	6.7	12.8	39
1 1/4 in. ABS-C	-14.3	10.0	49

15. The average Charpy V-notch notch toughness performance for a given heat of C steel can be established by random sampling, selecting a few plates at random without regard to ingot location or plate positions.

16. The Charpy V-notch toughness performance for a given heat of B steel cannot be adequately established by random sampling since bottom plates reflect a conservative estimate of transition temperature (T_V15) which is about 4 to 5 F above the mean for a given heat. For an indication in the spread in Charpy bar properties, a larger sampling of the erratic top plates will be required.

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APPENDIX I

SAMPLING AND STATISTICAL TECHNIQUES

A basic plate sampling plan was designed by Dr. Youden to obtain information on the:

a) variation of properties between plates from the same ingot

b) variation of properties between ingots from the same heat

c) variation of properties between ingots from different heat.

The following 12 plates underlined for each grade of steel and reported in Ref. 2 was employed in the initial phase of this investigation.

	S Ingot	M Ingot	L Ingot
Heat 1	$\underline{T}$ $\underline{C}$ B	$\underline{T}$ $\overset{*}{C}$ $\underline{B}$	$\overset{*}{T}$ C B
Heat 2	$\overset{*}{T}$ $\underline{C}$ $\underline{B}$	T $\overset{*}{C}$ B	$\underline{T}$ $\underline{C}$ B
Heat 3	T C B	T $\underline{C}$ $\underline{B}$	$\underline{T}$ $\overset{*}{C}$ $\underline{B}$

*Indicates a second sampling for the 3/4 in. ABS-B steel.

This selection made it possible to compare heats using plates from similar ingots and positions in the ingot and also to compare ingots from different parts of the same heat using plates from identical positions in the ingots.

A further study indicated that subsequent computations could be simplified by designating a different subset of 12 plates all of which enter into just two comparisons. This symmetry also simplified the statistical analysis. The revised selection of 12 plates underlined below is recommended for future work:

	S Ingot	M Ingot	L Ingot
Heat 1	$\underline{T}$ $\underline{C}$ B	$\underline{T}$ C $\underline{B}$	T C B
Heat 2	T C B	T $\underline{C}$ $\underline{B}$	$\underline{T}$ $\underline{C}$ B
Heat 3	T $\underline{C}$ $\underline{B}$	T C B	$\underline{T}$ C $\underline{B}$

Based on the information obtained from the previously described sampling scheme, a supplementary sampling program was followed in the second phase of this experimental program in order to augment the earlier findings. These additional samplings are described below for both grades of steel.

Class B Steel: From each of three heats (A, B and C), three plate samples were taken from a single ingot. For each heat, a different ingot location was selected; second, middle, and next to last. This pattern is represented below:

	Ingots		
Plates	S	M	L
Top	A	B	C
Center	A	B	C
Bottom	A	B	C

Class C Steel: From each of three heats (A, B and C), two plate samples were taken from each of two ingots, for a total of 4 samples per heat. The pattern for selection of these plate samples is represented below:

	Ingots		
Plates	S	M	L
Top	A	A, C	B
Center	A, B	C	C
Bottom	B	A	B, C

Specimen Selection Scheme for Charpy Impact Testing

The early work on the pre-1956 ABS steels indicated that in some plates the variation in notch-bar properties across the plate width was substantial. In order to determine statistically whether this edge to center discrepancy was significant and consistent, Dr. Youden devised a specimen selection scheme which involved the testing of four specimens at each temperature in such a way that four different regions across the plate width were always represented. Originally the method involved the testing of 4 specimens at each of 9 temperatures, thus requiring 36 individual Charpy bars per plate. However, it became feasible in later work to reduce the number of test temperatures necessary to develop that portion of the Charpy curves of primary interest from 9 to 7 temperatures thus requiring only 28 specimens per plate. This simplified scheme requiring only a total of 28 specimens is illustrated below:

Impact Test Blanks

Plate edge N 1		N 2		N 3		N 4	Plate Center
Spec. No.	Temp. *	Spec. No.	Temp.	Spec. No.	Temp.	Spec. No.	Temp.
3	a	14	g	24	f	38	e
4	b	15	a	25	g	39	f
5	c	16	b	26	a	40	g
6	d	17	c	27	b	41	a
7	e	18	d	28	c	42	b
8	f	19	e	29	d	43	c
9	g	20	f	30	e	44	d

*The intervals between successive temperatures are not necessarily of equal magnitude.

It was usually possible to machine at least 11 specimens from each impact blank thus providing a minimum reserve of from 2 to 4 specimens per blank depending on whether 9 or 7 test temperatures were employed.

Description of Statistical Techniques Used in the Analysis of Data on Notch-Toughness of Ship Steel

Analysis of Variance: A brief description of the manner in which the analysis of variance was employed in this investigation for a particular case will now be presented.

For each individual producer and each lot of plates tested, an analysis of variance was performed to determine if the effect of the specimen location within the plate is of sufficient importance to be included in a general sampling scheme. The classifications are as follows:

Location within plate:	edge, next to edge, next to center, and center
Plates within heats:	top, center, bottom
Heats	No. of heats within each manufacturer

The values used were the sums of energies absorbed by specimens tested at different temperatures (a range of 5 to 7 temperatures at 10 F intervals).

A typical summary of the analysis for a producer representing 3 heats, 3 plates within a heat, and four locations within a plate is presented in the following table:

Source of Variation	Mean Sum of Square	Degrees of Freedom	F (Ratio)
Between heats	29,778	2	
Plates within heats	2,491	6	
Location within plates	1,205	3	1.93
Residual (error)	624	24	
		35	

Since the critical value of F ratio at 5% level of significance for 3 and 24 degrees of freedom is 3.01, we accept the hypothesis of no effect for the locations.

When the method was applied to all steels, the results showed that out of ten cases, five of the F ratios were less than 1, four between 1 and 2 and only one had a value of 4.5. Hence it was concluded that locations within a plate need not be considered as important.

<u>Effects of Plate and Ingot Positions</u>. Analyses were made to determine whether the notch toughness properties depend on the location of the plate in an ingot and the location of an ingot in a heat. The following mathematical model was assumed.

$$y = m + b_1 x_1 + b_2 x_2 + b_3 x_3 + \ldots\ldots\ldots b_k x_k + e$$

where:

y = TV 15 or TV 25 transition temperature values

m = a constant

x_1, x_2, x_3: corresponding to top, center or bottom plate positions within an ingot. $x_1 = 1$, if plate is from top of ingot, x_1, $= 0$ otherwise, etc.

x_4, x_5, x_6,: corresponding to second, middle or next to last ingot from a heat. $x_4 = 1$, if ingot is the first one to be poured, $x_4 = 0$ otherwise, etc.

$x_7 \ldots x_p$: $x_i = 1$, for the ith heat, 0 otherwise

e: error, with $E(e) = 0$, $V(e) = \sigma^2$, and assumed to be normally distributed.

Subject to the restriction that sums of the coefficients for plate positions, ingot locations and heats are zeros, a least square fit was made to date from 24 plates of C steel and from 15 plates of B steel, both from the same producer. The fit for the latter sampling was made for plate positions and heats only since there was only one ingot position for each heat. The estimates of these coefficients were obtained and tested against their respective standard errors for significant differences from zero, or no effect.

Dependence of Notch-Toughness Properties on Chemical Composition and Processing Method: The same statistical technique used for plate positions was used to estimate the individual effects of mill practice variables on notch toughness. The estimates of the coefficients of these variables and their standard errors were calculated by least square fitting to 49 data points for C steel and 39 for B steel.

APPENDIX II

ABS RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF STEEL VESSELS

The current ABS requirements for hull plate of different thicknesses as incorporated in paragraph (10) of Section 39 of the 1961 edition of the Rules for Building and Classing Steel Vessels is presented as follows:

(10) Chemical Composition - Ladle Analysis

(a) Except as specified in paragraphs (b) and (c) the material shall conform to the requirements of Class A as to chemical composition.

(b) Material for plates over 1/2" up to 1" inclusive shall conform to the requirements of Class B as to chemical composition. (Material conforming to the requirements of Class C will be accepted.)

(c) Materials for plates over 1" and not exceeding 2" in thickness shall conform to the requirements of Class C as to chemical compositions. Where plates of over 1 3/8" thickness are used in important structural parts, it may be required that such plates be produced to special specifications. Plates over 2" in thickness are to be produced to specially agreed upon specifications. In both of these cases the purchaser shall indicate on the orders a notation indicating the agreed upon specification.

	Class A	Class B[2]	Class C[1]
Carbon, max. per cent	-	.21	.23[3]
Manganese, per cent		.80 to 1.10	.60 to .90
Phosphorus, max. per cent	.05	.05	.05
Sulphur, max. per cent	.05	.05	.05
Silicon, per cent	-	-	.15 to .30

Note 1 - Plate steels produced to the requirements of Class C shall be made with fine grain melting practice and the McQuaid-Ehn austenite grain size is to be determined.

Note 2 - Where the use of material of cold flanging quality has been specially approved (See Sec. 3, Par. 1) the manganese content may be reduced to the range of .60 to .90.

Note 3 - Plates specified to be normalized may have a maximum carbon of .24.

The changes in present specifications from those adopted after January 31, 1956 are as follows:

Class A

Phosphorus, max. per cent is now .05 (formerly .04)

Class B

Phosphorus, max. per cent is now .05 (formerly .04)

Class C

Phosphorus, max. per cent is now .05 (formerly .04)

Carbon, max. per cent is now .23 (formerly .24)

Note 3 has been added.

The changes in present specifications from those adopted in 1947 are as follows:

Class B

Carbon, max. per cent is now .21 (formerly .23)

Manganese per cent is now .80 to 1.10 (formerly .60 to .90)

Note 2 has been added.

Class C

Carbon, max. per cent is now .23 (formerly .25)

Note 3 has been added.

(12) Tensile Properties - (a) The material except as specified in par. (b) shall conform to the following requirements as to tensile properties.

	Structural Steel	Rivet Steel and Steel for Cold Flanging [b]
Tensile Strength, psi	58,000-71,000	55,000-65,000
Elongation in 8 in., min. %[c]	21	23
Elongation in 2 in., min. %[a, c]	24	-

Note a - When specimen shown in Fig. 2, Paragraph 6 is used.

Note b - The use of material of cold flanging quality is subject to special approval. See Section 3, Paragraph 1.

Note c - When tension test specimens of dimensions differing from those of Figs. 1 or 2 Paragraph (b) (c), are used, the required minimum elongation is to be specially agreed upon.

(b) Flat-rolled steel 3/16" and under in thickness, shapes less than 1 sq. in. in cross sections and round, square and hexagon bar less than 1/2" in thickness or diameter need not be subjected to tension tests but chemistry consistent with the above tensile properties should be applied.

(c) For material over 3/4" in thickness or diameter, a deduction from the percentage of elongation in 8" specified in par. (a) of 0.50 per cent shall be made for each increase of 1/8" of the specified thickness or diameter above 3/4". This deduction shall not exceed 3%.

(d) For material under 5/16" in thickness or diameter, a deduction from the percentage elongation in 8" specified in par. (a) of 1.25 per cent shall be made for each decrease of 1/32" of the specified thickness or diameter below 5/16".

(e) For raised pattern floor plates not exceeding 1/2" in thickness the requirement for elongation is waived.

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