SERIAL NO. **SSC-99**

First

PROGRESS REPORT

(Project SR-125)

on

NOTCH-TOUGHNESS PROPERTIES OF ABS SHIP PLATE STEELS

by

N. A. KAHN, E. A. IMBEMBO, and J. J. GABRIEL
Material Laboratory
New York Naval Shipyard

Transmitted through

NATIONAL RESEARCH COUNCIL'S
COMMITTEE ON SHIP STEEL

Advisory to

SHIP STRUCTURE COMMITTEE

Division of Engineering and Industrial Research
National Academy of Sciences - National Research Council
Washington, D. C.

June 10, 1955

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ADDRESS CORRESPONDENCE TO:

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

June 10, 1955

Dear Sir:

As part of its research program related to the improvement of hull structures of ships, the Ship Structure Committee is sponsoring an investigation of the properties of ship plate steels being produced to American Bureau of Shipping specifications at the Material Laboratory, New York Naval Shipyard. Herewith is a copy of the First Progress Report, SSC-99, of the investigation, entitled "Notch-Toughness Properties of ABS Ship Plate Steels" by N. A. Kahn, E. A. Imbembo and J. J. Gabriel.

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

Comments concerning this report are solicited and 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

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MATERIAL LABORATORY
NEW YORK NAVAL SHIPYARD

BUREAU OF SHIPS
Department of the Navy
Index No. NS-011-078

for

SHIP STRUCTURE COMMITTEE

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NOTCH-TOUGHNESS PROPERTIES OF ABS SHIP PLATE STEELS

ABSTRACT

This project is concerned with a survey of the notch-toughness properties and other characteristics of mild steel ship plate as procured by various commercial shipyards for new merchant ship construction under the American Bureau of Shipping Rules. The over-all objective is to determine the extent to which present-day ship plate steels have been improved, based principally upon a comparison of their Charpy V-notch properties with those established at the National Bureau of Standards on plates from fractured World War II ships.

Samples of Classes A, B, and C plates are being furnished on a continuous basis by the U. S. Coast Guard and represent scrap material remaining from plates used in new ship construction. Information relative to the background history of the samples is meager. To date, 32 Class A, 80 Class B, and 16 Class C plate samples (total 128) have been received.

On each sample, the Material Laboratory will determine the chemical composition (C, Mn, Si, Al), ferrite and McQuaid-Ehn grain sizes, static tensile properties, notch-toughness properties as evaluated by Navy tear tests at selected temperatures, and Charpy V-notch and keyhole-notch transition temperatures.

This progress report presents data obtained on 8 Class A,

44 Class B, and 8 Class C samples (total 60). On the basis of comparison of the 15 ft-lb Charpy V-notch transition temperatures with those established by the National Bureau of Standards, the preliminary findings indicate that the notch-toughness properties of ABS ship plate of current manufacture are considerably better than those of plate made during World War II.

INTRODUCTION

Project SR-125 was established by the Ship Structure Committee at the Material Laboratory in September 1952 for the purpose of surveying the notch-toughness properties and other characteristics of randomly selected samples of mild steel ship plate as currently procured by various commercial shipyards for merchant ship construction under the American Bureau of Shipping Rules (Appendix I). The results of this survey will be analyzed to determine the extent to which present-day ship plate steels have been improved relative to World War II steels, based principally upon a comparison of Charpy V-notch properties of the former with similar data obtained at the National Bureau of Standards on plates from fractured World War II ships (Project SR-106). The work of the National Bureau of Standards has been reported by Williams and Ellinger[1,2].

Project SR-125 parallels certain phases of a similar investigation now under way at the Material Laboratory on mild steel ship plate of the type being procured for Naval ship construction under Military Specification MIL-S-16113. Project SR-125 also parallels certain phases of Ship Structure Committee Project SR-139 recently established at the National Bureau of Standards and which will be concerned with a study of the properties of samples of currently produced ABS plate steels selected on the basis of a controlled sampling plan. This work has been performed under the general advisory guidance of the Committee on Ship Steel of the National Academy of Sciences-National Research Council.

MATERIAL

Arrangements were made by the Ship Structure Committee with the Merchant Marine Technical Division of U. S. Coast Guard Headquarters to obtain samples of plate for Project SR-125. The officer-in-charge of Marine Inspection in each of the various Coast Guard Districts throughout the country was requested to obtain samples, each between 2 to 6 square ft. in size, of ABS plate over 1/2 in. in thickness representing scrap material remaining from plates used in new merchant vessel construction. These were to be forwarded to the Material Laboratory, suitably identified with the direction of rolling, steel manufacturer, and heat number if known. The samples are to be furnished on a continuous basis until such time as a sufficient quantity has been tested and significant data established.

Table I represents an inventory of the number of sample plates of each thickness and class received from various sources from the inception of the program to December 1, 1954. This tabulation also indicates the corresponding number of plates on which tests have been virtually completed and on which data will be presented and discussed in this progress report. Tests on other plates are in progress. Very little information was received relative to the history of the samples.

Some samples in plate thickness of 1/2 in. and below (Class A) have been provided, although, as previously stated, the sampling was to be confined to plate over 1/2 in. in thickness (Classes B and C). However, it was considered desirable to study the properties of the Class A samples for purposes of comparison with the Class B and Class C materials.

PROCEDURE

In the present plan of investigation, subject to possible modification as the program advances, the experimental work outlined below is being performed on each sample plate.

Microscopic Examination. Microscopic examinations were made to confirm or establish the direction of rolling and to determine ferrite and McQuaid-Ehn grain sizes. For evaluation of the McQuaid-Ehn grain size, specimens were packed in a solid

SOURCE / PLATE THICK, IN.	CL. A		CLASS B								CLASS C					TOTAL	
	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 3/4	REC'D	TESTED
Bay City, Mich. Defoe Shipbuilding Co.			1		1											2	2
Boston, Mass. Coast Guard						1	1	2	1	7	1	1				14	7
Brooklyn, New York Todd Shipyards						1										1	1
Camden, New Jersey N.Y. Shipbuilding Co.			1	1		1	1	1		3	1					9	6
Chester, Pa. Sun Shipbuilding Co.		2		1		4			1	4	1					13	4
Chester, Pa. Supt. Shipbuilding			1													1	1
Lorain, Ohio American Shipbuilding Co.					2	3				1			1	2		9	4
Newport News, Va. Newport News S/B & D.D. Co.	3	9	1	5		2	3									23	12
New Orleans, La. Avondale Marine Ways				3												3	3
New Orleans, La. Coast Guard						1										1	1
Pascagoula, Miss. Ingalls Shipbuilding Co.	1	11	1	5	2	3	1									24	7
Quincy, Mass. Bethlehem Steel Co.			1													1	1
San Francisco, Calif. Beth. Pac. Coast Steel Co.		6		4		2	2			4	4	2		1	1	26	11
TOTAL — Rec'd., Each Size	4	28	6	19	5	18	8	3	2	19	7	3	1	3	1	127	--
TOTAL — Tested, Each Size	1	7	3	10	4	11	6	0	1	9	4	2	1	1	0	--	60
TOTAL — Rec'd., Each Class	32		80								15						
TOTAL — Tested, Each Class	8		44								8						

TABLE I - NUMBER OF ABS PLATE SAMPLES RECEIVED AND TESTED BY MATERIAL LABORATORY FROM INCEPTION OF PROJECT SR-125 TO DECEMBER 1, 1954 carburizing compound, heated to 1700°F., held 8 hours at heat, followed by furnace cooling.

Composition Analysis. The samples were analyzed for carbon content by chemical methods and for manganese, silicon and aluminum contents by spectrographic methods.

Static Tensile Tests. The static tensile properties were determined on a single specimen taken in the longitudinal direction. Wherever possible, flat-type tension specimens were utilized. In the case of samples which may be too short in the longitudinal direction to permit the preparation of flat specimens, or in the case of very heavy plate, cylindrical specimens will be employed.

While the ABS Rules contain no requirements for rate of loading in the tension test, the specimens were loaded at a crosshead speed of approximately 1/10 in. per minute, which is below the maximum values usually specified in the testing of structural steels, namely 1/8 in. per minute for yield point determination and 1 1/2 in. per minute for tensile strength determination.

Charpy V-Notch Tests. In the evaluation of notch-toughness properties by the Charpy V-notch test, longitudinal specimens were tested in triplicate at each of a number of temperatures so chosen as to define the lower portion of the energy-temperature relationship required for the establishment of the

15 ft-lb transition temperature, and if subsequently desired, the 10 and 20 ft-lb transition temperatures as well.

For plate 3/4 in. in thickness and over, the Charpy specimens were machined from a location approximately midway between the center of the plate thickness and one plate surface. In the case of lighter gage plate, one surface of the Charpy specimen was located close to a plate surface. The notches were cut perpendicularly to the original plate surfaces. Tests were performed in a 120 ft-lb Amsler impact testing machine under a striking velocity of 16.5 ft. per second corresponding to the maximum available kinetic energy of the pendulum.

The data obtained are intended specifically for comparison with the 15 ft-lb V-notch transition temperatures established at the National Bureau of Standards on plates from fractured World War II ships (Project SR-106).

<u>Charpy Keyhole-Notch Tests</u>. Many investigators have used and continue to use the Charpy keyhole-notch test for evaluating the notch toughness of steel, and for this reason, it was considered desirable to obtain the Charpy keyhole data for these samples.

In the evaluation of notch-toughness properties by Charpy keyhole-notch test, longitudinal specimens were tested in triplicate at each of a number of temperatures selected so as to establish the limits of the scatter region corresponding to the change from high to low energy levels. While various criteria have been proposed for defining the keyhole transition temperature, it was tentatively decided in this study to select the temperature at the middle of the scatter band as the transition temperature. For comparison purposes the 20 ft-lb transition temperatures were also established. The keyhole specimens were prepared and tested in the same manner as the V-notch specimens.

Navy Tear Tests. In the evaluation of notch-toughness properties by the Navy tear test, specimens taken in the longitudinal direction were tested at one or two selected temperatures. It is believed that this may provide sufficient information to compare the relative behavior of the samples among themselves and also with the mild steel plate samples obtained under the Military Specification. Specifically, tear tests were made initially at 70°F. In those cases where the fractures of three specimens of a plate tested at this temperature all showed predominantly fibrous fracture appearance (50% or more), no further tests were made. When the fracture appearance of any specimen tested at 70°F was predominantly granular (cleavage type fracture), tear tests were made at 90°F.

If any predominantly cleavage fractures are encountered in tests at 90°F., and should sufficient material be available, tests may be conducted at higher temperatures in an effort to locate the start of transition. In addition, on plates over

1 in. in thickness (Class C), it is planned (provided sufficient sample material remains) to perform some tear tests after laboratory normalizing in the event that tests at 90°F indicate granular fracture appearance for the "as-rolled" material. In this connection, it is to be noted that ABS Class C material is also of the type specified in MIL-S-16113 for plate 7/8 in. in thickness and over but, in addition, the Military Specification requires normalizing of plate in this thickness range.

The apparatus, experimental procedure, and method of evaluating results of tear tests have been fully described in several papers by Kahn and Imbembo[3,4,5]. In the case of plate over 1 1/4 in. thickness, the tear specimens were machined to a thickness of 1 1/4 in. by removing material from one plate surface only. This procedure was adopted in order to avoid excessive deformation of the loading holes which usually occurs in testing specimens greater than 1 1/4 in. in thickness.

RESULTS AND DISCUSSION

Results of experimental work on 8 Class A, 44 Class B, and 8 Class C plates have been summarized in Table II. The grouping of samples into these three classes was made on the basis of as-rolled plate thickness in accordance with ABS Rules (Appendix I). In each group of samples of a given plate thickness, the individual samples have been arranged in order of decreasing 15 ft-lb

CLASS	PLATE THICK IN.	PLATE CODE	COMPOSITION, % C	Mn	Si	Al	TENSILE PROPERTIES Y.P.,	T.S.,	ELONG.,% 8"	2"	GRAIN SIZE FERR	McQ-EHN	CHARPY TRANSITION TEMPERATURE, °F. 15 FT. LB.,V	KEYHOLE 20 FT. LB.	KEYHOLE **	TEAR T 70°F
A	7/16	91-55	0.21	0.37	0.03	0.004	39500	60800	-	39.5	8	2-3	44	-3	-15	S*
	1/2	91-54	0.25	0.34	0.05	0.003	34600	60500	30.5	-	7-8	1-2	67	43	20	C*
		91-37	0.22	0.54	0.03	0.006	34800	62400	30.5	-	6-8	2-4	64	27	10	C
		91-53	0.18	0.37	0.08	0.007	34800	58100	30.0	-	7-8	2-3	35	8	0	C
		91-49	0.21	0.43	0.07	0.005	34400	55200	32.5	-	7-8	3-4	26	-8	-15	S
		91-41	0.17	0.55	0.06	0.004	35400	58000	29.5	-	6-7	2-4	25	-15	-30	S
		91-39	0.17	0.57	0.06	0.016	39400	62700	28.3	-	7-8	3-4	20	-12	-20	S
		91-59	0.21	0.73-	0.05	0.005	36300	61500	25.8	-	7-8	3-4	12	-8	-20	S
	AVERAGE		0.20	0.50	0.06	0.007	35700	59800	29.6	-	-	-	36	5	-8	-
GRAND AV'G., CLASS A			0.20	0.49	0.05	0.006	36200	59800	29.6	-	-	-	37	4	-9	-
ABS SPECIFICATION CLASS A			-	-	-	-	32000 MIN.	58000-71000	21.0 MIN.	22.0 MIN.	-	-	-	-	-	-
B	9/16	91-13	0.22	0.81	0.04	0.005	38500	65200	28.0	-	7-8	2-4	45	0	-21	C
		91-15	0.21	0.76	0.04	0.008	39000	61500	31.9	-	8	1-3	15	6	0	S
		91- 6	0.18	0.80	0.03	0.009	34900	60200	-	50.0	7-8	2-3	10	0	2	S
	AVERAGE		0.20	0.79	0.04	0.007	37500	62300	30.0	-	-	-	23	2	-6	-
	5/8	91-10	0.22	0.67	0.06	0.008	35800	57300	32.8	-	5-6	1-3	35	-3	-8	S
		91-27	0.24	0.79	0.04	0.002	36200	64200	26.5	-	7-8	2-4	33	-10	-15	C
		91-57	0.17	0.46	0.06	0.010	33200	58200	32.0	-	6-7	1	32	15	5	S
		91-2A	0.19	0.78	0.05	0.010	35000	58500	26.5	-	7-8	1-3	26	21	15	S
		91-2C	0.21	0.74	0.04	0.006	32200	57800	32.3	-	6-7	1-3	23	21	20	S
		91-2B	0.18	0.80	0.05	0.009	31600	58100	34.2	-	6-7	1-3	20	15	15	S
		91- 7	0.22	0.76	0.07	0.010	40500	63600	29.8	-	8	2-3	18	-15	-20	S
		91-22	0.18	0.72	0.04	0.018	32100	56900	36.5	-	5-7	1-3	16	-18	-15	C
		91-16	0.25	0.78	0.05	0.009	38300	67600	28.3	-	6	2-3	15	-20	-30	S
		91-26	0.19	0.77	0.03	0.002	32200	54400	35.5	-	6-7	2-4	12	-19	-20	S
	AVERAGE		0.21	0.73	0.05	0.008	34700	59700	31.5	-	-	-	23	-1	-5	-

* S- Predominantly shear fracture on all specimens tested. C- Predominantly cleavage fracture in one or specimens.

** Temperature at middle of scatter band.

TABLE II- SUMMARY OF TEST RESULTS OBTAINED ON 60 ABS STEEL PLATES OF CURRENT MANUFACTURE

CLASS	PLATE THICK. IN.	PLATE CODE	COMPOSITION, % C	Mn	Si	Al	TENSILE PROPERTIES Y.P., psi	T.S., psi	ELONG.,% 8"	2"	GRAIN SIZE FERR	McQ-EHN	CHARPY TRANSITION TEMPERATURE, °F. 15 FT. LB., V	KEYHOLE 20FT. LB.	KEYHOLE ##	TEAR TEST 70°F.	90°F.
B	11/16	91-31	0.19	0.72	0.05	0.021	40800	63700	25.0	-	5-7	2-3	32	2	-10	S*	-
		91- 5	0.24	0.79	0.03	0.007	35900	65000	31.0	-	7-8	2-4	26	-5	-17	S	-
		91-48	0.23	0.81	0.07	0.008	39400	67600	-	35.0	6-8	2-4	3	--15	-25	S	-
		91-19	0.18	0.79	0.08	0.007	39700	61500	31.7	-	5-7	2-4	-10	-56	-57	S	-
	AVERAGE		0.21	0.78	0.06	0.012	38900	64500	29.2	-	-	-	13	-18	-27	-	-
	3/4	91-45	0.23	0.50	0.07	0.008	36400	65200	29.0	-	6-8	1-3	57	19	10	C*	S
		91- 8	0.21	0.50	0.02	0.005	38800	64000	28.7	-	7	2-4	55	20	0	C	C
		91- 4	0.27	0.73	0.14	0.005	38800	73000	-	36.5	5-6	1-3	41	8	-5	C	C
		91-51	0.17	0.75	0.05	0.010	30000	55200	33.0	-	6-7	3-4	31	5	0	C	C
		91- 3	0.22	0.71	0.06	0.010	37500	67800	29.8	-	6-7	2-3	27	-5	-8	C	C
		91-40	0.21	0.76	0.04	0.006	34900	64300	30.5	-	7-8	1-2	16	0	5	C	C
		91-32	0.17	0.85	0.05	0.007	32900	63300	31.5	-	7-8	2-3	13	0	-5	S	-
		91-47	0.19	0.70	0.05	0.013	35200	61400	33.5	-	7-8	2-4	7	-6	-5	S	-
		91- 1	0.21	0.83	0.05	0.005	40000	68100	-	36.5	7-8	2-3	4	-7	-15	C	S
		91-17	0.15	0.77	0.07	0.016	33000	54700	31.6	-	5-6	3-5	-4	-20	-30	S	-
		91-29	0.17	0.70	0.24	0.006	32800	61800	31.5	-	5-6	6-7	-20	-47	-55	S	-
	AVERAGE		0.20	0.71	0.08	0.008	35500	63500	31.0	-	-	-	21	-3	-10	-	-
	13/16	91-42	0.17	0.57	0.04	0.036	31600	57200	33.8	-	6	7-8	47	15	15	C	C
		91-36	0.17	0.65	0.04	0.027	30700	56600	39.5	-	5-6	2-4	37	8	5	C	C
		91-25	0.19	0.60	0.03	0.010	30900	54000	36.0	-	6	2-3	35	5	0	S	-
		91-20	0.24	0.92	0.06	0.005	41200	69900	29.8	-	7-8	1-3	31	7	-3	S	-
		91-28	0.26	0.67	0.06	0.003	32000	61400	29.0	-	5-6	2-3	30	-3	-10	C	C
		91-21	0.17	0.74	0.05	0.012	31700	53400	34.5	-	6-7	1-3	28	6	5	S	-
	AVERAGE		0.20	0.69	0.05	0.017	33000	58800	33.8	-	-	-	35	6	2	-	-
	15/16	91-58	0.24	0.60	0.05	0.005	33200	61500	30.5	-	6-7	1-2	47	23	10	C	C

* S- Predominantly shear fracture on all specimens tested. C- Predominantly cleavage fracture in one or more specimens.
\## Temperature at middle of scatter band.

TABLE II- CONTINUED

CLASS	PLATE THICK.,* IN.	PLATE CODE	COMPOSITION, % C	Mn	Si	Al	TENSILE PROPERTIES Y.P., psi	T.S., psi	ELONG.,% 8"	2"	GRAIN SIZE FERR.	McQ-EHN	CHARPY TRANSITION TEMPERATURE, °F. 15 FT. LB., V	KEYHOLE 20 FT. LB.	**	TEAR TEST 70°F.	90°F.
B	1	91-14	0.24	0.67	0.07	0.008	37900	63500	31.8	-	7-8	1-3	51	20	5	C*	S*
		91-30	0.20	0.76	0.04	0.003	28300	54100	33.0	-	5-6	2-4	47	5	0	C	C
		91-52	0.19	0.65	0.08	0.006	39200	60800	-	47.0	6	2-3	46	38	20	C	S
		91-12	0.22	0.64	0.06	0.006	32790	62800	31.8	-	7	2-3	45	24	15	C	C
		91-44	0.16	0.68	0.04	0.007	27600	54200	31.4	-	5-6	2-3	45	18	10	C	C
		91-50	0.19	0.70	0.04	0.005	32300	58200	35.5	-	5-7	2-4	45	26	15	C	C
		91-11	0.18	0.71	0.05	0.015	31900	57100	34.7	-	5-6	2-4	39	20	15	C	S
		91-46	0.16	0.75	0.04	0.012	29900	57600	33.5	-	5-7	2-3	37	10	5	C	C
		91-34	0.19	0.85	0.04	0.010	30100	56500	33.2	-	6-7	1-3	23	20	15	C	C
	AVERAGE		0.19	0.71	0.05	0.008	32500	58200	33.1	-	-	-	42	20	11	-	-
GRAND AV'G, CLASS B			0.20	0.72	0.06	0.010	34700	60900	31.8	-	-	-	28	3	-4	-	-
ABS SPECIFICATION CLASS B			0.23 MAX.	0.60-0.90	-	-	32000 MIN.	58000-71000	21.0 MIN.	22.0 MIN.	-	-	-	-	-	-	-
C	1 1/8	91-18	0.19	0.68	0.25	0.019	33700	61300	34.2	-	4-5	7-8	-3	-20	-20	C	S
		91-56	0.19	0.76	0.22	0.026	32100	58000	34.1	-	6	8	-13	-24	-50	C	C
		91-24	0.22	0.77	0.28	0.026	32200	59500	33.0	-	5-6	5-7	-16	-37	-55	S	-
		91-35	0.19	0.73	0.19	0.042	30800	58000	32.0	-	5-6	8	-18	-44	-40	C	C
	AVERAGE		0.20	0.74	0.24	0.028	32200	59200	33.3	-	-	-	-12	-31	-41	-	-
	1 1/4	91-23	0.21	0.66	0.19	0.010	31800	57400	32.6	-	5	5-7	10	-25	-27	C	C
		91-43	0.16	0.73	0.21	0.049	32700	59000	31.7	-	5-6	8	-2	-40	-45	C	C
	AVERAGE		0.19	0.70	0.20	0.030	32300	58200	32.2	-	-	-	4	-33	-36	-	-
	1 3/8	91- 9	0.19	0.61	0.20	0.040	36300	59200	27.3	-	5-7	7-8	-23	-45	-55	C	S
	1 1/2	91-33	0.15	0.62	0.23	0.025	33600	61000	29.2	-	4-6	8	3	-20	-35	C	C
GRAND AV'G., CLASS C			0.19	0.70	0.22	0.030	32900	59200	31.8	-	-	-	-8	-32	-41	-	-
ABS SPECIFICATION CLASS C			0.25 MAX.	0.60-0.90	0.15-0.30	***	32000 MIN.	58000-71000	21.0 MIN.	22.0 MIN.	-	-	-	-	-	-	-

* S- Predominantly shear fracture on all specimens tested. C- Predominantly cleavage fracture in one or more specimens.
** Temperature at middle of scatter band.
*** Shall be made with fine grain practice.

TABLE II- CONCLUDED

Charpy V-notch transition temperature.

The following deviations from ABS specification limits for chemical composition and tensile properties were considered permissible in order to arrive at a practical assessment of conformity of the samples to ABS requirements:

* Carbon content--0.04% above maximum limit
* Manganese content--0.04% below and above minimum and maximum limits, respectively
** Yield point--1000 psi below minimum limit
** Tensile strength--2000 psi below and above minimum and maximum limits, respectively

* ABS Rules are based on ladle analysis. The variations indicated represent accepted deviations (from ladle analysis) in check analyses of individual pieces made from a heat. (See ASTM Specification A131-53T)

** ABS Rules require two tensile tests per heat and permit a retest if values obtained are within the indicated variations.

On the basis of the above, the number of plate samples which do not fully conform to ABS requirements either because of chemistry or tensile property deviations (underlined in Table II) is as follows:

	No.	% of Total No. of Samples
Class A	1	12.5
Class B	13	29.5
Class C	1	12.5
All Classes	15	25

From the data presented in Table II, the following general observations may be made:

15 out of 60

I. Class A Plates

1. Using silicon and aluminum contents as criteria, all plates appear to have been rolled from semikilled ingots.
2. All plates showed low residual aluminum contents and correspondingly coarse McQuaid-Ehn grain sizes.
3. Two plates showed manganese contents acceptable for Class B plate.
4. It is interesting to note that those samples in which the manganese content approached 0.60% or was within the 0.60/0.90% range, exhibited Charpy transition temperatures at the lower end of the over-all range for the Class A plates.

II. Class B Plates

1. Judging from the silicon and aluminum contents, the great majority of the plates are semikilled, but it will be noted that plate 91-29 (3/4 in. thick) contains 0.24% Si and plates 91-31 (11/16 in.), 91-42 (13/16 in.), and 91-36 (13/16 in.) contain between 0.021 and 0.036% Al. These plates (with the possible exception of 91-31) are sufficiently deoxidized that they are either killed or are approaching the killed steel type of practice.
2. All plates were classified as being of the coarse-grain type by the McQuaid-Ehn test with the exception of sample

91-29 (3/4 in. thick) which was silicon killed and sample 91-42 (13/16 in. thick) which showed an aluminum content of 0.036%. It is unusual that plate 91-29 showed a fine McQuaid-Ehn grain size and yet a low aluminum content, since silicon killing (without aluminum) would normally produce a coarse grain steel. Although plates 91-31 and 91-36 showed rather high total aluminum contents, the McQuaid-Ehn grain size was coarse. Plate 91-29 exhibited the lowest Charpy transition temperatures of all Class B plates, while those of 91-42 were relatively high.

3. In those cases where the manganese content was well below the specified minimum of 0.60%, the Charpy transition temperatures were at the upper end of the range for a particular plate thickness group.

III. Class C Plates

1. All plates were fine-grained on the basis of the McQuaid-Ehn test and, in general, showed high aluminum contents, as would be expected from the requirement that Class C plate shall be made with a fine-grain practice. In addition, all steels were fully killed with silicon.

Graphs showing typical Charpy energy-temperature relationships are presented in Figs. 1 through 5. These graphs also

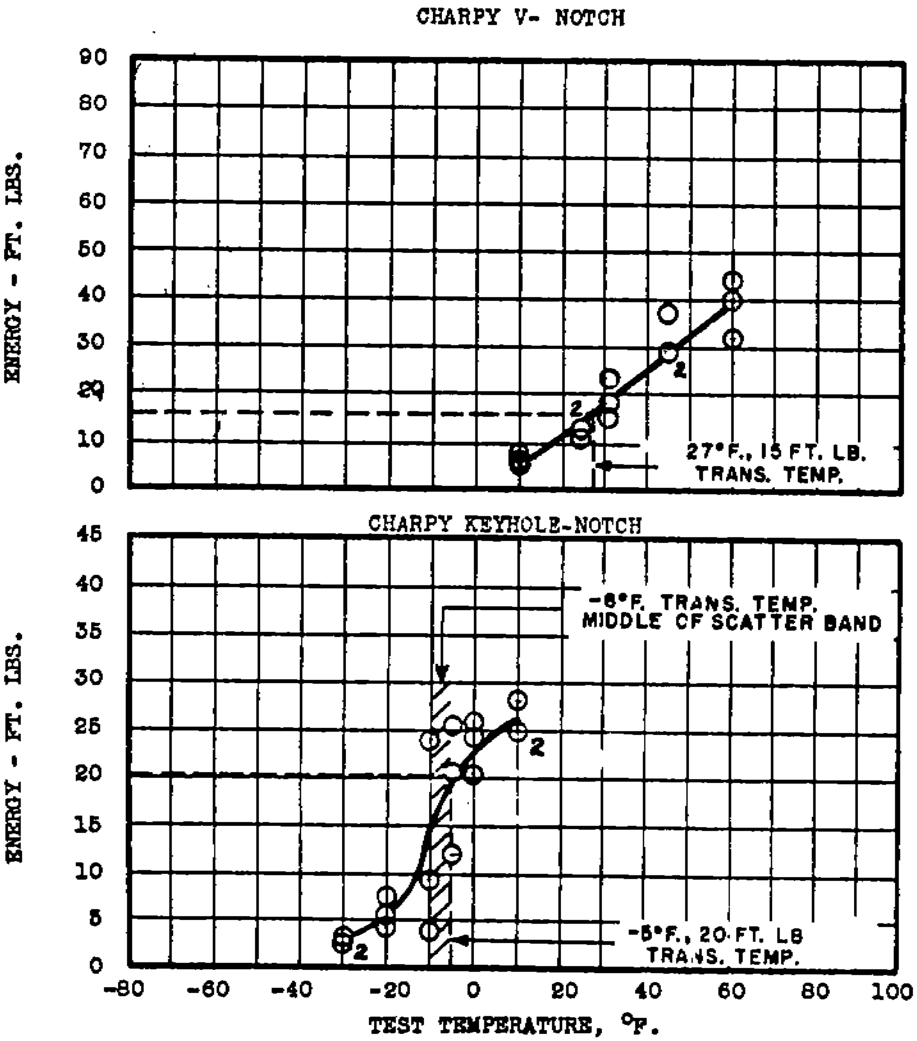

Fig. 1- CHARPY ENERGY-TEMPERATURE RELATIONSHIPS FOR 3/4" THICK, ABS-B PLATE, MATL. LAB. PLATE CODE 91-3

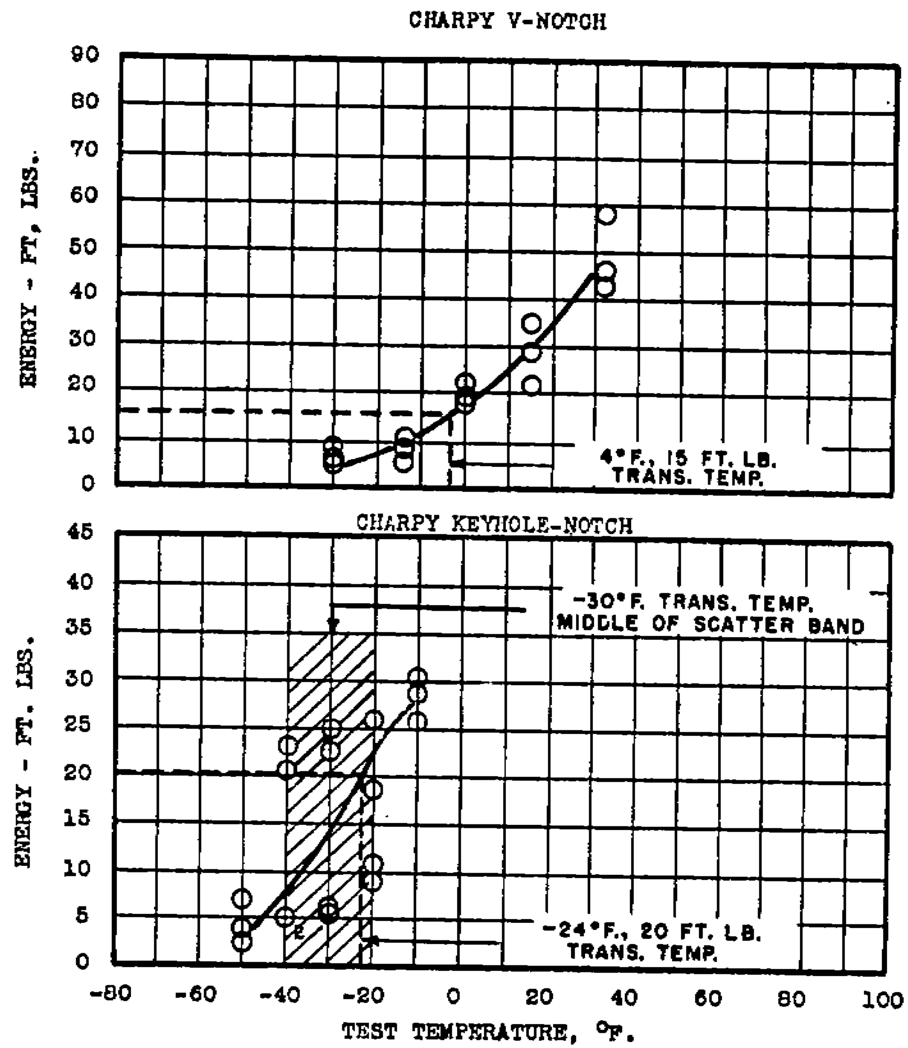

Fig. 2- CHARPY ENERGY-TEMPERATURE RELATIONSHIPS FOR 3/4" THICK, ABS-B PLATE, MATL. LAB. PLATE CODE 91-17

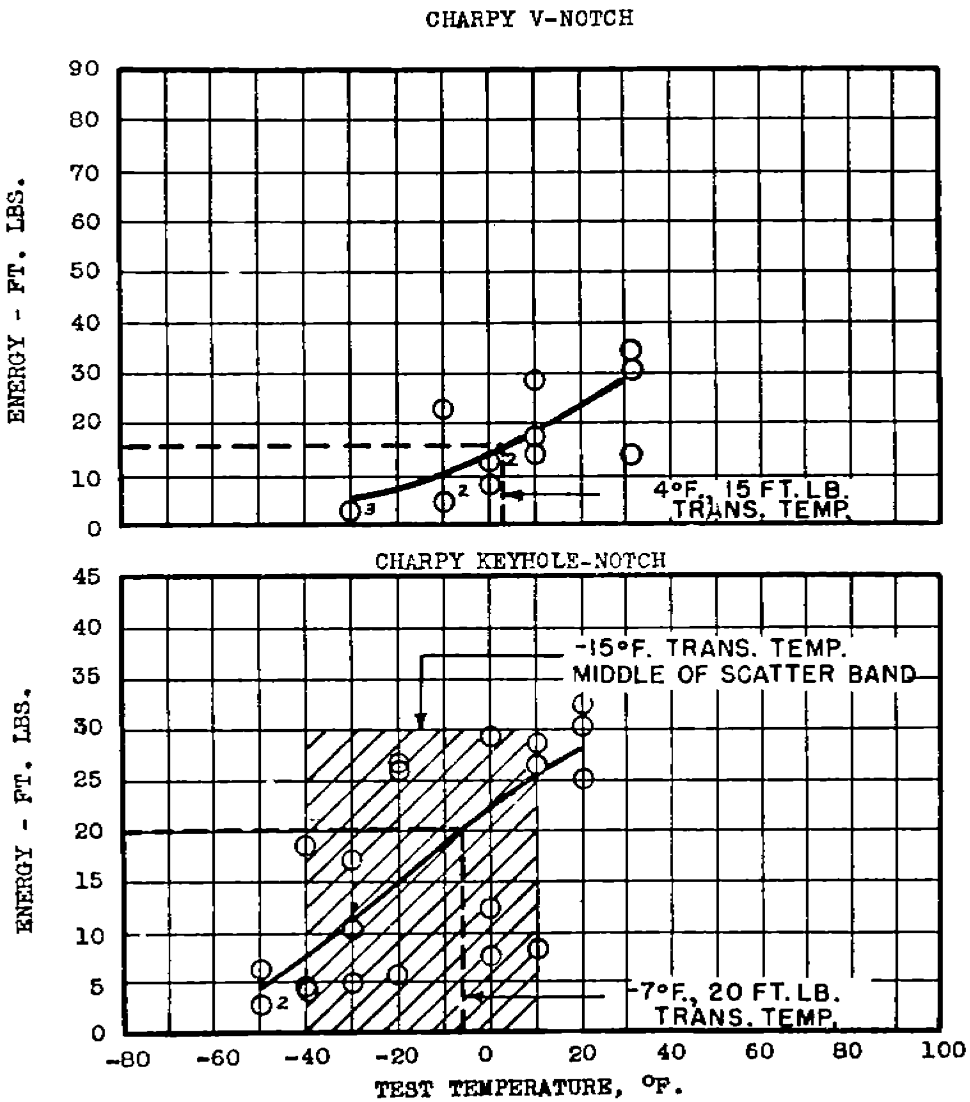

Fig. 3- CHARPY ENERGY-TEMPERATURE RELATIONSHIPS FOR 3/4" THICK, ABS-B PLATE, MATL. LAB. PLATE CODE 91-1

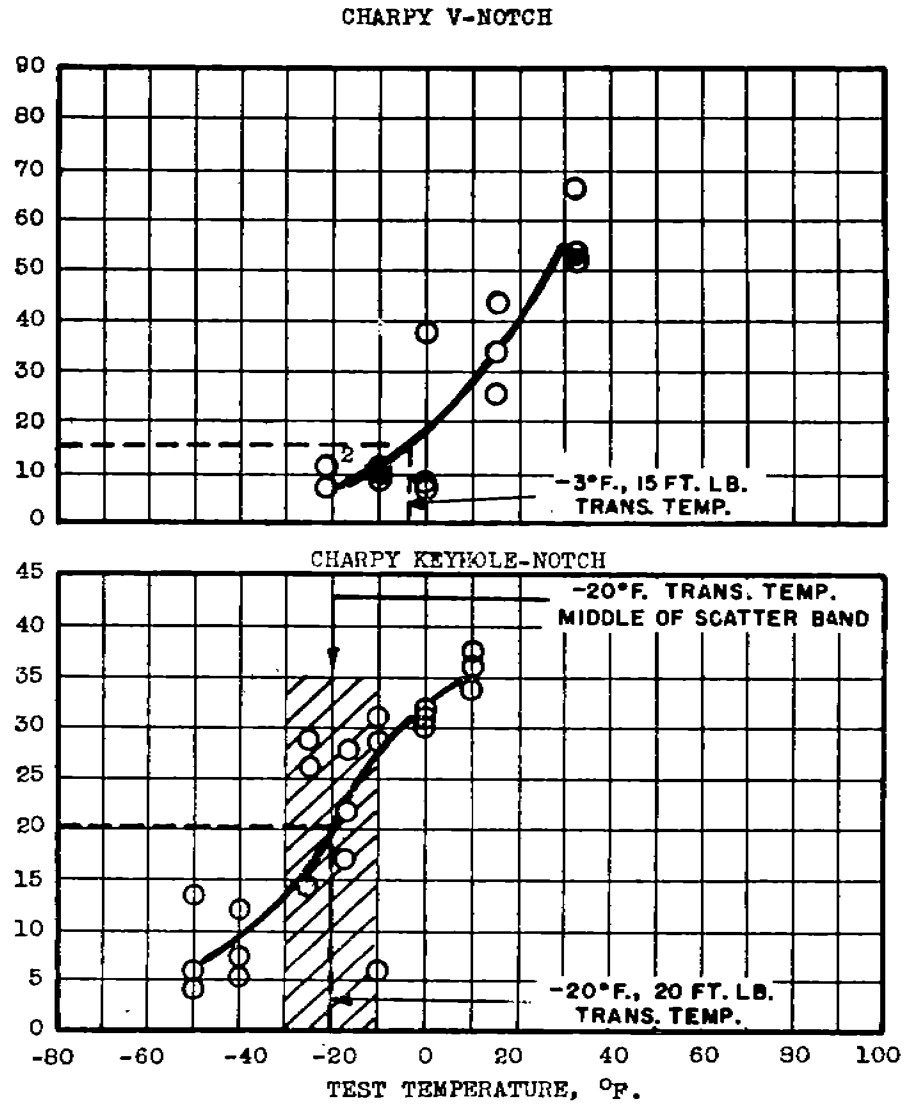

Fig. 4- CHARPY ENERGY-TEMPERATURE RELATIONSHIPS FOR 1 1/8" THICK, ABS-C PLATE, MATL. LAB. PLATE CODE 91-18

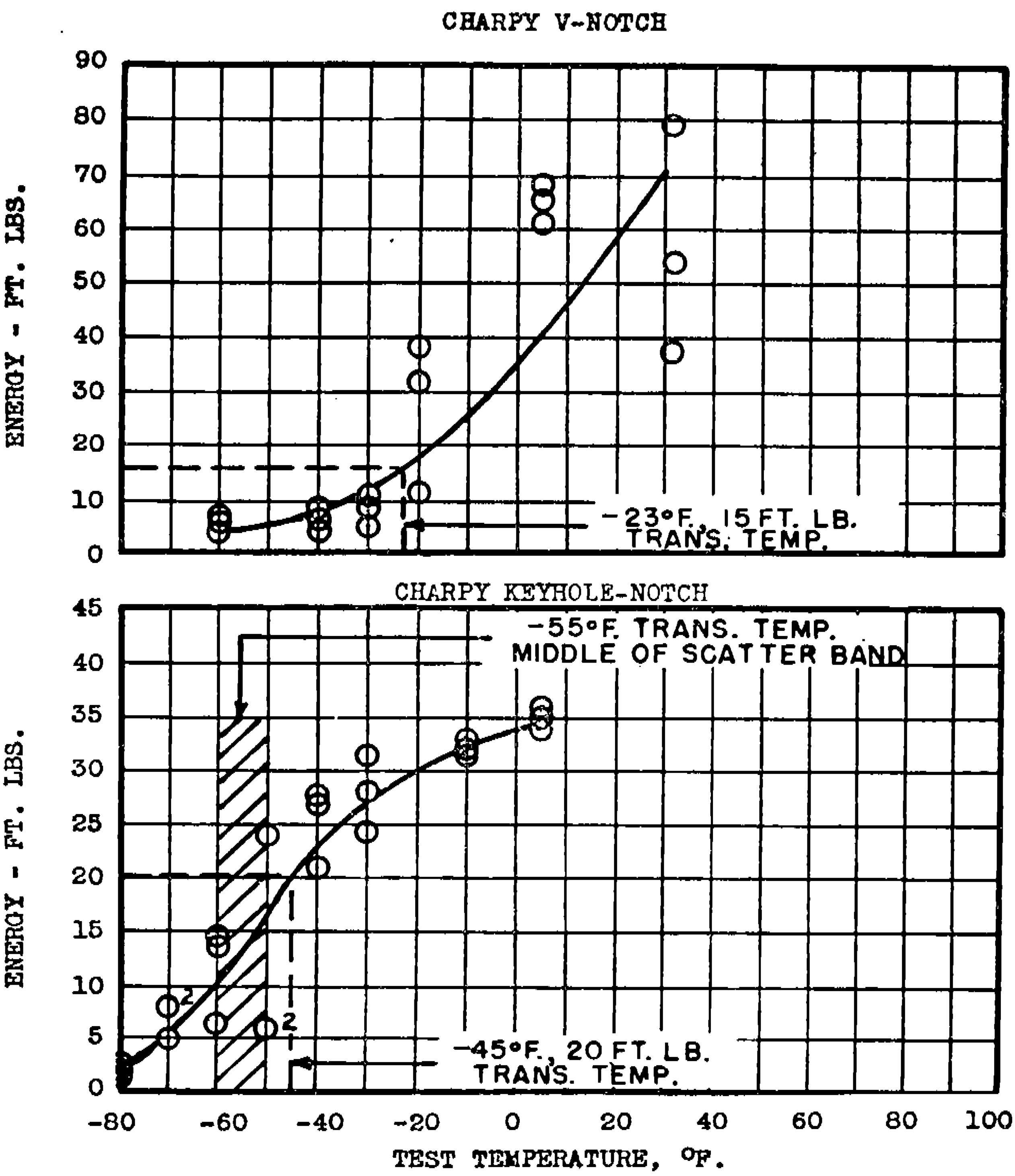

Fig. 5- CHARPY ENERGY-TEMPERATURE RELATIONSHIPS FOR 1 3/8" THICK, ABS-C PLATE, MATL. LAB. PLATE CODE 91-9

indicate the methods of defining the transition temperatures. It is to be observed that the width of the scatter band in the keyhole test varies considerably. For example, in the case of the three 3/4 in. thick Class B plates (Figs. 1, 2, and 3) the widths of the scatter band are 5°, 20°, and 50°F, respectively. In view of the wide scatter in energy values in the keyhole test, it may be difficult at times to locate accurately an average energy-temperature curve and; accordingly, this might affect the validity of the transition temperature selected at a particular energy level, such as 20 ft-lb. It was therefore considered more desirable to define the transition temperature for keyhole-notch tests as that temperature corresponding to the middle of the scatter band. However, transition temperatures based on a 20 ft-lb level have also been included for comparison. Wide scatter in the energy values is sometimes encountered in the V-notch test, as illustrated in Fig. 5, but this generally occurs at temperatures above the region of immediate interest, namely, the 15 ft-lb transition temperature.

As would be anticipated, the Charpy 15 ft-lb V-notch transition temperatures were invariably higher than the keyhole transition temperatures. The following tabulation indicates differences between Charpy V and keyhole transition temperatures as previously defined:

Steel	Difference between 15 ft-lb V and 20 ft-lb K Transition Temperatures: Range	Average	Difference between 15 ft-lb V and Middle of Scatter K Trans. Temperature: Range	Average
Class A	20 to 47°F	33°F	32 to 59°F	46°F
Class B	2 to 46°F	25°F	3 to 66°F	32°F
Class C	11 to 38°F	24°F	17 to 43°F	33°F

These data indicate that the difference between Charpy V and keyhole transition temperatures varies over a considerable range. Perhaps part of this variation is associated with the inherent difficulty of precisely determining the transition temperatures. However, the average differences shown in the column at the right appear to be in line with those indicated by other investigators.

A preliminary study of the data of Table II did not reveal any well defined correlation between Charpy transition temperature and carbon or manganese contents. In Fig. 6 the 15 ft-lb Charpy V-notch transition temperatures have been plotted against the manganese-to-carbon ratios for the ABS-Class A and Class B steels as well as a number of other rimmed and semikilled mild steel plates. Although the scatter is rather high, the over-all trend indicates a lowering of transition temperature with increase in manganese-to-carbon ratio.

The 15 ft-lb Charpy V-notch transition temperatures have been plotted against plate thickness in Fig. 7. While the data show considerable scatter, there is an indication of an increase in transition temperature with increase in plate thickness of the

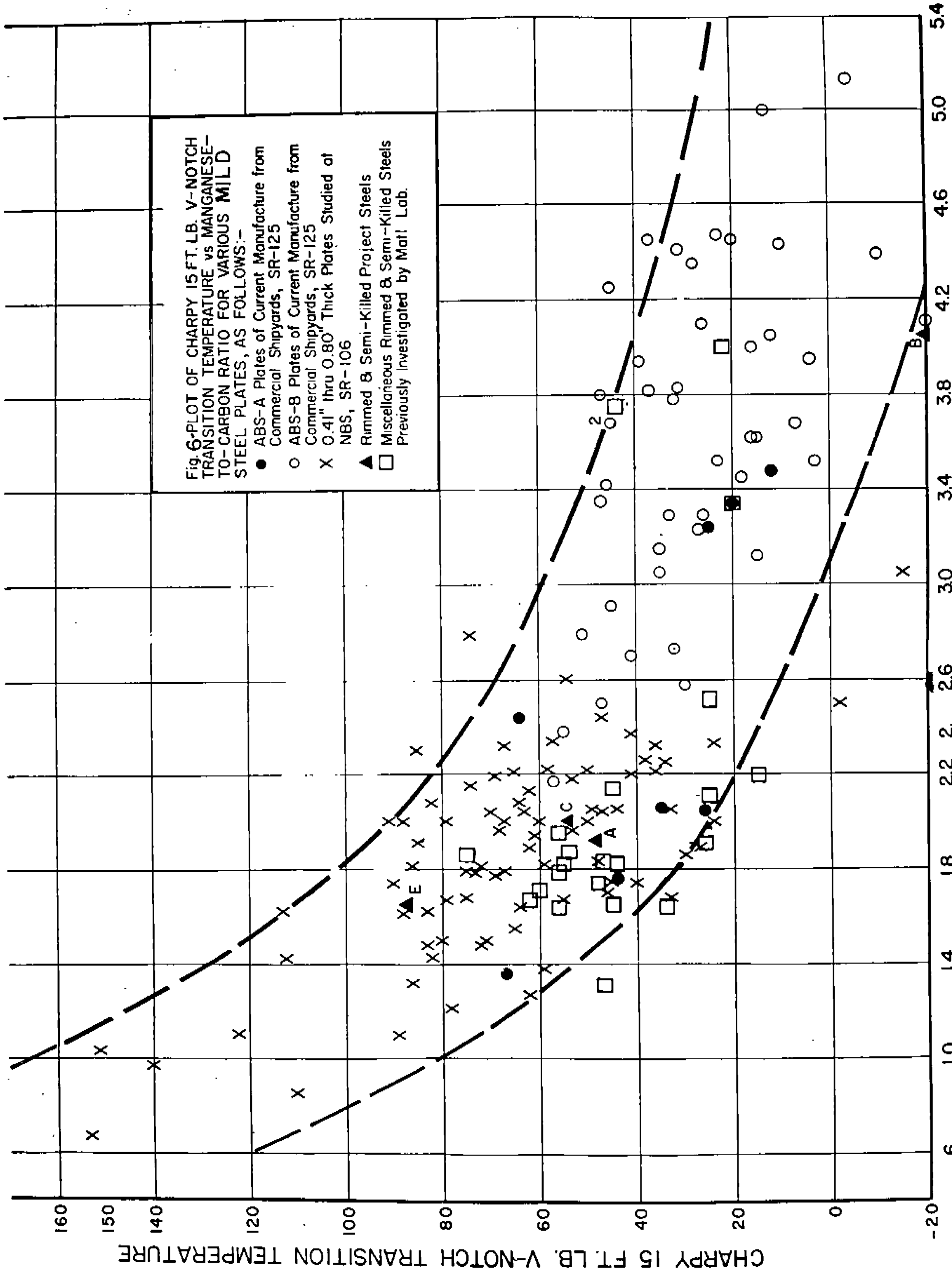

Fig. 6-PLOT OF CHARPY 15 FT. LB. V-NOTCH TRANSITION TEMPERATURE vs MANGANESE-TO-CARBON RATIO FOR VARIOUS MILD STEEL PLATES, AS FOLLOWS:-

- ● ABS-A Plates of Current Manufacture from Commercial Shipyards, SR-125
- ○ ABS-B Plates of Current Manufacture from Commercial Shipyards, SR-125
- × 0.41" thru 0.80" Thick Plates Studied at NBS, SR-106
- ▲ Rimmed & Semi-Killed Project Steels
- □ Miscellaneous Rimmed & Semi-Killed Steels Previously Investigated by Mat'l Lab.

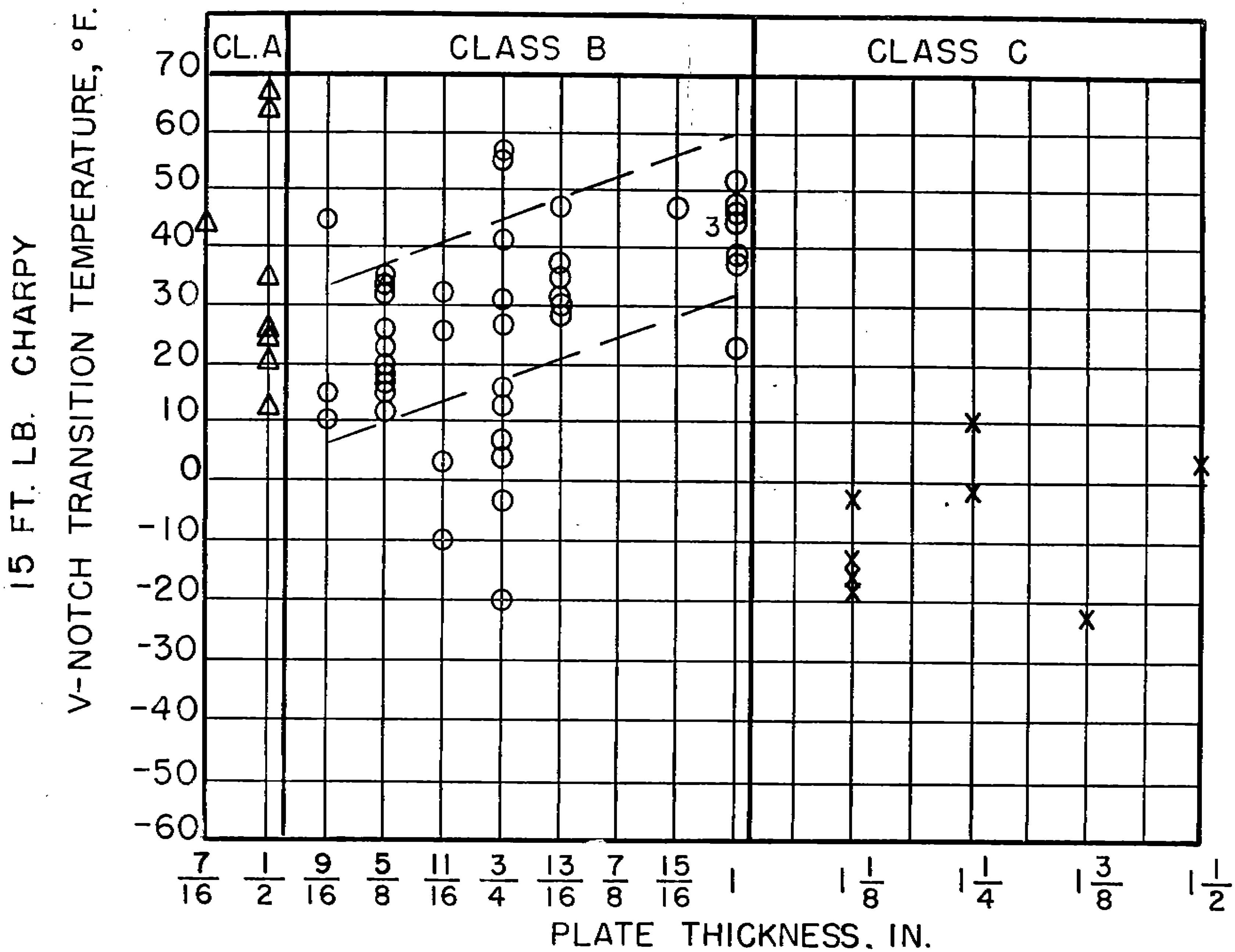

Fig. 7- PLOT OF 15 FT. LB. CHARPY V-NOTCH TRANSITION TEMPERATURE vs PLATE THICKNESS OF ABS STEELS OF CURRENT MANUFACTURE

Class B steels. It is to be also observed that the Class C steels, despite the heavier plate thickness, showed transition temperatures which are well below those of the 1-in. thick Class B plates and also, on the whole, well below those of all Class B plates. The average transition temperature of the Class C plates was -8°F as compared to an average of +28°F for the Class B plates. These figures indicate a definite advantage to be derived from the use of a fully killed, fine grain practice in the manufacture of heavier gage plate. Fig. 7 also shows that the transition temperatures of the Class A plates are, on the whole, higher than those of the Class B plates in thicknesses of 9/16 in. and 5/8 in.

In a previous report to the Bureau of Ships(6), the Material Laboratory covered results of tests on 28 ABS-B and 4 ABS-C plates representing the initial sampling. With respect to 15 ft-lb Charpy V-notch transition temperatures, the following tabulation shows little change in the initially indicated trends by the results obtained on the additional samples tested since the previous report(6):

	Class A	Class B	Class C
First Group of Plates Tested (32 Total)			
No. in each Class	0	28	4
Range of Trans. Temp.	--	-20--+55°F	-23--+10°F.
Average Trans. Temp.	--	+25°F	-8°F
First and Second Group of Plates Tested (60 Total)			
No. in each class	8	44	8
Range of Trans. Temp.	+12--+67°F	-20--+57°F	-23--+10°F
Average Trans. Temp.	+36°F	+28°F	-8°F

The relative fracture behavior of the plates in the Navy tear test has been summarized in Table III. In the case of the Class B plates, the data clearly show that fewer plates exhibit shear fracture at 70° and 90°F as the plate thickness increases. This means that the notch toughness, as evaluated by this fracture appearance criterion, decreases with increasing plate thickness. A comparison of the data for the Class C plates and the Class B plates indicates that the Class C plates have only slightly better notch toughness than the 1 in. Class B plates and are actually poorer than the Class B plates 13/16 in. and under in thickness. It may be seen in Table II and Fig. 7, however, that according to the V-notch Charpy tests, the Class C steel has a 50°F lower Charpy V-notch transition temperature than the 1-in. Class B plates and a 31°F lower Charpy transition temperature than even the 5/8 in. Class B plates. It is very apparent, therefore, that the Charpy tests and the tear tests rate these two steels quite differently.

In this connection, it is to be noted that under Military Specification MIL-S-16113, plates 7/8 in. in thickness and over are required to be of the ABS-C composition and practice but, in addition, are required to be normalized. Results of tear tests on this material indicate that there are advantages to be derived in the way of improved notch toughness by extending the Class C composition and practice requirements to plate of lighter gage

TABLE III

RELATIVE FRACTURE BEHAVIOR OF PLATES IN NAVY TEAR TEST

			Test Temp.: 70°F		Test Temp.: 90°F*	
			Shear Fracture		Shear Fracture	
Class	Plate Thick In.	Total No. of Plates	No.	% Total	No.	% Total
A	7/16 to 1/2	8	5	63	7	88
	9/16 to 11/16	17	14	82	17	100
	3/4 to 13/16	17	7	41	9	53
B	15/16 to 1	10	0	0	3	30
	All	44	21	48	29	66
C	1 1/8 to 1 1/2	8	1	13	3	38

*While plates which developed shear fractures at 70°F were not actually tested at 90°F, it was assumed that their fracture behavior at 90°F would be in the shear mode.

than that specified in the ABS Rules and by normalizing.

The graphs in Fig. 8 show frequency distributions of the 15 ft-lb Charpy V-notch transition temperature of the 44 ABS-B plates from the commercial shipyards and 38 fracture source plates investigated by the National Bureau of Standards under SR-106[1,2]. The vertical bars indicate the number of plates in each 10°F interval of transition temperature. It is to be observed that the transition temperatures of the 44 ABS-B plates were all below the lowest (62°F) of the fracture source plates. The two distribution graphs show no overlap, and the graph for the Class B plates is displaced to a region of considerably lower temperature as compared to that of the fracture source plates of World War II manufacture. This improvement in notch-toughness properties may be attributed to the fact that present ABS Rules impose a maximum limit on carbon content, and specify manganese in the range of 0.60/0.90%, whereas the Rules in existence during World War II contained no requirements for chemical composition.

It is expected that frequency distribution graphs similar to those of Fig. 8 will be developed for Class A and C plates as soon as a sufficient number of these have been tested.

CONCLUSIONS

On the basis of the data presented in this progress report, it may be tentatively concluded that the notch-toughness

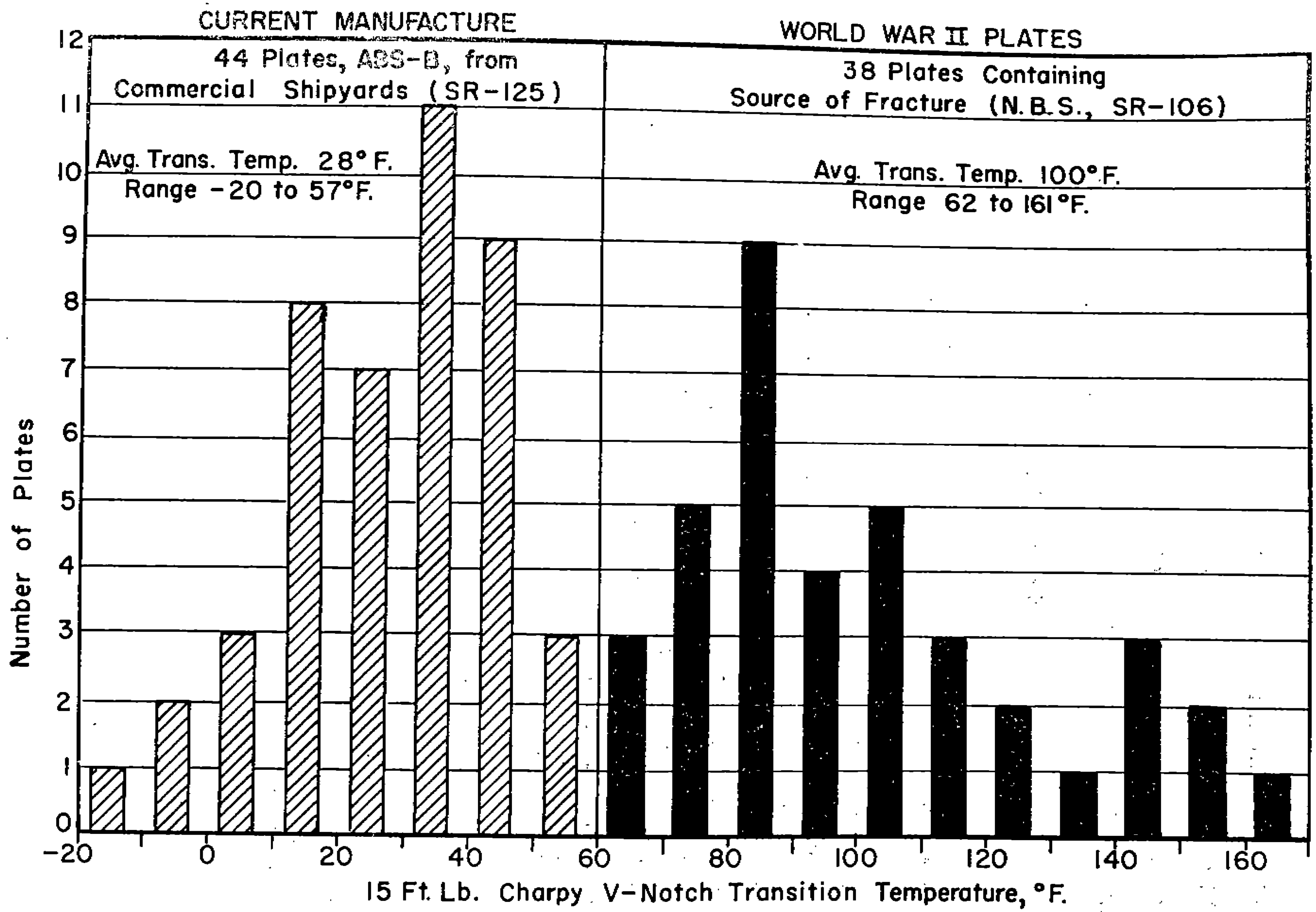

FIG. 8 - FREQUENCY DISTRIBUTION OF 15 FT. LB. CHARPY V-NOTCH TRANSITION TEMPERATURES OF ABS SHIP PLATE STEELS

properties of ABS ship plate of current manufacture are considerably better than those of plate made during World War II. Final conclusions are being deferred until such time as all samples involved in the program have been investigated.

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2. Williams, M. L. "Analysis of Brittle Behavior in Ship Plates," Presented at Symposium on Metallic Materials at Low Temperatures, 56th Annual Meeting of A. S. T. M., 28 June 1953. See also: Williams, M. L. "Analysis of Brittle Behavior in Ship Plates," Ship Structure Committee Report, Serial No. NBS-5, February 7, 1955.

3. Kahn, N. A., and Imbembo, E. A. "A Method of Evaluating Transition from Shear to Cleavage Failure in Ship Plate and Its Correlation with Large-Scale Plate Tests," <u>The Welding Journal</u>, Res. Suppl., April 1948, P. 169-s.

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5. Kahn, N. A., and Imbembo, E. A., "Further Study of Navy Tear Test," <u>The Welding Journal</u>, Res. Suppl., February 1950, P. 84-s.

6. Imbembo, E. A. and Gabriel, J. J. "Report of Investigation on the Properties of Currently Produced ABS Ship Plate Steel--Ship Structure Committee Project SR-125," Material Laboratory, New York Naval Shipyard, Project 4936-91, Progress Report 1, 10 March 1954.

APPENDIX I

ABS SPECIFICATIONS FOR STRUCTURAL STEEL FOR HULLS

(From "Rules for Building and Classing Steel Vessels," American Bureau of Shipping, 1952)

Chemical Composition--Ladle Analysis

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

(b) Plates over 1/2 in. and up to 1 in., inclusive, in thickness shall conform to the requirements of Class B as to chemical composition. Plates over 1 in. in thickness shall conform to the requirements of Class C as to chemical composition.

	Class A	Class B	Class C*
Carbon, max. %	--	0.23	0.25
Manganese, %	--	0.60--0.90	0.60--0.90
Phosphorus, max. %**	0.04	0.04	0.04
Sulfur, max., %	0.05	0.05	0.05
Silicon, %	--	--	0.15--0.30

*Plate steels produced to the requirements of Class C shall be made with fine grain practice.

**Where steel is made by the acid process the maximum percent phosphorus permitted may be 0.06.

Tensile Properties

(a) The material, except as specified in Paragraph (b), shall conform to the following requirements as to tensile properties:

	Structural steel	Rivet Steel and steel for cold flanging
Tensile strength, psi	58,000--71,000	55,000--65,000
Yield point, min, psi	32,000	30,000
Elongation in 8 in., min, %	21	23
Elongation in 2 in., min, %	22	--

APPENDIX I (Continued)

(b) Flat-rolled steel 3/16 in. and under in thickness, shapes less than 1 sq. in. in cross section, and bars, other than flats, less than 1/2 in. in thickness or diameter, need not be subjected to tension tests.

(c) For material over 3/4 in. in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in Paragraph (a) of 0.25% shall be made for each increase of 1/32 in. of the specified thickness or diameter above 3/4 in. to a minimum of 18%.

(d) For material under 5/16 in. in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in Paragraph (a) of 2.00% shall be made for each decrease of 1/32 in. of the specified thickness or diameter below 5/16 in.