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INVESTIGATION OF THE NOTCH-TOUGHNESS PROPERTIES OF ABS SHIP PLATE STEELS

SSC-142

BY

J. J. GABRIEL AND E. A. IMBEMBO

SHIP STRUCTURE COMMITTEE

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October 1, 1962

Dear Sir:

As part of its research program related to the improvement of hull structures of ships, the Ship Structure Committee sponsored a project at the Material Laboratory, New York Naval Shipyard, to establish the notch toughness and other related properties of ship plate steels produced to American Bureau of Shipping specifications.

Herewith is a copy of the final report of this investigation, Serial No. SSC-142, entitled Investigation of the Notch-Toughness Properties of ABS Ship Plate Steels by J. J. Gabriel and E. A. Imbembo.

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.

Sincerely yours,

T. J. Fabik
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

Serial No. SSC-142

Final Report
of
Project SR-125

to the

SHIP STRUCTURE COMMITTEE

on

INVESTIGATION OF THE NOTCH-TOUGHNESS PROPERTIES OF ABS SHIP PLATE STEELS

by

J. J. Gabriel and E. A. Imbembo

Material Laboratory
New York Naval Shipyard

under

Bureau of Ships
Department of the Navy
Index No. NS-011-078

transmitted through

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Washington, D. C.
U.S. Department of Commerce, Office of Technical Services
October 1, 1962

ABSTRACT

SR-125 was initiated for the purpose of surveying notch-toughness properties of ship plate procured by various shipyards for merchant ship construction under ABS rules. The main objective was to determine the extent to which post World War II steels have been improved, based principally on a comparison of their Charpy V-notch properties with those established by the National Bureau of Standards for fractured plates from World War II ships.

The initial part of the program (prior to 1956) covered plate procured to the requirements of the 1948 ABS Rules and included 37 samples of Class A, 81 of Class B and 14 of Class C. In view of the 1956 changes in the ABS Rules, the sampling program was extended to cover primarily the new Class B type but some additional samples of Class C were included to supplement the relatively small number received in the previous sampling. The extended program included 76 samples of Class B and 12 of Class C.

The results of the survey indicate that since the 1956 revision of the ABS Rules for Ship Steel, the range and average transition temperatures (15 ft-lb Charpy V) for the new material have been found to be -40 to 29 F and 2 F, respectively, for ABS Class B plates, and -46 to 13 F and -13 F, respectively, for ABS Class C plates, as compared with an average of 90 F for World War II fracture-source plates and 68 F for fracture-through plates.

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INTRODUCTION

Project SR-125 was established by the Ship Structure Committee at the Material Laboratory, New York Naval Shipyard in September 1952 for the purpose of surveying the notch-toughness properties of randomly selected samples of mild steel plate as procured by various commercial shipyards for merchant ship construction under the Rules of the American Bureau of Shipping. The principal objective was to determine the extent to which the notch-toughness properties of present-day ship plate steels have been improved relative to World War II steels, based primarily on a comparison of their behavior in the Charpy V-notch test with that of fractured plates from World War II ships, which were studied at the National Bureau of Standards.[1,2]

Prior to 1948, the ABS Rules contained no chemical composition requirements for hull plate; the requirements consisted only of certain specified tensile and cold-bend test properties. Recognizing that these specifications provided no control over notch-toughness, which became of importance in view of the previous incidence of brittle type failures in welded ships, the American Bureau of Shipping in 1947 decided to include in the Rules additional requirements to improve the notch-toughness of structural steel for hulls. The existing requirement that the steel be made by either the electric furnace or open-hearth process was retained and some minor modifications were made in the tensile and bend test requirements. The significant change was the incorporation of chemical composition requirements and, in addition, a requirement that plates of the highest class be rolled from silicon-killed steel made with a fine grain practice. Accordingly, the following was incorporated in the 1948 ABS Rules:

	Class A Plates not exceeding 1/2 in. and all shapes	Class B Plates over 1/2 in. but not exceeding 1 in.	Class C* Plates over 1 in.
Carbon, max., %	-	0.23	0.25
Manganese, %	-	0.60-0.90	0.60-0.90
Phosphorus, max., %	0.04	0.04	0.04
Sulphur, 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.

Since there had been no serious record of fractures in relatively thin plates or in shapes, the American Bureau of Shipping decided that no major change in specifications was necessary for plates not over 1/2 in. thick and for shapes (Class A).

The next major change in the specifications appeared in the 1956 Rules and became effective February 1, 1956. The circumstances which led to this revision were described in November 1957 by D.P. Brown, [3] President of the American Bureau of Shipping. Insofar as dangerous fractures are concerned, Brown indicated that the specifications in existence from 1948 to 1956 had proven to be completely successful in that there were no reported cases of either major or minor fractures in the shell or strength decks of vessels built with material conforming strictly to the requirements. It was pointed out, however, that several serious casualties had occurred in foreign-built ships which created some concern as to whether or not Class B steel was as far removed from the danger area as is desirable. In the case of one ship which broke in two, the plates at the source of fracture and for some distance away were in the order of 7/8 in. thickness. All available information indicated that these plates conformed closely to the 1948 Class B specification, but missed strict compliance by only a small deficiency in manganese content. In another case involving the breaking in two of a nearly new vessel, the material in the large area containing the fracture source was determined to comply with 1948 Class B specifications but its thickness was slightly over 1 in. In these two casualties, the material had missed strict compliance with the requirements of the 1948 specifications; in the first instance, by only a small amount of manganese and in the second case, by only a small margin of thickness. It was therefore considered desirable to effect a further shift away from the danger area in the Class B steel range and it was decided that this could be done most economically and conveniently by an additional increase in the amount of manganese specified and lowering the amount of carbon permitted. As a result, in the early part of 1956, the requirements for Class B steel were modified to limit the carbon to 0.21% and to specify manganese in the range of 0.80-1.10%. In the case of Class C steel, the steel producers agreed to a lowering of the maximum carbon content to 0.24% and, at their request, a limit of 2 in. in thickness for the class was set. In addition, the 1956 rules indicated that special specifications may be required, such as normalizing, for Class C plate over 1-3/8 in. thickness.

The work described in this report 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 Coast Guard requested the Officer-in-Charge of Marine Inspection in each of the various Coast Guard districts throughout the country to obtain samples, each between 2 to 6 sq ft in size, of ABS plate over 1/2 in. in thickness representing material remaining from plates used in merchant vessel construction. These were to be forwarded to the Material Laboratory, suitably identified with direction of rolling, steel manufacturer, and heat number, if known. The samples were to be furnished on a continuous basis until such time as a sufficient quantity had been tested and significant data established.

Table I represents an inventory of the sample plates of each thickness and class included in the testing program which were received from various sources since the inception of the work to the latter part of 1955. The 1948 ABS Rules were applicable to these samples and preliminary data on some of these were presented.[4-6] It is to be noted from Table I that a number of samples in plate thicknesses of 1/2 in. and below (Class A) were provided although, as previously stated, the sampling was intended to be confined to plate over 1/2 in. in thickness (Classes B and C). However, it was decided to include the Class A samples in the testing program for purposes of comparison with Classes B and C.

SOURCE (Geographical Area) / Plate Thickness In.		ABS CLASS (BY THICKNESS) A		B								C							TOTAL
		7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 3/8	1 7/16	1 1/2	
Bay City, Mich.				1		1													2
Boston, Mass.							1	1	1	1	7			1					12
Camden, N.J.				1	1		1	1	1		3		1						9
Chester, Pa.			3	1	2	1	4			1	4		1						17
Lorain, Ohio						2	3					1				1		2	9
Newport News, Va.		3	9	1	5		2	3											23
New Orleans, La.					3		1												4
Pascagoula, Miss.		1	14	1	2	3	2	1											24
Quincy, Mass.				1															1
San Francisco, Calif.			7		6		4	3			4		3	1	2			1	32
TOTAL	Each Size	4	33	6	19	7	18	9	2	2	18	1	5	2	2	1	0	3	132
	Each Class	37		81								14							

TABLE I. INVENTORY OF SAMPLES OF PLATE COVERED BY THE 1948 ABS RULES

At about the time that the experimental work on the above plates had been completed, a new sampling program was initiated in January 1957 by letter instructions from Coast Guard Headquarters to the Marine Inspection Service. This required sampling of plate over 1/2 in. thickness (i.e., Classes B and C) at the rate of one or two per month from each commercial shipyard. This extended sampling program was intended to cover mainly materials of the revised Class B chemistry procured under the 1956 Rules but, at the same time, it provided for additional samples of Class C plate to supplement the relatively small number included in the earlier sampling.

Table II presents an inventory of the samples of plate included in the extended testing program and which were received in the period from January 1957 to January 1959. In many cases, particularly in the earlier sampling program, little information was available as to the previous history of the samples. The experimental work was completed in the Spring of 1960.

SOURCE (Geographical Area) / Plate Thickness In.	ABS CLASS (BY THICKNESS)																	TOTAL
	A		B								C							
	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1-1/16	1-1/8	1-3/16	1-1/4	1-3/8	1-7/16	1-1/2	
Boston, Mass.			1	3		4		1	1	10		2		1				23
Camden, N.J.			1	4		2		1	2	1			1					12
Chester, Pa.			3		1	2		1										7
Toledo, Ohio					5					1								6
Newport News, Va.						4		1		1								6
Pascagoula, Miss.			2	2		2		1		1						1	1	10
San Francisco, Calif.			2	3	1	2		2	1	6	3	1		2				23
Unknown				1														1
TOTAL — Each Size	0	0	9	13	7	16	0	7	4	20	3	3	1	3	0	1	1	88
TOTAL — Each Class	0		76								12							

TABLE II. INVENTORY OF SAMPLES OF PLATE COVERED BY THE 1956 ABS RULES

PROCEDURE

The following tabulation indicates the specific types of tests made on the plate samples:

	Plates Procured Under 1948 ABS Rules	Plates Procured Under 1956 ABS Rules
Microscopic examination	X	X
Composition analysis	X	X
Static tensile test	X	
Charpy V-notch test	X	X
Charpy Keyhole test	X	
Navy tear test	X	

In the later stages of the work on the plates covered by the 1948 Rules, it was decided as a result of discussions of the project by the Committee on Ship Steel to discontinue Charpy keyhole and Navy tear tests in view of the emphasis placed by various investigators on the V-notch test in studies of brittle fracture behavior and the limited amount of information which could be gained from tear tests made only at selected temperatures (the size of the sample plates precluded more extensive testing). Even if a full series of tear tests were made, the information obtained would disclose the fracture appearance transition temperature and not the ductility transition which was considered to be of paramount concern. Consequently, the data for some of the 1948 Rules samples do not include Charpy keyhole and tear tests and those for the 1956 Rules samples also do not include the static tensile test which was considered of marginal value insofar as the project objective was concerned. Details of the experimental work conducted are outlined in the following paragraphs.

Microscopic Examinations. These were made to confirm or establish the direction of rolling and to determine ferrite and McQuaid-Ehn (austenite) grain sizes. In the case of the latter, specimens were packed in a solid carburizing compound heated to 1700°F, held 8 hours at heat, followed by furnace cooling. Grain sizes were estimated by the comparison method, i.e., by comparing the ferrite grains and those in the hypereutectoid zone of the carburized pieces with standard ASTM grain size charts.

Composition Analysis. The samples were analyzed for carbon, manganese, silicon and aluminum contents, mainly for the purpose of typing the steel composition.

Static Tensile Test. Tensile properties were determined on a single specimen taken in the longitudinal direction. In most cases, flat type tension specimens were utilized. Cylindrical specimens were employed when the thickness (heavy gages) or limited size of the samples precluded the preparation of flat specimens.

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 average energy temperature curve, from which the 15-ft-lb transition temperatures and, in some cases, the 25-ft-lb transition temperatures were obtained.

For plate 3/4 in. in thickness and over, the Charpy specimens were taken from a location approximately midway between the center of the plate thickness and one plate surface. In the case of lighter gage plate, one side of the specimen was located close to a plate surface. The notches were cut perpendicularly to the original plate surfaces. Specimens representing the 1948 Rules plates were fractured in a 120 ft-lb Amsler testing machine under a striking velocity of 16.5 fps corresponding to the maximum available kinetic energy of the pendulum. Initial tests of Class B plates under the 1956 Rules showed a few where the energy absorption (at temperatures corresponding to the upper level of the energy-temperature relationship) exceeded the 120 ft-lb capacity of the Amsler machine. Accordingly, the remainder of the tests were performed in a 220 ft-lb Riehle machine under a striking velocity of 18.1 fps.

The data obtained were intended specifically for comparison with the 15-ft-lb V-notch transition temperatures established at the National Bureau of Standards on fractured plates from World War II ships.[1]

<u>Charpy Keyhole-Notch Tests</u>. At the time this project was initiated, many investigators had used and were continuing to use the Charpy keyhole test for evaluating the notch-toughness of steel and it was therefore considered desirable to obtain keyhole-notch data for the SR-125 plate samples. However, as indicated previously, keyhole-notch tests were subsequently discontinued.

In the evaluation of notch-toughness by the Charpy keyhole-notch test, longitudinal specimens were tested in triplicate at each of a number of temperatures so selected as to establish the limits of the scatter region corresponding to the change from high to low energy levels. Different criteria have been used by various investigators for defining the keyhole transition temperature. In this report, two transition temperatures were established: one corresponding to the temperature at the middle of the scatter band, and the other at the 20 ft-lb level (as taken from the average energy-temperature curve). The keyhole specimens were prepared and tested in the same manner as the V-notch specimens using the Amsler machine.

TABLE III
RESULTS OF TESTS ON CLASS A PLATES REPRESENTING THE 1948 ABS RULES

Plate Thick. In.	Plate Code	Composition, % C	Mn	Si	Al	Mn/C	Tensile Properties Y.P. psi	T.S. psi	Elong. % 8"	2"	Grain Size Ferrite	McQ-Ehn	Charpy V Trans. Temp., F 15 Ft-lb V	Keyhole 20 Ft-lb	MOB*	Tear Test 70 F	90 F
7/16	91-74	.21	.39	.03	.003	1.9	34200	56500	28.0	-	8	1-3	50	3	-30	S**	-
(4	-55	.21	.37	.03	.003	1.8	39500	60800	-	39.5	8	2-3	44	-3	-10	S	-
Plates)	-63	.17	.40	.09	.006	2.3	NT	NT	-	-	7-8	2-3	33	NT	NT	S	-
	-70	.20	.49	.07	.006	2.5	34400	56300	32.0	-	8	2-3	28	-3	-5	S	-
Avg		.198	.413	.06	.005	2.1	36000	57900	30.0	-	8	2 1/2	39	-1	-15	-	-
	91-67	.30	.37	.04	.003	1.2	36000	61900	21.5	-	8	1-2	80	50	20	C***	C
1/2	-54	.25	34	.05	.003	1.4	34600	60500	30.5	-	7-8	1-2	67	43	20	C	C
(33	-37	.22	.54	.03	.006	2.5	34800	62400	30.5	-	6-8	2-4	64	27	10	C	S
Plates)	-109	.16	.53	.05	.003	3.3	NT	NT	-	-	8	2-3	61	Δ	-30	C	S
	-108	.22	.35	.05	.002	1.6	31900	58300	26.5	-	7-8	1-2	60	13	-20	S	-
	-122	.24	.43	.06	.010	1.8	NT	NT	-	-	7-8	2-3	55	6	5	C	S
	-78	.19	.32	.03	.004	1.7	34600	56000	30.0	-	7-8	1	47	0	-20	S	-
	-106	.15	.36	.05	.002	2.4	39600	60400	26.5	-	7-8	1-2	47	-10	-25	S	-
	-65B	.24	.51	.03	.004	2.1	NT	NT	-	-	8	2-3	43	0	Δ	NT	NT
	-120	.20	.54	.06	.003	2.7	35200	57500	33.5	-	7-8	1-2	43	-4	-5	C	S
	-98	.19	.81	.08	.002	4.3	32700	56500	27.0	-	7-8	1-2	37	0	-30	S	-
	-62	.23	.60	.07	.010	2.6	34000	58500	31.0	-	8	1-3	35	-5	-15	S	-
	-105	.23	.57	.09	.003	2.5	37800	60000	32.5	-	7-8	1-2	35	17	10	S	-
	-133	.21	.58	.05	.004	2.8	35900	61900	30.5	-	6-7	2-3	35	20	0	S	-
	-115	.19	.69	.06	.002	3.1	35100	57200	32.5	-	7-8	1-2	33	-5	-5	S	-
	-112	.19	.52	.11	.002	2.7	38600	61600	30.5	-	7-8	1-2	32	-2	-15	S	-
	-65A	.19	.42	.07	.005	2.2	34400	55400	29.5	-	7-8	2-3	32	NT	NT	S	-
	-138	.19	.61	.06	.004	3.2	35400	59200	25.5	-	6-7	2-3	28	-20	-45	S	-
	-53	.18	.37	.08	.007	2.1	34800	58100	30.0	-	7-8	2-3	27	8	0	C	S
	-130	.15	.69	.05	.004	4.6	35800	57500	30.0	-	6-7	1-2	27	-23	-30	S	-
	-49	.21	.43	.07	.005	2.0	34400	55200	32.5	-	7-8	3-4	26	-8	-10	S	-
	-41	.17	.55	.06	.004	3.2	35400	58000	29.5	-	6-7	2-4	25	-15	-30	S	-
	-111	.19	.56	.09	.005	2.9	38300	61500	31.5	-	7-8	2-3	22	8	5	S	-
	-126	.21	.56	.08	.004	2.7	38600	62800	27.0	-	7-8	2-3	22	-22	-40	S	-
	-39	.17	.57	.06	.016	3.4	39400	61700	28.3	-	7-8	3-4	20	-12	-20	S	-
	-136	.18	.60	.10	.003	3.3	39600	64900	25.5	-	7	2-3	19	-20	-30	S	-
	-59	.21	.73	.05	.005	3.5	36300	61500	25.8	-	7-8	3-4	12	-8	-20	S	-
	-93A	.27	.90	.07	.002	3.3	39500	63500	-	30.0	7-8	2	10	NT	NT	C	S
	-84	.19	.72	.07	.007	3.8	36100	58800	28.0	-	7-8	2-3	10	-12	-20	S	-
	-87	.14	.72	.11	.006	5.1	33400	55400	30.0	-	7-8	2-3	5	NT	NT	S	-
	-95	.16	.82	.13	.003	5.1	36300	60400	26.5	-	7-8	3-4	-12	-28	Δ	S	-
	-81	.18	.79	.10	.005	4.4	36400	56200	28.0	-	7-8	2-3	-18	-35	-35	S	-
	-101	.12	.68	.10	.004	5.7	38000	59600	30.0	-	6-7	1-2	-24	-50	-50	S	-
Avg.		.200	.571	.07	.005	2.9	36100	59400	29.0	-	7 1/2	2 1/4	30	-3	-15	-	-
Grand Avg. (37 Plates)		.200	.554	.07	.005	2.8	36100	59300	29.1	-	7 1/2	2 1/4	31	-3	-15	-	-
ABS Specification, Class A (1948 Rules)							32000 (Min)	58000 71000	21.0 Min.	22.0 Min.							

* MOB - Temperature at middle of scatter band
** S - Predominantly fibrous fracture in all specimens tested
*** C - Predominantly granular fracture in one or more specimens
NT - Not tested
Δ - Insufficient tests conducted to establish value

The apparatus, experimental procedure and method of evaluating results of tear tests have been fully described in several papers by Kahn and Imbembo.[7-9] Tear specimens were tested in full plate thickness except in the case of plate over 1 1/4 in. thickness where the specimens were machined to a thickness of 1 1/4 in. by removing material from one plate surface. This procedure was adopted in order to avoid excessive deformation of the loading pin holes which usually occurs in testing specimens of greater thickness.

Navy Tear Tests. Specimens taken in the longitudinal direction were tested at one or two selected temperatures. It was believed that this might provide sufficient information to compare the relative behavior of the samples among themselves but, for reasons indicated above, tear testing was subsequently discontinued. In those cases where tear tests were made, they were conducted initially at 70F. If the fractures of three specimens tested at this temperature all showed predominantly fibrous appearance (50% or more), no further tests were made. When the fracture appearance of any specimen tested at 70F was predominantly granular (less than 50% fibrous), tests were then made at 90F.

RESULTS AND DISCUSSION

Samples Representing the 1948 ABS Rules.

Results of experimental work on 37 Class A, 81 Class B, and 14 Class C plates are summarized in Tables III, IV and V, respectively. The grouping of samples into these three classes was made on the basis of as-rolled plate thickness in accordance with ABS Rules. For each plate thickness, the samples have been arranged in order of decreasing 15-ft-lb Charpy V-notch transition temperature.

The following general observations may be made from these data:

Class A Plates (Table III)

a. Using aluminum and silicon contents as criteria, all plates appear to have been rolled from semikilled ingots.

b. The plates showed low residual aluminum contents and correspondingly coarse McQuaid-Ehn (austenite) grain sizes.

c. Thirteen of the 1/2 in. thick plates showed manganese contents in the range specified for Class B (0.60/0.90%). In this connection, a manganese content of 0.56% may be considered as the lower limit of Class B chemistry in view of the fact that the Rules are based on ladle analysis and a minus 0.04% variation from the specified 0.60% min. represents an accepted ASTM deviation in check analyses of individual pieces from a heat. On this basis, 5 additional 1/2 in. plates or a total of 18 may be considered to be of Class B chemistry.

d. The 1/2 in. thick samples in which the manganese content approached 0.60% or was within the 0.60/0.90% range, exhibited Charpy V-notch transition temperatures at the lower end of the overall range.

Class B Plates (Table IV)

a. Judging from the aluminum and silicon contents, all plates were considered to have been rolled from semikilled steel, with the following exceptions:

Plate No.	Plate Thick.	Si, %	Al, %	McQ-Ehn Gr. Size
91-132	11/16 in.	.26	.003	2
91-31	11/16 in.	.05	.021	2/3
91-29	3/4 in.	.21	.006	6/7
91-123	3/4 in.	.30	.030	7/8
91-36	13/16 in.	.04	.027	2/4
91-42	13/16 in.	.04	.036	7/8
91-38	1 in.	.18	.004	2/4

These plates (with the possible exception of 91-31) are sufficiently deoxidized that they are either killed or approaching the killed steel type of practice. Plates 91-29 and 91-123 conform to Class C requirements.

b. All plates were classified as being of the coarse-grain type by the McQuaid-Ehn test with the exception of 91-29 which was silicon killed, and 91-123 and 91-42 which showed a aluminum contents in the range of 0.030-0.036% (see tabulation in paragraph immediately above). It is unusual that plate 91-29 showed a fine austenite grain size with a low aluminum content, since silicon killing (without aluminum) would normally produce a coarse grain size; however, it is possible that some other grain refining element was employed. Although plates 91-31 and 91-36 showed rather high total aluminum contents, the austenite grain size was coarse. Of the fine grain steels, plates 91-29 and 91-123 exhibited the lowest Charpy V transition temperatures of all Class B plates, while that of 91-42 was

TABLE IV
RESULTS OF TESTS ON CLASS B PLATES REPRESENTING THE 1948 ABS RULES

Plate Thick. In.	Plate Code	Composition, % C	Mn	Si	Al	Mn/C	Tensile Properties Y.P. psi	T.S. psi	Elong. % 8"	2"	Grain Size Fer-rite	McQ-Ehn	Charpy Transition Temperature, °F V 15 Ft-lb	Keyhole 20 Ft-lb	MOB*	Tear Test 70°F	90°F
	91-13	.22	.81	.04	.004	3.7	38500	65200	28.0	-	7-8	2-4	45	0	-21	C***	B**
9/16	-60	.19	.74	.05	.009	3.9	32400	55200	29.5	-	7-8	2-3	39	NT	NT	B	-
(6 plates)	-15	.21	.76	.04	.008	3.6	39000	61500	31.9	-	8	1-3	15	6	0	B	-
	-6	.18	.80	.03	.009	4.4	34900	60200	-	50.0	7-8	2-3	10	0	2	B	-
	-93B	.18	.74	.09	.006	4.1	31600	53200	26.0	-	7-8	2-3	5	NT	NT	B	-
	-90	.14	.71	.10	.008	5.1	35000	56800	30.0	-	7-8	2-4	2	-30	-35	B	-
Avg.		.187	.760	.06	.008	4.1	35200	58700	29.1	-	7 1/2	2 1/2	19	-6	-14	-	-
	91-10	.22	.67	.06	.008	3.2	35800	57300	32.8	-	5-6	1-3	35	-3	-10	B	-
	-83	.20	.71	.07	.005	3.5	35600	62800	32.5	-	7-8	2-3	35	0	-15	C	B
5/8	-94	.16	.69	.06	.005	4.3	32500	55400	27.5	-	7-8	1	35	NT	NT	B	-
(19 plates)	-27	.24	.79	.04	.002	3.3	36200	64200	26.5	-	7-8	2-4	33	-10	-15	C	B
	-92	.15	.61	.06	.003	4.1	31200	53500	-	56.5	7-8	2-3	31	NT	NT	C	B
	-99	.16	.68	.09	.004	4.3	31400	54600	32.0	-	7-8	1-2	28	NT	NT	C	B
	-128	.20	.79	.04	.004	4.0	33600	59200	30.5	-	6-7	1-2	27	-10	-10	C	B
	-2A	.19	.78	.05	.010	4.1	35000	58500	26.5	-	7-8	1-3	26	21	15	B	-
	-2C	.21	.74	.04	.006	3.5	32200	57800	32.3	-	6-7	1-3	25	20	20	B	-
	-114	.18	.74	.11	.002	4.1	38400	65000	30.0	-	6-7	1-2	23	-16	-25	C	B
	-107	.21	.71	.11	.002	3.4	36000	62400	30.5	-	7-8	1-2	23	NT	NT	B	-
	-127	.26	.81	.05	.004	3.1	36600	62700	25.5	-	7	2-3	22	-20	-25	C	B
	-28	.18	.80	.05	.009	4.4	31600	58100	34.2	-	6-7	1-3	20	15	15	B	-
	-7	.22	.76	.07	.010	3.5	40500	63600	29.8	-	8	2-3	18	-15	-20	B	-
	-103	.13	.81	.05	.005	6.2	42100	67500	27.0	-	7-8	2-3	18	-15	-20	B	-
	-22	.18	.72	.04	.018	4.0	31800	56500	36.5	-	5-7	1-3	16	-18	-15	C	B
	-16	.25	.78	.05	.009	3.1	38300	67600	28.3	-	6	2-3	15	-20	-30	B	-
	-137	.17	.87	.07	.005	5.1	38100	61800	31.5	-	7-8	2-3	15	-22	-25	B	-
	-26	.19	.77	.03	.002	4.1	32200	54400	35.5	-	6-7	2-4	12	-19	-20	B	-
Avg.		.194	.749	.06	.006	3.9	35200	60200	30.5	-	7	2 1/4	24	-7	-12	-	-
	91-73	.20	.61	.05	.005	3.0	29400	55700	32.0	-	7	1-2	52	NT	NT	B	-
11/16	-129	.22	.86	.03	.005	3.9	35300	60700	29.0	-	7	1-2	43	-14	-25	C	B
(7 plates)	-132	.25	.82	.26	.003	3.3	44200	76000	-	36.5	7-8	2	36	0	-15	C	C
	-31	.19	.72	.05	.021	3.8	40800	63700	25.0	-	5-7	2-3	32	2	-10	B	-
	-5	.24	.79	.03	.007	3.3	35900	65000	31.0	-	7-8	2-4	26	-5	-13	B	-
	-48	.23	.81	.07	.008	3.5	39400	67600	-	35.0	6-8	2-4	3	-15	-25	B	-
	-19	.18	.79	.08	.007	4.4	39700	61500	31.7	-	5-7	2-4	-10	-56	-57	B	-
Avg.		.216	.771	.08	.008	3.6	37800	64300	29.7	-	6 3/4	2 1/4	26	-15	-24	-	-
	91-104	.19	.74	.04	.003	3.9	40400	70500	-	37.0	7-8	1-2	52	10	0	C	C
	-71	.21	.80	.04	.008	3.8	31200	56600	32.0	-	7-8	1-2	42	-10	-20	C	C
3/4	-4	.27	.73	.14	.005	2.7	38800	73000	-	36.5	5-6	1-3	41	8	-5	C	C
(18 plates)	-121	.26	.81	.07	.004	3.2	42200	67200	-	52.0	7-8	1-2	37	15	10	C	B
	-102	.18	.72	.06	.004	4.0	36100	61200	33.5	-	7-8	1-2	35	0	0	C	C
	-131	.18	.81	.03	.004	4.5	33600	59500	32.0	-	6-7	1-2	34	0	0	C	C
	-51	.17	.75	.05	.010	4.4	30000	55200	33.0	-	6-7	3-4	31	5	0	C	C
	-85	.19	.72	.07	.008	3.8	32000	56400	29.0	-	7	2-3	31	5	-15	B	-
	-3	.22	.71	.06	.010	3.2	37500	67800	29.8	-	6-7	2-3	27	-5	-8	C	C
	-134	.21	.78	.09	.004	3.7	36900	62800	32.0	-	7	1-2	20	10	5	C	B
	-40	.21	.76	.04	.006	3.6	34900	64300	30.5	-	7-8	1-2	16	0	10	C	C
	-118	.19	.75	.10	.002	3.9	40000	71000	-	35.0	7-8	2-3	15	-20	-45	C	B
	-32	.17	.85	.05	.007	5.0	32900	63300	31.5	-	7-8	2-3	13	0	-5	B	-
	-47	.19	.70	.05	.013	3.7	35200	61400	33.5	-	7-8	2-4	7	-6	-5	B	-
	-1	.21	.83	.05	.005	4.0	40000	68100	-	36.5	7-8	2-3	4	-7	-15	C	B
	-17	.15	.77	.07	.016	5.1	33000	54700	31.6	-	5-6	3-5	-4	-23	-30	B	-
	-29	.17	.70	.24	.006	4.1	32800	61800	31.5	-	5-6	6-7	-20	-47	-55	B	-
	-123	.19	.77	.30	.030	4.1	41100	66500	29.0	-	7-8	7-8	-22	-57	-80	B	-
Avg.		.200	.763	.09	.008	3.8	36000	63400	31.5	39.4	7	2 3/4	20	-7	-14	-	-
	91-42	.17	.57	.04	.016	3.3	31600	57200	33.8	-	6	7-8	47	15	15	C	C
13/16	-125	.15	.67	.08	.003	4.5	34000	58600	32.0	-	7-8	3-4	57	15	15	C	C
(9 plates)	-36	.17	.65	.04	.027	3.8	30700	56600	39.5	-	5-6	2-4	37	8	5	C	C
	-25	.19	.60	.03	.010	3.2	31200	54400	36.0	-	6	2-3	35	5	5	B	-
	-97	.16	.75	.09	.002	4.7	NT	NT	-	-	6-7	1-2	33	NT	NT	C	C
	-20	.24	.93	.06	.005	3.8	41200	69900	29.8	-	7-8	1-3	31	7	-3	B	-
	-28	.26	.67	.06	.003	2.6	32000	61400	29.0	-	5-6	2-3	30	-3	-10	C	C
	-21	.17	.74	.05	.010	4.4	31700	53400	34.5	-	6-7	1-3	28	6	5	B	-
	-76	.15	.73	.10	.013	4.9	34100	56600	31.0	-	7-8	1-2	-2	-15	-45	B	-
Avg.		.184	.700	.06	.011	3.8	33300	58500	33.2	-	6 1/2	3	32	2	-2	-	-
7/8	91-77	.17	.60	.04	.005	3.5	29200	55000	33.0	-	7-8	1-2	50	NT	NT	C	C
(2 plates)	-68	.13	.59	.08	.008	4.5	NT	NT	-	-	6-7	1-2	45	NT	NT	B	-
Avg.		.150	.595	.06	.007	4.0	-	-	-	-	7	1 1/2	48	-	-	-	-
15/16	91-58	.24	.60	.05	.005	2.5	33200	61500	30.5	-	6-7	1-2	47	23	10	C	C
(2 plates)	-61	.17	.80	.06	.011	4.7	30800	56200	32.0	-	7	1-2	35	NT	NT	C	C
Avg.		.205	.700	.06	.008	3.4	32000	58900	31.3	-	6 3/4	1 1/2	41	-	-	-	-

TABLE IV (Continued)

Plate Thick In.	Plate Code	Composition, % C	Mn	Si	Al	Mn/C	Tensile Properties Y.P. psi	T.S. psi	Elong. % 8"	2"	Grain Size Fer-rite	McQ-Ehn	Charpy Transition Temperature, °F V 15 ft-lb	Keyhole 20 ft-lb	MOB*	Tear Test 70°F	90°F
	91-91	.22	.69	.06	.005	3.1	30000	59000	30.0	-	7	1-2	45	NT	NT	C	C
	-80	.13	.63	.06	.012	4.8	32500	55700	29.5	-	6-7	1-3	53	NT	NT	C	C
	-116	.19	.69	.06	.002	3.6	30900	60100	-	41.0	6-7	2-3	52	NT	NT	C	S
	-14	.24	.67	.07	.008	2.8	37900	63500	31.8	-	7-8	1-3	51	20	5	C	S
	-100	.15	.70	.05	.002	4.7	34500	59100	-	40.0	7-8	1-2	51	18	0	C	C
	-110	.23	.60	.10	.003	2.6	36400	60600	-	39.5	7-8	1-2	50	12	0	C	C
	-30	.20	.76	.04	.003	3.8	28100	54100	33.0	-	5-6	2-4	47	5	5	C	C
	-52	.19	.65	.08	.006	3.4	39200	60800	-	47.0	6	2-3	46	42	20	C	S
1	-68	.20	.74	.05	.007	3.7	29800	57900	32.5	-	7	2	46	NT	NT	C	C
(18 plates)	-12	.22	.64	.06	.006	2.9	32700	62600	31.8	-	7	2-3	45	24	15	C	C
	-41	.16	.68	.04	.007	4.3	27600	54200	31.4	-	5-6	2-3	45	18	10	C	C
	-50	.19	.70	.04	.005	3.7	32300	58200	35.5	-	5-7	2-4	60	26	15	C	C
	-117	.19	.75	.06	.002	3.9	35500	68200	-	39.0	7-8	1	60	10	0	C	C
	-11	.18	.71	.05	.015	3.9	31900	57100	34.7	-	5-6	2-4	29	20	15	C	S
	-46	.16	.73	.04	.012	4.6	29900	57600	33.5	-	5-7	2-3	17	10	5	C	C
	-38	.25	.79	.18	.004	3.2	46800	80300	-	32.5	7	2-4	10	-5	-35	NT	NT
	-34	.19	.85	.04	.010	4.5	30100	56500	33.2	-	6-7	1-3	15	20	20	C	C
	-82	.22	.67	.07	.003	3.0	29400	55400	33.0	-	6-7	1-2	23	NT	NT	C	C
Avg.		.195	.703	.06	.006	3.6	33100	60100	32.5	39.8	6 1/2	2 1/4	44	17	6	-	-
Grand Average (81 Plates)		.195	.734	.07	.007	3.8	34800	60900	31.3	40.9	6 3/4	2 1/4	29	-1	-9	-	-
ABS Specification, Class B, 1948 Rules Max.		.23	.60 / .90				32000 Min.	58000 / 71000	21.0 Min.	22.0 Min.							

* Temperature at middle of scatter band
** S - Predominantly fibrous fracture in all specimens tested
*** C - Predominantly granular fracture in one or more specimens
NT - Not tested

TABLE V
RESULTS OF TESTS ON CLASS C PLATES REPRESENTING THE 1948 ABS RULES

Plate Thick. In.	Plate Code	Composition, % C	Mn	Si	Al	Mn/C	Tensile Properties Y.P. psi	T.S. psi	Elong. % 8"	2"	Grain Size Fer-rite	McQ-Ehn	Charpy Transition Temperature, °F V 15 ft-lb	V 25 ft-lb	Keyhole 20 ft-lb	MOB*	Tear Test 70°F	90°F
1 1/16	91-66	.24	.68	.25	.019	2.8	NT	NT	NT	NT	7-8	8	0	18	-45	-65	S**	-
1 1/8	-72	.15	.65	.23	.012	4.3	32800	57200	30.5	-	6	6-7	2	18	-27	-40	C***	S
(5	-18	.19	.68	.25	.019	3.6	33700	61300	34.2	-	4-6	7-8	-3	10	-20	-20	C	S
plates)	-24	.22	.77	.28	.026	3.5	32200	59500	33.0	-	5-6	5-7	-16	1	-37	-55	S	-
	-35	.19	.73	.19	.042	3.8	30900	58300	32.0	-	5-6	8	-18	-3	-44	-40	C	C
	-56	.19	.76	.22	.026	4.0	32100	58000	34.1	-	6	8	-20	-2	-24	-40	C	C
Avg.		.188	.718	.23	.025	3.8	32300	58900	32.8	-	5 1/2	7 1/4	-11	5	-30	-39	-	-
1 3/16	-23	.21	.66	.19	.010	3.1	31800	57400	32.6	-	5	5-7	10	25	-25	-27	C	C
(2 plates)	-89	.19	.71	.25	.026	3.7	35600	62500	29.5	-	6-7	8	10	25	-43	-60	C	S
Avg.		.200	.685	.22	.018	3.4	33700	60000	31.1	-	5 3/4	7	10	25	-34	-44	-	-
1 1/4	-79	.23	.69	.27	.044	3.0	32600	63900	29.0	-	6-7	7-8	6	27	-40	-60	C	S
(2 plates)	-43	.16	.73	.21	.049	4.6	32700	59000	31.7	-	5-6	8	-2	8	-40	-50	C	C
Avg.		.195	.710	.24	.047	3.6	32700	61500	30.4	-	6	7 3/4	2	18	-40	-55	-	-
1 3/8	-9	.19	.61	.20	.040	3.2	36300	59200	27.3	-	6-7	7-8	-23	-10	-45	-50	C	S
1 1/2	88	.20	.68	.25	.020	3.4	41500	68000	-	35.0	6-7	8	5	20	-20	-35	C	C
(3 plates)	33	.15	.62	.23	.025	4.1	33600	61000	29.7	-	4-6	8	3	10	-20	-35	C	C
	-86	.12	.61	.25	.025	5.1	34000	58000	-	41.5	5-6	8	-28	-20	Δ	-60	S	-
Avg		.157	.637	.24	.023	4.1	36400	62300	-	38.3	5 1/4	8	-7	3	-20	-40	-	-
Grand Average (14 plates)		.188	.684	.23	.027	3.6	33800	60300	31.2	38.3	5 3/4	7 1/2	-5	9	-33	-45	-	-
ABS Specification Class C, 1948 Rules ΔΔ		0.25 Max.	0.60 / 0.90	.15 / .30	-		32000 Min.	58000 / 71000	21.0 Min.	22.0 Min.								

* Temperature at middle of scatter band
** S - Predominantly fibrous fracture in all specimens tested
*** C - Predominantly granular fracture in one or more specimens

NT - Not tested
Δ - Insufficient tests conducted to establish value
ΔΔ - Shall be made with fine grain practice.

relatively high.

Class C Plates (Table V)

a. All plates are 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, as required.

b. In view of the fact that some investigators feel that Charpy V transition temperatures of steels of the Class C type should be based on an energy level higher than 15 ft-lb, Table V also includes 25 ft-lb transition temperatures.

Some plates exhibited tensile properties which deviated appreciably from the requirements of the Rules. Considering the uncertain background history, it is possible that these may not have been procured under ABS Rules. However, in view of the large number of samples included in the program, it is considered that the overall trends established are still valid.

A graphical summary of the results of longitudinal Charpy V-notch tests of the 132 samples covered by the 1948 Rules is presented in Fig. 1. This graph shows the percentage of plates in each 10 F interval of transition temperature plotted against the 15 ft-lb transition temperature. Included is a frequency distribution for 47 fracture-source and 73 fracture-through plates from World War II ships.[1] With the exception of three plates, all of the fracture-source plates contained 0.55% Mn or less. The three plates which had manganese contents of 0.56, 0.56, and 0.67% exhibited transition temperatures (59, 83, 66 F, respectively), at the lower end of the overall range of 59 to 152 F. The frequency distribution of the SR-125 samples combines all Class A, B and C plates, and it is to be noted that the graph is displaced to a region of considerably lower temperature as related to that of the fracture-source plates, the average transition temperature for the former being 26 F, as compared to 90 F for the latter, and 68 F for the fracture-through plates.

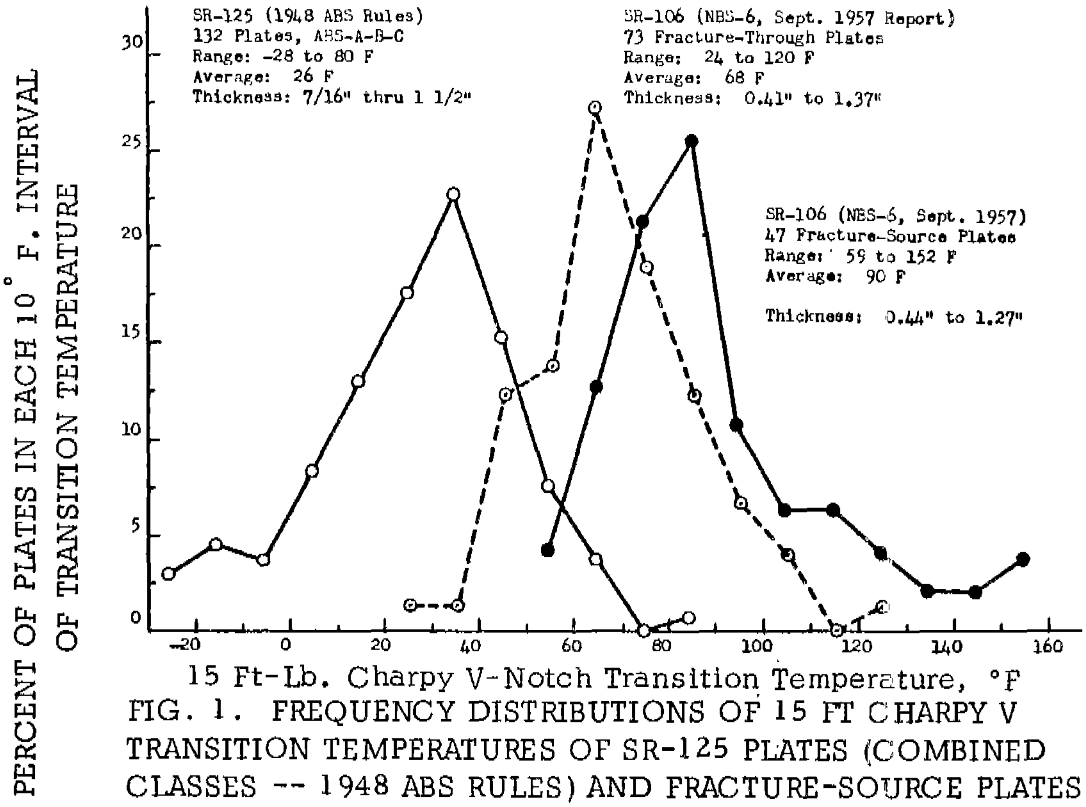


FIG. 1. FREQUENCY DISTRIBUTIONS OF 15 FT CHARPY V TRANSITION TEMPERATURES OF SR-125 PLATES (COMBINED CLASSES -- 1948 ABS RULES) AND FRACTURE-SOURCE PLATES (SR-106)

A breakdown of the data for the 132 SR-125 plates is indicated in the frequency distributions of Fig. 2, in which the plates have been grouped as A, B and C in accordance with ABS classification based on thickness. Overall ranges and averages of 15-ft-lb Charpy V transition temperatures are as follows:

	Range	Average
Class A	-24 to 80 F	31 F
Class B	-22 to 65 F	29 F
Class C	-28 to 10 F	-5 F
Fracture-source	59 to 152 F	90 F

It is to be noted from the above and Fig. 2 that the behavior of the Class A and B plates is similar except that the plot for the Class A plates shows more of an overlap with that of the fracture-source plates. Aside from transition temperature differences attributed to smaller gage thickness, the relatively good performance of the Class A plates as compared to Class B can be explained by the fact that approximately half of the Class A samples

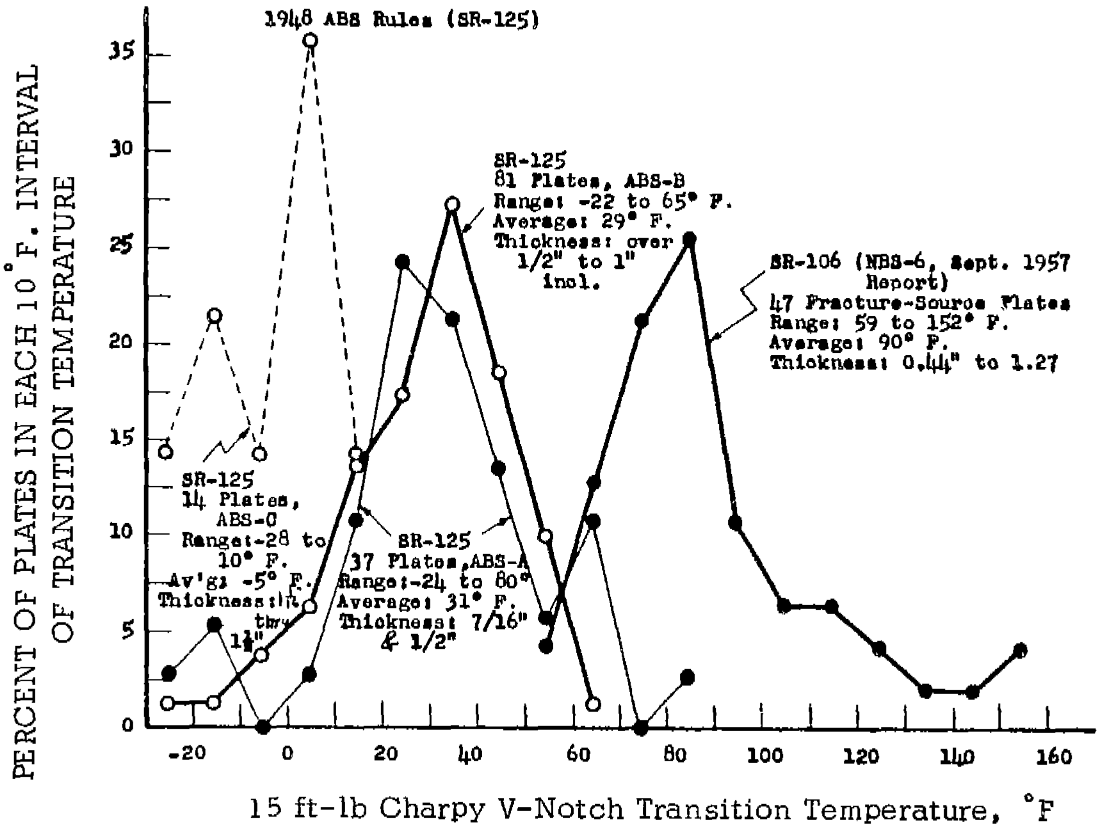


FIG. 2. FREQUENCY DISTRIBUTIONS OF 15 FT-LB CHARPY V TRANSITION TEMPERATURES OF SR-125 PLATES (BY CLASSES BASED ON THICKNESS--1948 ABS RULES) AND FRACTURE-SOURCE PLATES (SR-106)

are in reality of Class B chemistry (0.56% Mn is being considered here as the lower limit for Class B chemistry on check analyses). The following tabulation provides a comparison among the three classes on the basis of the ABS thickness classification and chemistry type:

	Thickness, in.	No. Plates	15-ft-lb Charpy V Transition Temp. °F Range	Avg.
Class A, by thickness	1/2 & Under	37	-24 to 80	31
Class A, by chemistry (Mn<0.56%, S.K.)	1/2 & Under	19	25 to 80	45
Class B, by thickness	Over 1/2 thru 1	81	-22 to 65	29
Class B, by chemistry (Mn.56/.94%, virtually all S.K., coarse grain)	1/2 thru 1	97	-24 to 65	28
Class C, by thickness	Over 1 thru 1 1/2	14	-28 to 10	-5
Class C, by chemistry (Mn.56/.94%, F.K., fine grain)	3/4 thru 1 1/2	16	-28 to 10	-7

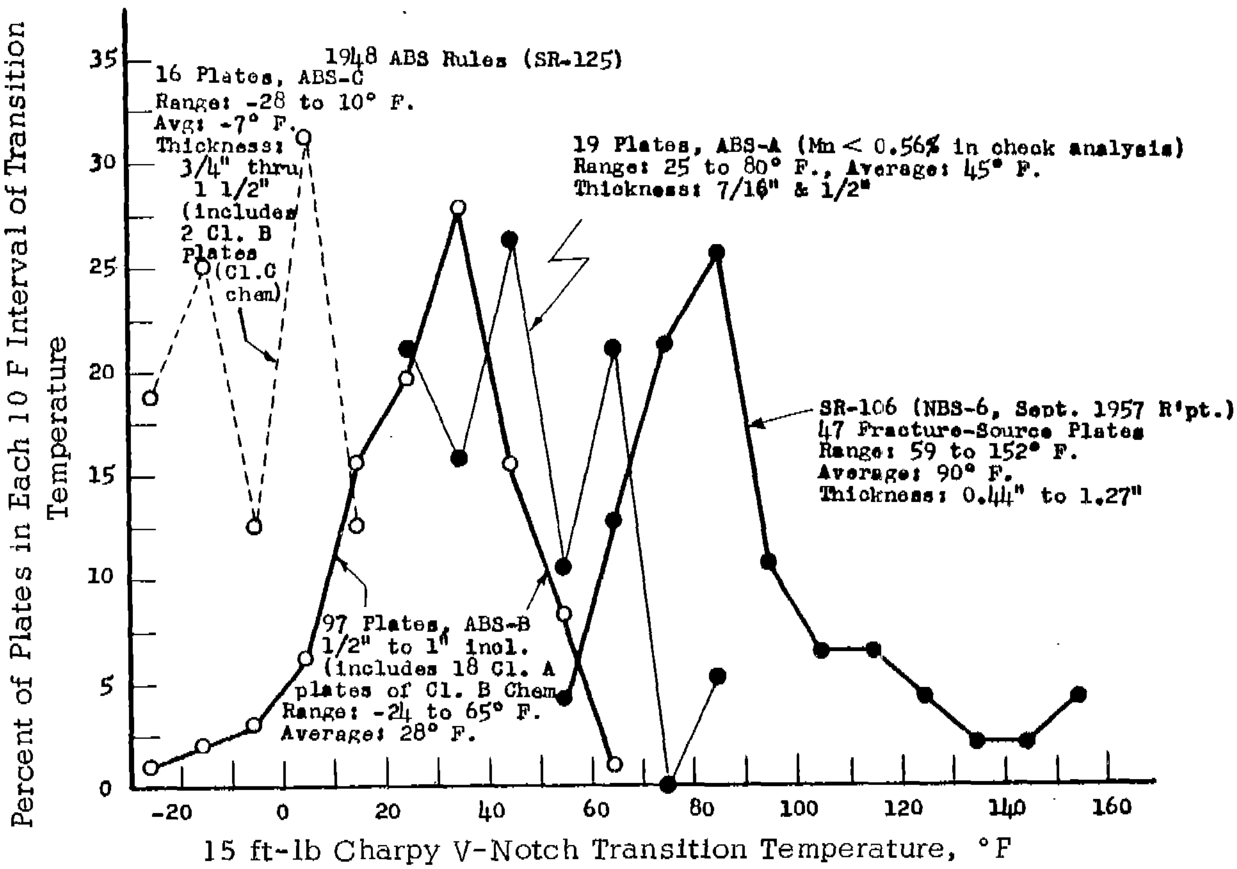


FIG. 3. FREQUENCY DISTRIBUTIONS OF 15 FT-LB CHARPY V-TRANSITION TEMPERATURES OF PLATES PROCURED UNDER 1948 ABS RULES (BY CLASSES BASED ON CHEMISTRY) AND FRACTURE-SOURCE PLATES (SR-106)

Figure 3 presents the frequency distributions based on rearrangement of the data in accordance with classification of the plates by chemistry types rather than by thickness. From the above tabulation and comparison of Fig. 3 with Fig. 2, it is to be noted that the position of the Classes B and C materials relative to the grouping by thickness are virtually unchanged. However, the position of the plot for the Class A type analysis, as a result of exclusion of the 18 plates of Class B chemistry, is appreciably shifted to a region of higher temperature with the overall range of transition temperature changed from -24/80 F to 25/80 F and the average from 31 to 45 F. This, of course, is due to the fact that this plot includes only those Class A thickness plates with Mn under 0.56%.

Class (By Thickness)	Plate Thickness In.	Total No. of Plates Tested	Test Temp.: 70°F. Fibrous Fracture No.	% Total	Test Temp.: 90°F* Fibrous Fracture No.	% Total
A	7/16 to 1/2	36	28	78	34	94
B	9/16 to 5/8	25	16	64	25	100
	11/16 to 3/4	25	11	44	16	64
	13/16 to 7/8	11	5	45	5	45
	15/16 to 1	19	0	0	4	21
	All Class B	80	32	40	50	63
C	Over 1 to 1 1/2	14	3	21	8	57

TABLE VI
RELATIVE FRACTURE BEHAVIOR OF PLATES IN NAVY TEAR TEST
(Samples Representing 1948 ABS Rules)

Class (By Chemistry Type)	Thickness In.	Total No. of Plates Tested	Test Temp.: 70°F Fibrous Fracture No.	% Total	Test Temp.: 90°F* Fibrous Fracture No.	% Total
A	7/16 to 1/2	18	11	61	16	89
B	1/2	18	17	94	18	100
	9/16 to 5/8	25	16	64	25	100
	11/16 to 3/4	23	9	39	14	61
	13/16 to 7/8	11	5	45	5	45
	15/16 to 1	19	0	0	4	21
	All Class B	96	47	49	66	69
C	3/4 to 1 1/2	16	5	31	10	63

* While plates which developed fibrous fractures at 70° were not actually tested at 90°F, it can be assumed that their fractures at 90°F would be fibrous.

The following tabulation indicates differences between Charpy keyhole and V transition temperatures, as previously defined:

Steel (by chemistry type)	ΔT (°F) between 20 ft-lb K and 15 ft-lb V Trans. Temp. Range	Average	Δ (°F) Between Middle of Scatter B and K and 15 ft-lb V Trans. Temp. Range	Average
A	19/57	38	27/91	54
B	4/57	31	5/73	38
C	4/53	29	17/70	41

These data indicate that the difference between Charpy keyhole and V-transition temperatures varies over a considerable range, but there were relatively few values at or close to the extremities of the above indicated ranges. Perhaps part of this variation is associated with the inherent difficulty of precisely determining the transition temperatures. However, the average differences appear to be in line with those indicated by other investigators.

The relative fracture behavior of the plates in the Navy tear test has been summarized in Table VI. In the case of Class B plates, the data indicate that, in general, as the plate thickness increases, fewer plates exhibit fibrous fracture at 70 and 90 F. This means that for a given kind of steel the notch-toughness, as evaluated by this fracture appearance criterion, decreases with increasing plate thickness. A similar trend was noted for the Charpy test, as will be seen later. In the upper portion of Table VI, covering the steel classifications by thickness, it would appear that in tests made at 70 F, the Class A plates are superior to Class B. This is in part due to thickness effect but it is also influenced by the fact that half of the Class A thickness plates are of Class B chemistry. In the lower portion of the tabulation, these 18 plates (1/2 in. thick) were removed from the Class A category and put into Class B; the superiority of the Class B type analysis for plates of like thickness is now evident. While Table VI shows the Class C material to be superior to some of the heavier gages of Class B, its performance is not as good as that of the lighter gage Class B or, for that matter, Class A plates. However, the Charpy test rates Class C as considerably superior in notch-toughness to both Class A and B. It is considered that the thickness effect is more pronounced in the tear test and overrides the improvements in chemistry in going from Class A to Class C. It is apparent, therefore, that the two testing techniques rate the steels quite differently.

Samples Representing the 1956 ABS Rules

Results of experimental work on 76 Class B and 12 Class C plates are summarized in Tables VII and VIII, respectively. The grouping of the data is similar to that for the samples representing the 1948 rules. In the case of the Class B plates (Table VII), it is to be noted that four 1 in. thick plates (Nos. 95-231, -207, -180, -258) are of the Class C type which is permissible under the Rules. On the basis of silicon content (Al was not determined for this series), all other Class B plates appear to be made of semikilled steel, with a coarse grain practice except for four plates (Nos. 95-221 (11/16 in), 95-211(3/4 in), 95-235(3/4 in), 95-182(1 in)) which exhibited a fine austenite grain. Referring to Table VIII, it may be noted that the transition temperatures of the 1 7/16 in and 1-1/2 in. thick Class C plates are among the lowest which would suggest that these plates may have been normalized in line with the requirements of the 1956 Rules for plate over 1 3/8 in. thickness.

TABLE VII
RESULTS OF TESTS ON CLASS B PLATES REPRESENTING THE 1956 ABS RULES

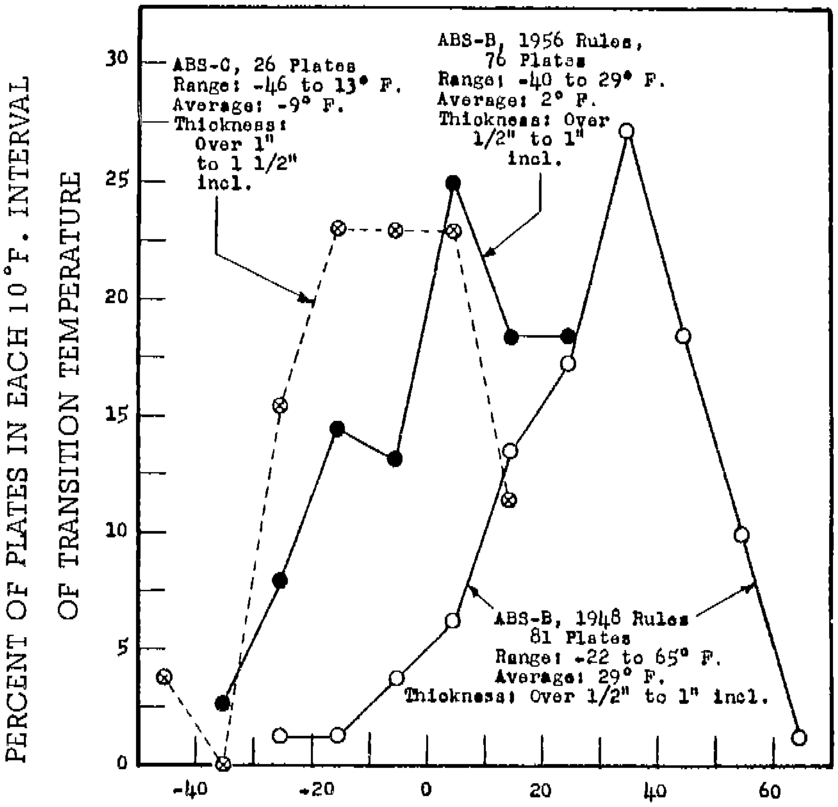
Plate Thick., In.	Plate Code	Composition, % C	Mn	Si	Mn/C	Grain Size Ferrite	McQ-Ehn	Charpy V 15 Ft-Lb Trans. Temp. °F
9/16	95-219	.22	1.05	.07	4.8	8	2	28
	-218	.19	1.03	.08	5.4	7	2	20
(9 plates)	-202	.14	.92	.04	6.6	7	1-2	15
	-217	.15	.91	.04	6.1	7	1-2	12
	-162	.16	.96	.05	6.0	6-7	2-3	8
	-174	.15	1.01	.05	6.7	6-7	1-2	3
	-212	.19	1.06	.08	5.6	8	1	-2
	-183	.13	1.03	.06	7.9	7-8	1-2	-11
	-232	.14	82	.07	5.9	6-7	2-4	-23
	Avg.	.163	.977	.06	6.0	7.0	2.0	6
5/8	95-238	.22	.89	.03	4.0	7	2	20
	-214	.14	.89	.05	6.4	6	1-2	15
(13 plates)	-241	.21	.98	.04	4.7	7-8	1-2	12
	-213	.15	1.02	.04	6.8	5-6	2	10
	-253	.21	.92	.07	4.4	8	2-3	10
	-234	.24	1.13	.04	4.7	7-8	1-2	0
	-250	.15	1.08	.03	7.2	7-8	1-2	0
	-193	.17	1.01	.04	5.9	7-8	1-2	-3
	-184	.13	.89	.05	6.8	7-8	1-2	-4
	-248	.15	.96	.05	6.4	7-8	2	-8
	-206	.18	.99	.06	5.5	7-8	1	-11
	-186	.14	1.04	.06	7.4	7	1-2	-18
	-226	.11	1.02	.09	9.3	7	2-3	-20
	Avg.	.169	.986	.05	5.8	7 1/4	1 3/4	0
11/16	95-161	.19	.85	.03	4.5	7	2-3	23
	-220	.17	.87	.05	5.1	7	2-3	22
(7 plates)	-191	.12	.97	.05	8.1	7	1-2	14
	-176	.17	1.02	.04	6.0	6-7	1-2	0
	-177	.18	1.04	.04	5.8	6-7	1-2	-2
	-229	.14	.87	.04	6.2	7	1-2	-5
	-221	.18	1.04	.08	5.8	7	6-7	-40
	Avg.	.164	.951	.05	5.8	7.0	2 1/2	2
3/4	95-210	.14	.88	.06	6.3	6-7	1-2	29
	-175	.18	.96	.04	5.3	6-8	1-2	23
(16 plates)	-173	.17	1.18	.07	6.9	7	1-2	22
	-171	.20	.92	.04	4.6	6-7	1-2	20
	-240	.20	1.06	.04	5.3	7-8	2-3	14
	-244	.19	1.09	.05	5.7	6-7	1-2	13
	-223	.20	.96	.09	4.8	6-7	2-3	7
	-236	.21	1.01	.03	4.8	7	1-2	7
	-179	.18	.94	.05	5.2	7	1-2	5
	-222	.19	.97	.06	5.1	6-7	1	4
	-249	.15	1.04	.02	6.9	7-8	2	-1
	-211	.17	1.04	.02	6.9	7-8	2	-10
	-227	.24	1.00	.09	4.2	7	1-2	-12
	-235	.18	1.02	.06	5.7	6-7	6-7	-15
	-254	.14	1.10	.04	7.9	7-8	3-4	-21
	-200	.14	.97	.06	6.9	7-8	1-2	-25
	Avg.	.180	1.008	.06	5.7	7.0	2 1/2	4

TABLE VII (Continued)

Plate Thick In.	Plate Code	Composition, % C	Mn	Si	Mn/C	Grain Size Ferrite	McQ-Ehn	Charpy V 15 Ft-Lb Trans. Temp. °F
7/8	95-237	.22	1.02	.03	4.6	6-7	1-2	28
	-168	.16	.87	.05	5.4	6-7	2-3	22
(7 plates)	-257	.18	.89	.03	4.9	6-7	1-2	20
	-239	.20	1.05	.03	5.3	6-7	1-2	18
	-199	.15	1.07	.06	7.1	6-7	2	17
	-215	.17	.96	.05	5.7	6	1	4
	-165	.16	1.10	.04	6.9	6-7	1-2	-17
	Avg.	.177	.994	.04	5.6	6 1/2	1 3/4	13
15/16	95-224	.18	1.03	.09	5.7	6-7	2-3	10
	-203	.14	.95	.04	6.8	6	1	8
(4 plates)	-205	.14	.97	.05	6.9	5-6	1	-7
	-228	.14	1.00	.07	7.1	6-7	2-3	-27
	Avg.	.150	.988	.06	6.6	6 1/4	1 3/4	-4
1	95-247	.16	.96	.04	6.0	6-7	1-2	28
	-190	.17	1.11	.07	6.5	7-8	1-2	26
(20 plates)	-197	.15	.93	.04	6.2	6	1	13
	-209	.18	1.11	.07	6.2	6	1	10
	-192	.14	1.06	.04	7.6	7	1-2	8
	-167	.14	.98	.06	7.0	6-7	1-2	7
	-245	.19	1.08	.07	5.7	7	1-2	7
	-178	.16	1.05	.05	6.6	7-8	1-2	6
	-185	.14	1.02	.05	7.3	7	1-2	5
	-187	.21	1.11	.08	5.3	7-8	1-2	5
	-246	.18	1.05	.04	5.8	7-8	2-3	5
	-166	.16	.98	.05	6.1	6	1-2	2
	-231*	.15	.70	.28	4.7	5-6	6-7	-5
	-243	.17	1.01	.07	5.9	7	1	-11
	-225	.16	.94	.09	5.9	6-7	1-2	-15
	-207	.19	.80	.21	4.2	6-7	7	-16
	-180	.17	.79	.20	4.6	6	7-8	-17
	-182	.16	1.12	.08	7.0	6-7	8	-23
	-188	.16	.99	.06	6.2	6-7	1-2	-30
	-258*	.17	.90	.20	5.3	6-7	7	-32
	Avg.	.166	.985	.09	5.9	6 3/4	3.0	-1
	Grand Avg. (76 Plates)	.169	.987	.06	5.8	6 3/4	2 1/4	2
	Grand Avg. excl. 4 Cl.C Plates	.169	.998	.05	5.9	6 3/4	2.0	3
	ABS Specification, Class B* 1956 Rules	.21 Max.	.80/1.10	-				

* Class C type acceptable for Class B.

Frequency distributions of the 15-ft-lb Charpy V transition temperatures are shown in Fig. 4. The plot for the 26 Class C plates includes the 14 plates covered in the first sampling program since the requirements of the 1956 Rules are not radically different than the 1948 Rules, except that the former may require normalizing of plate over 1 3/8 in. thickness. The following shows no marked



15 ft-lb Charpy V-Notch Transition Temperature, °F
(Note: Distributions for plates based on classification of samples by plate thickness)

FIG. 4. FREQUENCY DISTRIBUTIONS OF CHARPY V TRANSITION TEMPERATURES OF ABS-C, ABS-B (1956 RULES), AND ABS-B (1948 RULES)

differences between the first and second sampling of Class C plate:

	No. of	Charpy V Transition Temp., °F			
		15 ft-lb		25 ft-lb	
	Plates	Range	Aver.	Range	Aver.
1948 Rules	14	-28/10	-5	-20/27	9
1956 Rules	12	-46/13	-13	-25/25	6

However, a pronounced improvement is evident in the behavior of Class B plate as a result of the 1956 change in composition. It is to be noted that the transition temperatures of the new Class B plate are in the range of -40 to 29 F with an average of 2 F, as compared to a range of -22 to 65 F with an average of 29 F for the previous type. The average transition temperature of Class B plate furnished under the 1956 Rules is therefore about 27 F lower than that of the former Class B and approaches that of Class C plate. A comparison of the average carbon and manganese

TABLE VIII

RESULTS OF TESTS ON CLASS C PLATES REPRESENTING THE 1956 ABS RULES

Plate Thick. In.	Plate Code	Composition, % C	Mn	Si	Al	Mn/C	Grain Size Ferrite	McQ-Ehn	Charpy V Trans. Temp. °F 15 Ft-Lb	25 Ft-Lb
1 1/16	95-233	.19	.74	.18	.01	3.9	6	7	-4	3
(3 plates)	-251	.15	.82	.18	-	5.5	6	7	-8	12
	-256	.16	.68	.19	-	4.3	6-7	7	-10	9
	Avg.	.167	.747	.18	-	4.5	6 1/4	7	-7	8
1 1/8	95-172	.16	.63	.21	.010	3.8	6-7	7	13	25
(3 plates)	-201	.15	.84	.17	.04	5.6	5-6	7-8	-11	21
	-196	.18	.79	.20	.014	4.4	5-6	7	-13	10
	Avg.	.163	.753	.19	.02	4.6	5 3/4	7 1/4	-4	19
1 3/16	95-194	.13	.77	.20	.015	5.9	6	7-8	-30	-11
1 1/4	95-242	.21	.75	.20	.02	3.6	6	6-7	3	19
(3 plates)	-189	.17	.79	.20	.02	4.6	6	8	-10	3
	-181	.20	.75	.26	.04	3.8	6-7	7-8	-11	15
	Avg.	.193	.763	.22	.03	4.0	6 1/4	7 1/4	-6	12
1 7/16	91-198	.15	.71	.23	.02	4.7	8	7-8	-28	-13
1 1/2	91-252	.17	.89	.18	-	5.2	8	7-8	-46	-25
Grand Avg. (12 Plates)		.168	.763	.20	.02	4.5	6 1/2	7 1/4	-13	6
ABS Specification Class C*, 1956 Rules		.24 Max.	.60/.90	.15/.30	-					

* Shall be made with fine grain practice.

contents and Mn/C ratios for the old and new Class B plate is given below:

Procured Under	C, %	Mn, %	Mn/C
1948 Rules	0.195	0.734	3.8
1956 Rules*	0.169	0.998	5.9

* Excluding 4 plates of Class C Chemistry

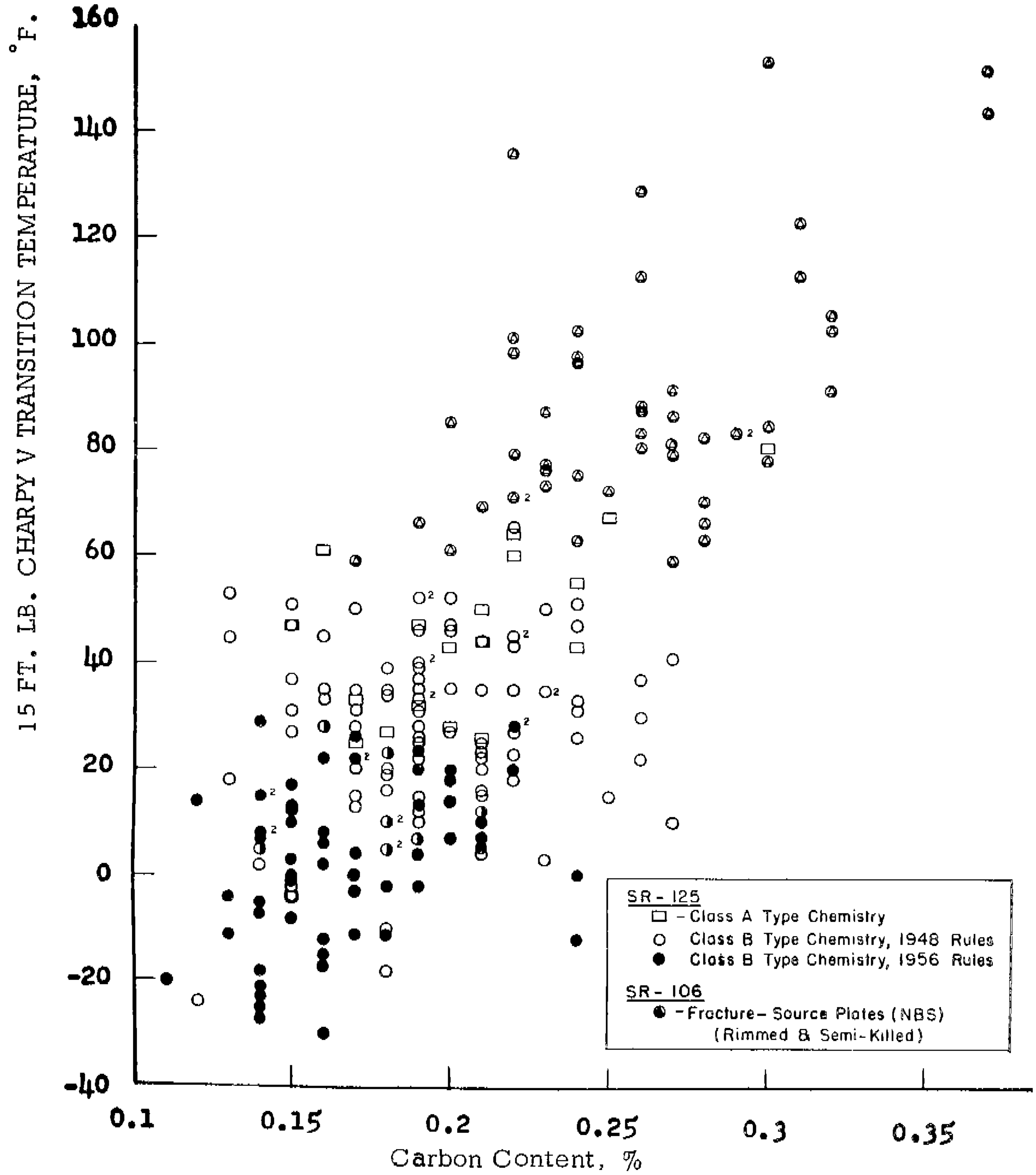


FIG. 5. PLOT OF 15 FT-LB CHARPY V TRANSITION TEMPERATURE VS CARBON CONTENT OF SEMIKILLED, COARSE-GRAIN STEELS (SR-125)

Samples Representing the 1948 and 1956 ABS Rules.

Plots of carbon, manganese, and Mn/C ratio vs the 15-ft-lb Charpy V transition temperature are presented in Figs. 5-7, respectively. The plots for the SR-125 samples include only coarse-grain, semi-killed steels. The

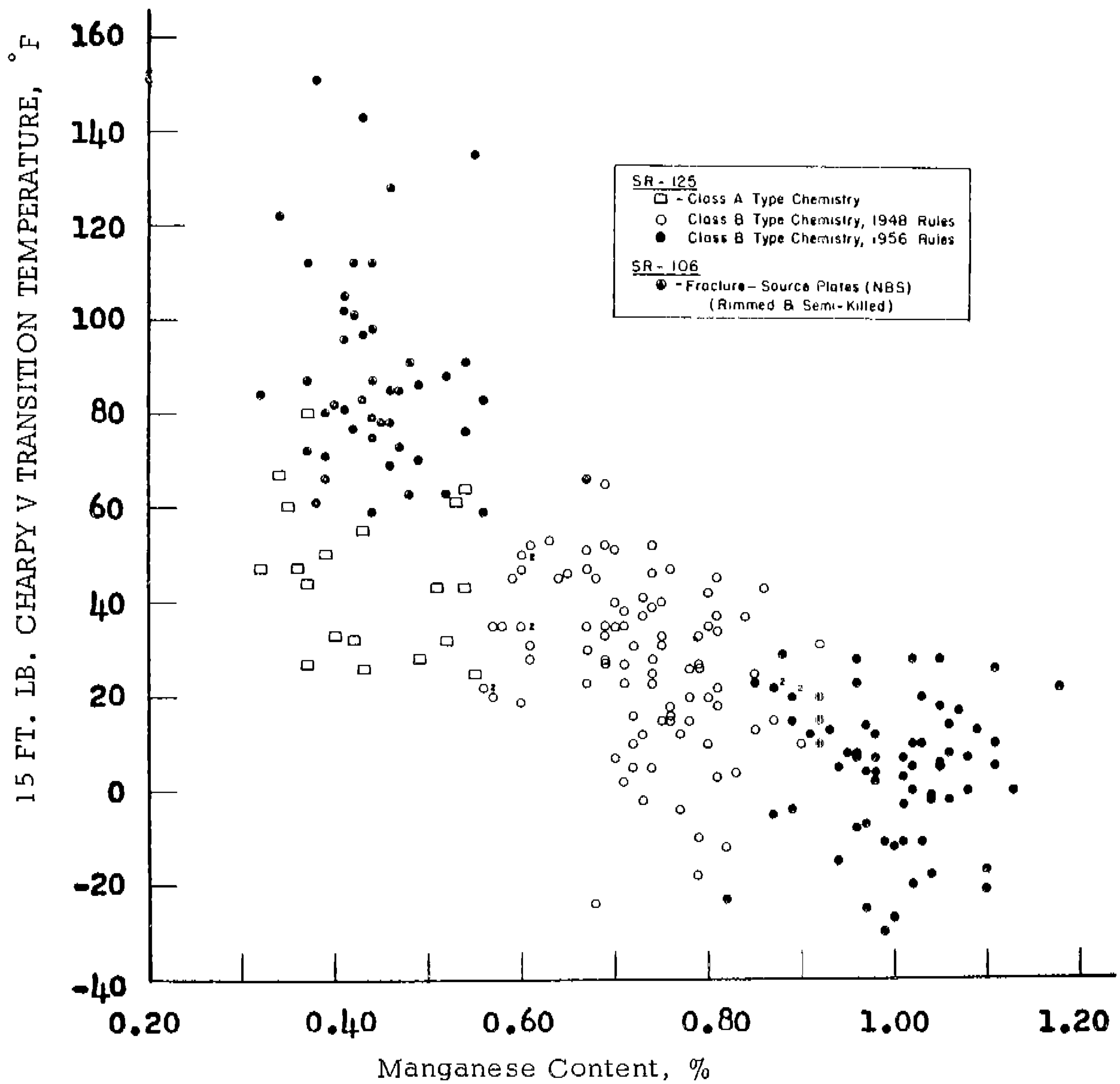


FIG. 6. PLOT OF 15 FT-LB CHARPY V TRANSITION TEMPERATURE VS MANGANESE CONTENT OF SEMIKILLED, COARSE GRAIN STEELS (SR-125)

data for the 47 fracture-source plates (NBS-SR106) are slso shown. While the scatter in values is high, the general trends are an increase in transition temperature with increase in carbon and a decrease in transition temperature with increase in carbon and a decrease in transition temperature with increase in manganese and Mn/C ratio.

The 15-ft-lb Charpy V transition temperatures have been plotted against plate thickness in Figs. 8 and 9. Figure 8 is based on classification of steels by thickness while Fig. 9 is based on chemistry types.

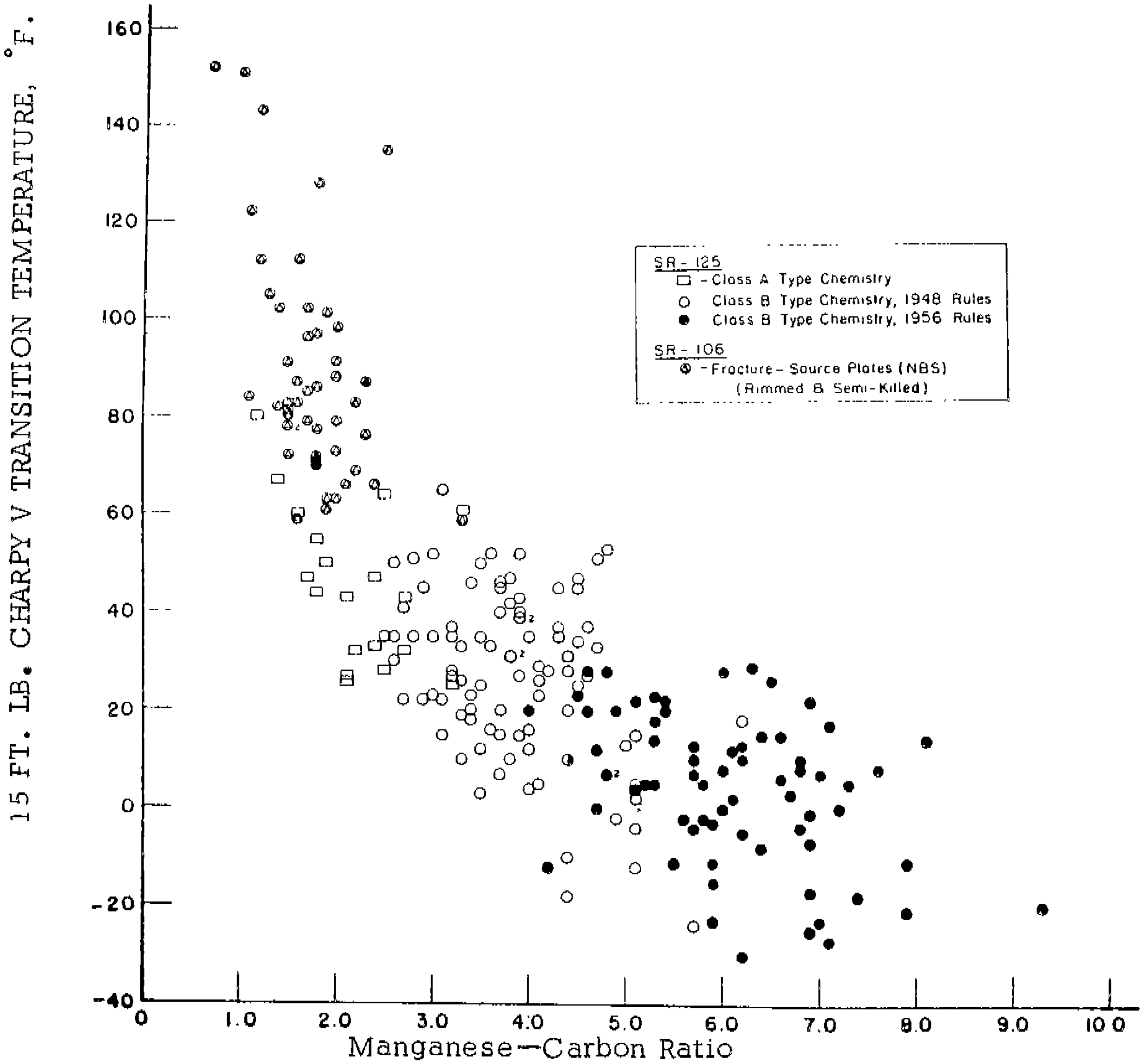


FIG. 7. PLOT OF 15 FT-LB CHARPY V TRANSITION TEMPERATURE VS Mn/C RATIO OF SEMIKILLED, COARSE GRAIN STEELS (SR-125)

In the case of the Class B steels (1948 Rules), there is an indication of increase in transition temperature with increase in plate thickness, particularly when one considers all plate thicknesses of the Type B chemistry (Fig. 9). The Class B plates (1956) Rules do not show any well-defined trend with regard to changes in plate thickness. The Class C steels show a slight increase in transition temperature with increase in plate thickness up to 1 1/4 in. followed by a decrease for the heavier thicknesses. It is suspected that the heavier gage plates may have been normalized, which would account for the decrease. The relative behavior of the different

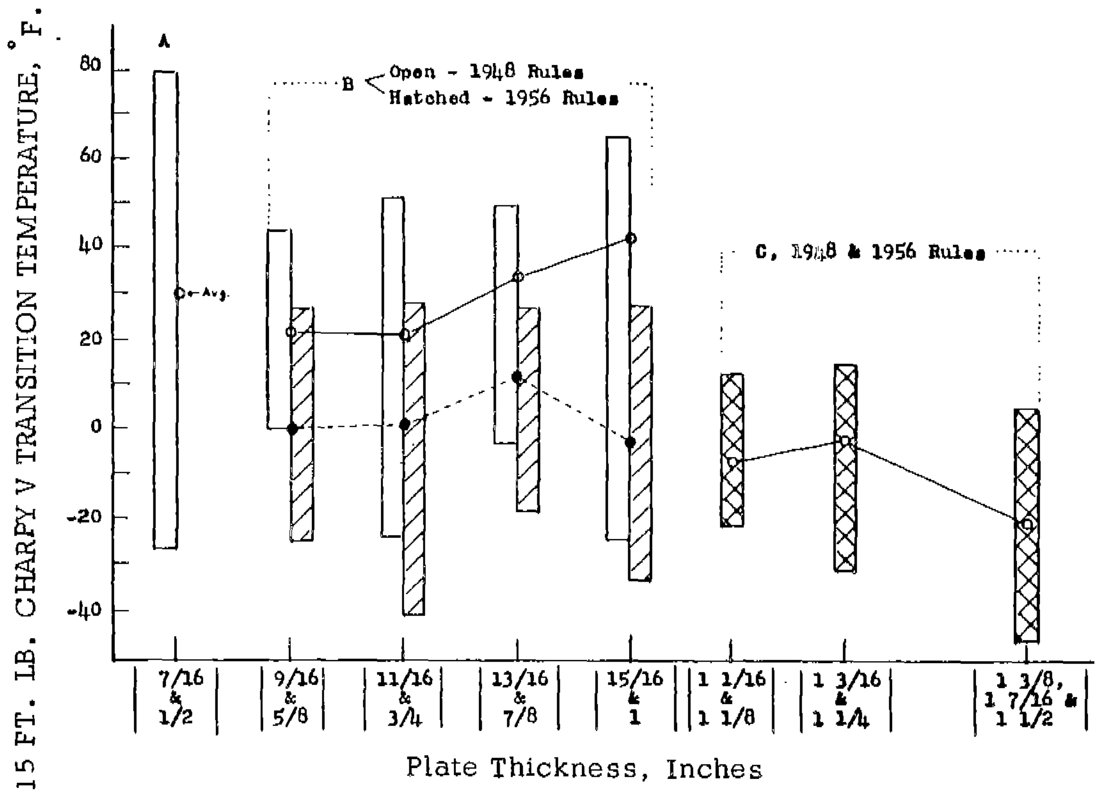


FIG. 8. PLOT OF 15 FT-LB CHARPY V TRANSITION TEMPERATURE VS THICKNESS OF ABS PLATE, CLASSES A, B, AND C (BASED ON THICKNESS CLASSIFICATION)

chemistry types is clearly evident in Fig. 9.

An overall summary of the Charpy V transition temperatures is given in Table IX and shown graphically in Fig. 10. These data have been previously discussed with the exception of the behavior of Class C at the 25 ft -lb level which is similar to that of the new Class B (1956 Rules) at the 15 ft-lb level.

While it is recognized that ferrite grain size has an influence on transition temperature, no evidence of such was found in the data reported herein. This lack of supporting data may be due to the use of a relatively unsophisticated method of grain size measurement or, more probably, to the masking effect of other variables.

As a result of a paper[10] by G. M. Boyd of Lloyd's Register of Shipping an examination was made of the SR-125 data to determine the extent to which

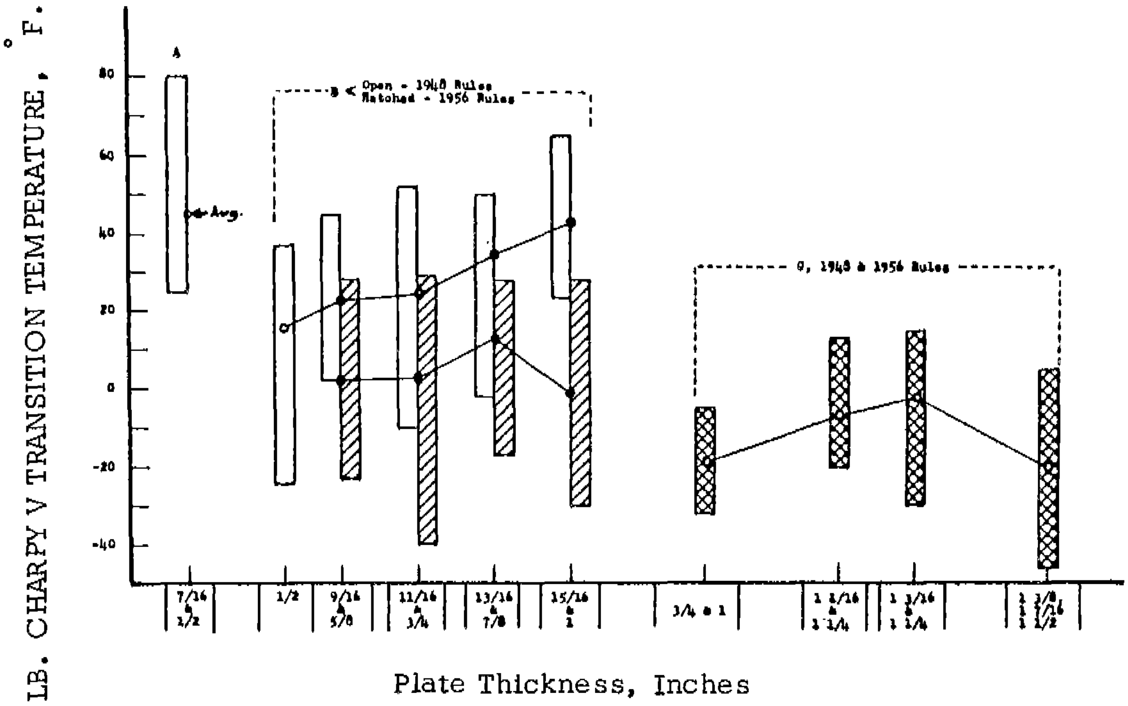


FIG. 9. PLOT OF 15 FT-LB CHARPY V TRANSITION TEMPERATURE Vs THICKNESS OF ABS PLATE, CLASSES A, B AND C (BASED ON CHEMISTRY TYPE)

the ABS steels would meet revised Lloyd's Register requirements. Before presenting the results, it might be pertinent to review the portion of Boyd's work which is concerned with these requirements. Figure 11 shows data gathered by Boyd on casualty material and represents a plot of Charpy per cent fibrous vs Charpy V ft-lb at the casualty temperature. "Success" plates (black circles) represent those which fractured in a ductile manner or in which a brittle fracture originating outside the plate was arrested. "Failure" plates (open circles) are those which were completely traversed by a brittle fracture. The "borderline" plates (crosses) represent those which cannot be classified in either of the above groups. These data indicate that if a minimum of 35 ft-lb is combined with a maximum of 70% crystallinity (30% fibrous), the separation between "successes" and "failures" is fairly good, the bulk of the failures lying in Quadrant I.

Boyd considered that both energy and crystallinity should be measured

TABLE IX

OVERALL SUMMARY OF CHARPY V TRANSITION TEMPERATURES

Steel	Year of ABS Rules	Classification by	Charpy V Transition Temp. °F 15 Ft-Lb Range	15 Ft-Lb Aver.	25 Ft-Lb Range	25 Ft-Lb Aver.
Fracture-Through Plates	Prior to 1948	- -	24/120	68	-	-
Fracture-Source Plates	Prior to 1948	- -	59/152	90	-	-
A	1948	Thickness	-24/80	31	-	-
		Chemistry	-25/80	45	-	-
B	1948	Thickness	-22/65	29	-	-
		Chemistry	-24/65	28	-	-
C	1948	Thickness	-28/10	- 5	-20/27	9
		Chemistry	-28/10	- 7	-20/27	8
B	1956	Thickness	-40/29	2	-	-
		Chemistry	-40/29	3	-	-
C	1956	Thickness	-46/13	-13	-25/25	6
		Chemistry	-46/13	-14	-25/25	4
C	1948 & 1956	Thickness	-46/13	- 9	-25/27	8
		Chemistry	-46/13	-11	-25/27	6

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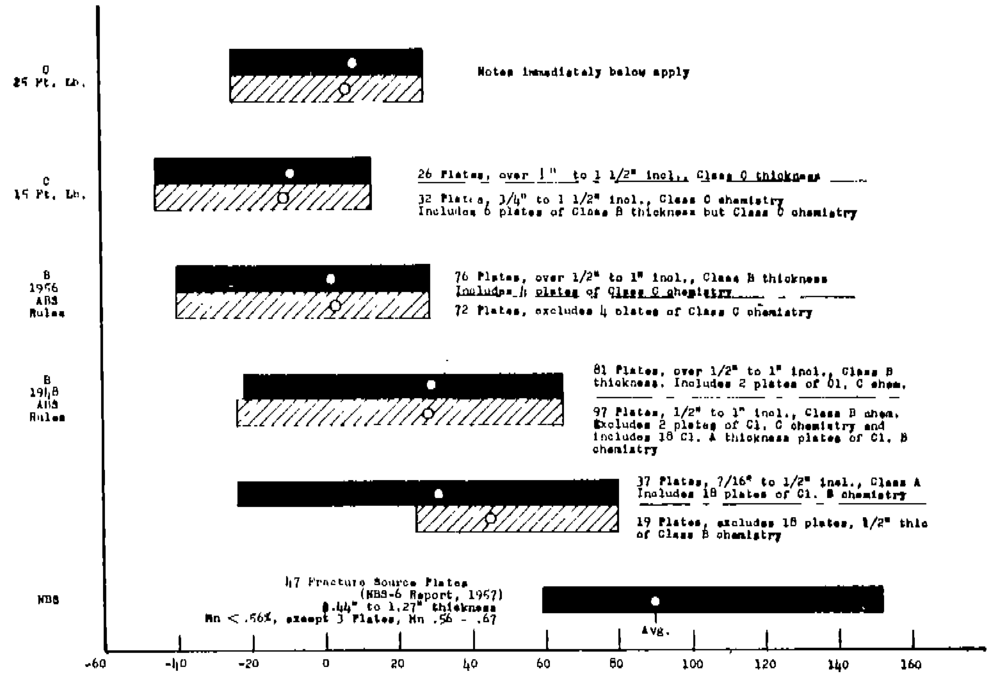
at a test temperature of 0° C which was chosen partly for its significance to service and partly for its reproducibility under laboratory conditions. He examined the above mentioned requirements from the standpoint of availability of steels which would meet these requirements. Figure 12 shows the results of his survey which indicated that an adequate percentage of available steels would comply, and the requirements were accordingly incorporated in the Rules of Lloyd's Register. However, the crystallinity requirement was suspended[10] pending the accumulation of further



Charpy V-Notch Transition Temperature, °F
(15 ft-lb except where otherwise indicated)

FIG. 10. OVERALL SUMMARY OF CHARPY V TRANSITION TEMPERATURES

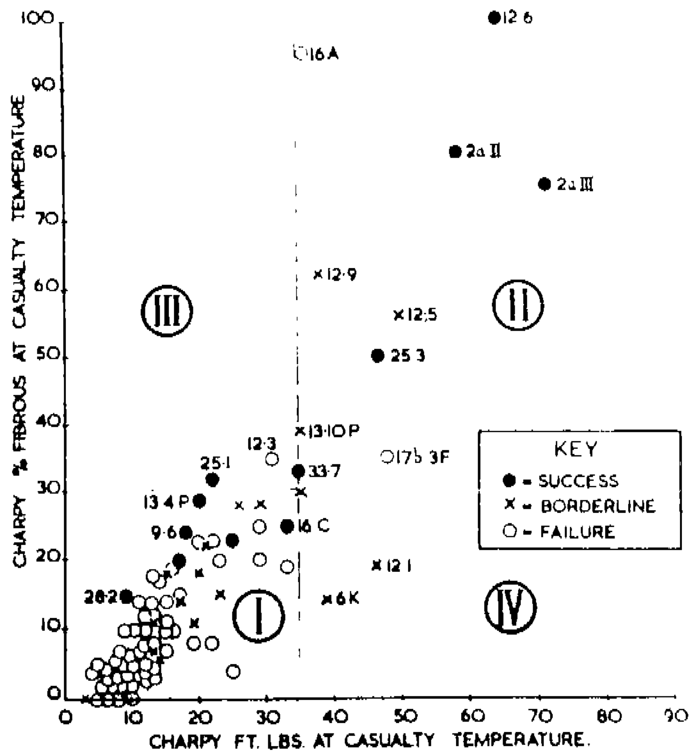


FIG. 11. DATA FROM TESTS ON SHIP CASUALTY MATERIAL (Fig. 8D, Ref. 10)

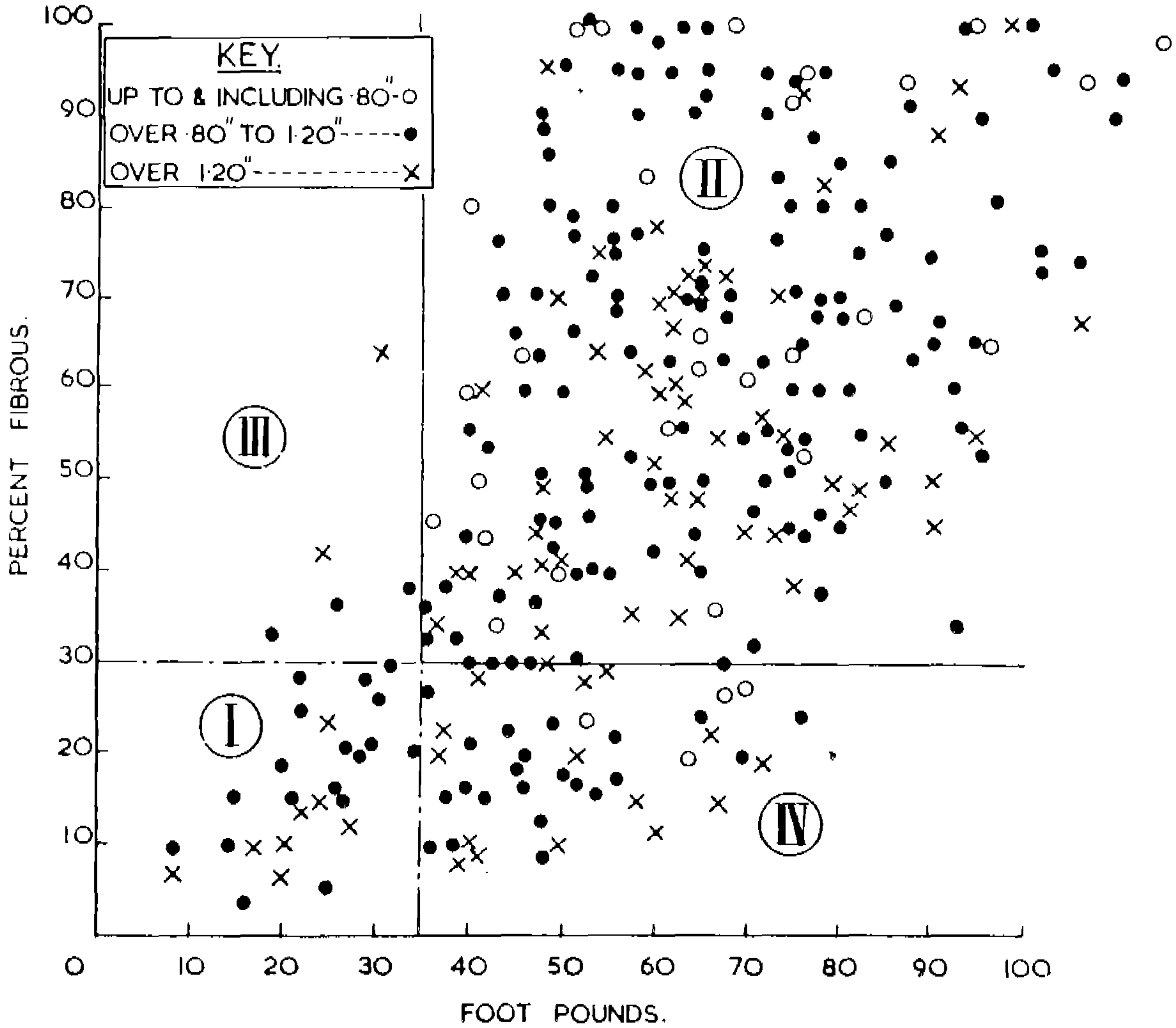


FIG. 12. GRAPH SHOWING THE RELATIONSHIP BETWEEN ENERGY AND PERCENTAGE FIBROUS IN THE CHARPY V TEST AT 0° C. FOR A LARGE NUMBER OF SAMPLES OF SHIP STEEL THAT HAD THE SAME REQUIREMENTS FOR TENSILE STRENGTH (Fig. 7, Ref. (10)).

data, since the steel makers apparently had little experience in the application of such a criterion under production conditions. It is the understanding of the authors that Fig. 12 encompasses various kinds of carbon steel ranging from semikilled, controlled rolled to fully-killed, fine grain and normalized.

With regard to the SR-125 samples, an examination was made of the fractures of those Charpy specimens of Class B steel which had not as yet been discarded and which had been tested at 30 F (approximately 0°C). The

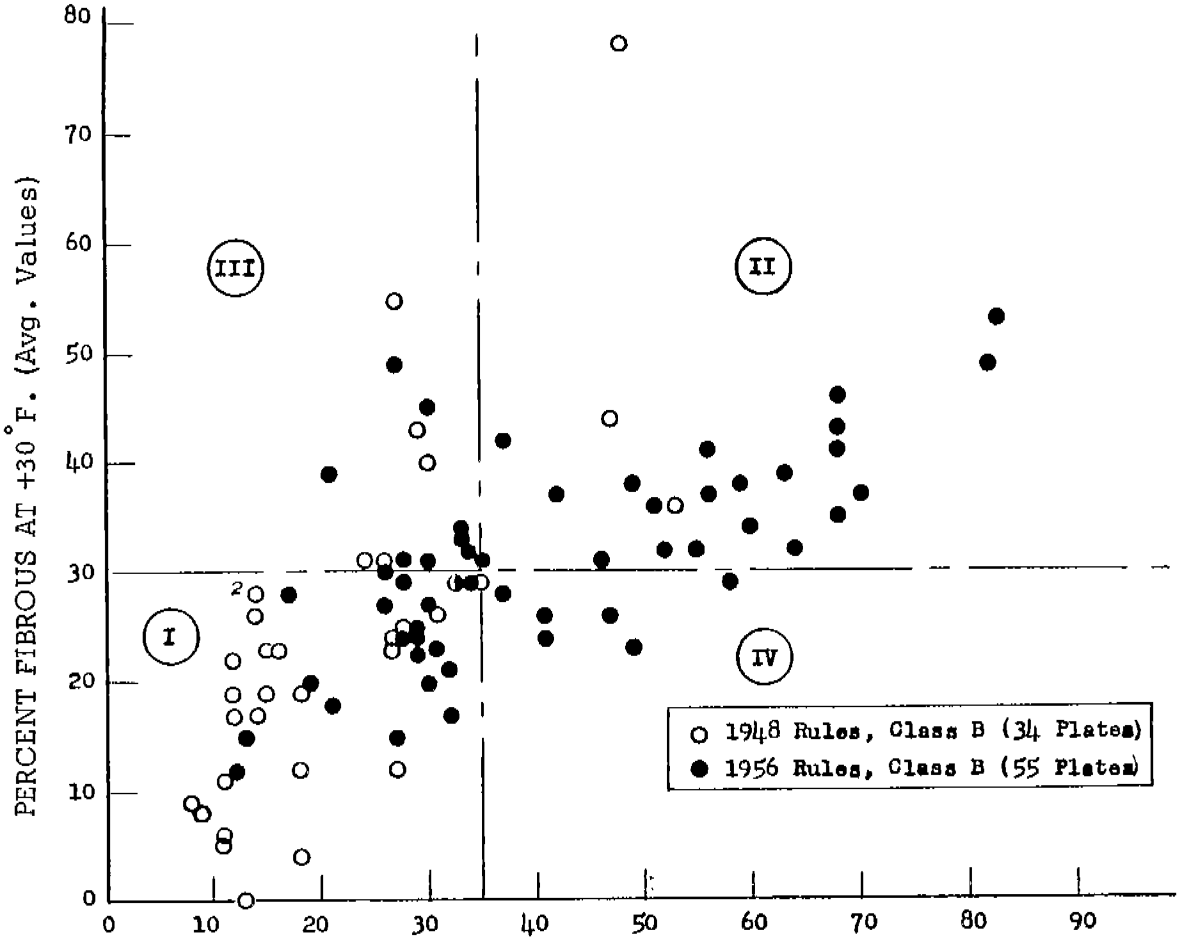


FIG. 13. PLOT OF PER CENT FIBROUS vs FT-LB IN CHARPY V-NOTCH TESTS AT 30 F OF CLASS B PLATES.

results are presented in Fig. 13. No points are shown for Class C plate in view of the very small number for which specimens still remained or which had been tested at 30 F. The picture does not look quite as good as that shown in Fig. 12 in that there is a much smaller percentage of plates which meet both the fibrosity and energy requirements, as judged by the number which fall in Quadrant II. However, the graph does indicate the relative superiority of the 1956 Class B plates (black circles) as compared to the 1948 Class B material (open circles). It is to be also noted that a number of the 1956 Class B plates fall short of the requirements by only slight amounts. The following tabulation shows the distribution of the plates with respect to the quadrants of Fig. 13:

	Class B 1948 Rules	Class B 1956 Rules
Total No. Plates Examined	34	55
% in Quadrant I	73.5	36.4
% in Quadrant II	8.8	38.2
% in Quadrant III	14.7	14.5
% in Quadrant IV	2.9	10.9
% meeting 35 ft. lb.	11.8	49.1
% meeting 30% fibrosity	23.5	52.7

In the case of the 1948 Class B plates, only a small percentage (8.8) fell in Quadrant II, i.e., those which meet both the energy and fibroisty requirements. The improvement in Class B plates brought about by the 1956 Rules is evident in that the respective figure is 38.2. At the bottom of the above tabulation are indicated the percentage of plates which met the energy requirement (without regard to fracture appearance) and the percentage which met the fibrosity requirement (without regard to energy value). Here again, the improvement in Class B material resulting from the 1956 Rules is also evident.

The above was presented at the March 1960 joint meeting of the Committee on Ship Steel and the Ship Structure Subcommittee. At that time, Mr. R. Vanderbeck of the U. S. Steel Corporation pointed out that the comparison of Class B material with Lloyd's requirements can be misleading inasmuch as the Class B steel is not used in the same locations as the material specified by Lloyd's Register. He indicated that the latter specifies special notch-toughness steel in certain areas only whereas the ABS Rules are intended to provide a fairly uniform toughness for the entire hull structure.

CONCLUSIONS

It is concluded that the notch-toughness properties of ABS ship plate of current manufacture are considerably better than those of material represented by the fracture-source plates in World War II ships. This improvement was first partially effected as a result of the material requirement revisions of the 1948 ABS Rules and subsequently furthered by the 1956 modifications. On the basis of discussion (with Bureau of Ships personnel) of the findings of this report and of a previous report[11] covering ship plate as formerly procured by the Navy, it may be noted that the current Military Specifications[12] for carbon steel structural plate for ships was made essentially equivalent to the requirements of the 1959 ABS Rules.

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