SSC-160

GEOMETRIC EFFECTS OF PLATE THICKNESS

BY

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SHIP STRUCTURE COMMITTEE

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ADDRESS CORRESPONDENCE TO:
SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

February 7, 1964

Dear Sir:

The Ship Structure Committee is sponsoring, at Lehigh University, a research project entitled "Selection of Steels for Heavy-Section Ship Plate." The purpose is to determine experimentally the optimum composition and/or heat treatment for steel plates up to 4-in. thicknesses intended for ship construction.

Herewith is the First Progress Report by R. D. Stout, C. R. Roper and D. A. Magee, entitled Geometric Effects of Plate Thickness.

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

Comments on this report would be welcomed and should be addressed to the Secretary, Ship Structure Committee.

Yours sincerely,

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

SSC-160

First Progress Report
of
Project SR-162
"Selection of Steels for Heavy-Section Ship Plate"

to the

Ship Structure Committee

GEOMETRIC EFFECTS OF PLATE THICKNESS

by

R. D. Stout, C. R. Roper and D. A. Magee

Lehigh University

under

Department of the Navy
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Washington, D. C.
National Academy of Sciences-National Research Council
February 7, 1964

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INTRODUCTION

In the design and construction of ships of large tonnages, one of the most pressing problems is the selection of hull material that will provide a suitable combination of strength, weldability, and resistance to brittle fracture. The Ship Steel Committee initiated Project SR-162 at Lehigh University to develop information which would enable the selection of the optimum composition and heat treatment of ship steel for use in heavy sections.

The initial phase of the program, covered by the present report, was intended to establish an adequate testing method to measure the resistance of steel of these section sizes to brittle fracture, and to determine whether the level of performance must be raised to counteract size effects as the plate thickness increases.

The metallurgical effects of plate thickness upon sensitivity to brittle fracture are well established. As plate section increases, the limited hot work and the slower cooling rates following rolling or heat treatment favor coarser grain size and inhomogeneity in the plate microstructure which are harmful to notch toughness. This trend can be balanced at least in part by compositional changes such as lowering the carbon content and adding beneficial deoxidizing and alloying elements(1), and by the use of accelerated cooling.(2)

In contrast to the metallurgical effects, the geometrical effects of plate thickness on brittle fracture are less clearly understood. Broadly, an increase in the dimensions of a steel section tends to increase the restraint upon plastic deformation in the steel and thus promotes notch brittleness. The dimensional effect of plate thicknesses above 1½ inches has not been studied extensively. In early investigations,(3,4) testing was limited to room temperature and no transition temperatures were obtained. The effect of size was dramatic in steels with transition temperatures close enough to room temperature, so that thin specimens failed in a ductile manner but thick ones were brittle. In some studies all of the specimen dimensions including the notch radius were increased proportionately; thus no information was obtained on the separate effects of width, thickness, or span. Akita,(5) using oversized Charpy bars, and Parker,(1) using wide plates, both concluded that the effect of plate thickness on transition temperature reached essentially a maximum at about one-inch thickness. On the other hand, results on Tipper tests reported by Holliday(6) and on the Bagsar tests reported by Epstein(7) indicated a continuing effect of plate thickness up to 4 inches.

For these reasons, it was considered necessary to plan a series of tests which would furnish information on the quantitative effect on transition temperature of the plate thickness and of the other specimen dimensions. A previous investigation at Lehigh University(8) had suggested that there might be a levelling off of the size effect when the specimen dimensions exceeded certain moderate limits. In the present investigation, three testing methods were selected to provide a variety of loading conditions: the van der Veen test, the Bagsar test, and the drop-weight test. In the van der Veen test, the specimen is loaded in slow bending with the plate thickness oriented in the width direction of the beam. The Bagsar test uses a large C-shaped specimen loaded eccentrically in tension. The drop-weight specimen is a bend specimen loaded dynamically with the plate thickness oriented as the height of the beam. Details of these tests are given later.

In these tests the plate thickness was varied from 3/4 to 3 inches. The other lateral dimensions and the span of the specimens were varied to examine the separate effect of each specimen dimension on transition temperature and the possible interaction among these effects. The basic question to be answered was this: how can the size effect of plate thickness on transition temperature be evaluated without interference from the size effect of the other dimensions of the specimen? Some assurance that the problem was soluble was available from wide-plate tests(9) which showed that plate widths from 3 inches to 72 inches did not seriously affect the transition temperatures of plates 3/4-inch thick.

To broaden the applicability of the results, transition temperatures were determined by both ductility and fracture transition criteria in the van der Veen and Bagsar tests. Deflections at failure, lateral contraction at the notch, maximum loads, and fracture appearance were all recorded.

The testing program of Phase One was carried out on a heat of ABS Class C steel normalized to minimize metallurgical differences among plate thicknesses. A heat of "T-1" steel was also tested by the van der veen method to check the results obtained on the carbon steel.

EXPERIMENTAL PROGRAM

The Steels

The chemical analyses, heat treatments, and mechanical properties of the ABS Class C steel and the "T-1" steel are presented in Tables 1 to 8. Heat No. 2 of the ABS Class C

TABLE 1. PLATE ANALYSES OF ABS - C STEEL

PLATE THICKNESS	C	Mn	P	S	Si	FERRITE GRAIN SIZE
Heat No. 1						
3/4"	.16	.78	.011	.026	.21	9.5
1 "	.17	.79	.011	.027	.22	9.4
1-1/2"	.17	.78	.012	.027	.21	9.4
2 "	.17	.82	.010	.022	.23	9.1
3 "	.17	.82	.010	.022	.23	8.6
Heat No. 2						
1 "	.16	.66	.013	.022	.20	
2 "	.16	.75	.010	.022	.26	
3 "	.19	.73	.010	.026	.22	

TABLE 2. HEAT TREATMENT OF ABS - C STEEL

PLATE THICK-NESS	FINISHING TEMP. OF ROLLING		NORMALIZING PROCEDURE	
	Heat 1	Heat 2	AUSTENITIZING TEMPERATURE	TIME AT TEMP.
3/4"	1810°F	-	1675°F	1 hr.
1 "	1850°F	1770°F	1675°F	1 hr.
1-1/2"	1870°F	-	1675°F	1-1/4 hrs.
2 "	1875°F	1860°F	1675°F	1-1/2 hrs.
3 "	1890°F	1860°F	1675°F	1-3/4 hrs.

TABLE 3. MECHANICAL PROPERTIES OF ABS - C STEEL PLATE (NORMALIZED)

PLATE THICKNESS	YIELD STRENGTH (psi)	TENSILE STRENGTH (psi)	% ELONGATION
Heat No. 1			
3/4"	42,900	66,700	28.0 in 8"
1 "	43,200	65,700	27.0 in 8"
1-1/2"	41,000	66,000	25.0 in 2"
2 "	41,500	66,500	31.0 in 2"
3 "	39,000	66,000	33.0 in 8"
Heat No. 2			
1 "	36,500	63,600	28 in 8"
2 "	33,500	63,750	38 in 2"
3 "	31,500	62,500	38 in 2"

TABLE 4. ANALYSIS OF "T-1" STEEL

Plate Thickness	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	B
1/2-inch	0.16	0.80	0.007	0.017	0.21	0.31	0.90	0.50	0.47	0.036	0.009	0.004
3/4-inch	0.17	0.78	0.008	0.018	0.19	0.30	0.91	0.49	0.47	0.034	0.008	0.004
1-inch	0.16	0.81	0.007	0.017	0.22	0.31	0.87	0.50	0.46	0.035	0.008	0.004
2-inch	0.15	0.81	0.007	0.017	0.23	0.30	0.87	0.51	0.47	0.035	0.009	0.004

TABLE 5. HEAT TREATMENT OF "T-1" STEEL PLATES

PLATE THICK -NESS	AUSTENITIZING			TEMPERING		
	Temp.	Total Time in Furnace	Estimated Time at Temp.	Temp.	Total Time in Furnace	Estimated Time at Temp.
1/2"	1700° F.	86 min.	66 min.	1260° F.	47 min.	27 min.
3/4"	1700° F.	124 min.	94 min.	1260° F.	80 min.	50 min.
1 "	1700° F.	93 min.	53 min.	1230° F.	93 min.	53 min.
2 "	1700° F.	250 min.	170 min.	1220° F.	185 min.	105 min.

*All plates were water-quenched cold after austenitizing

TABLE 6. MECHANICAL PROPERTIES OF "T-1" STEEL PLATES

PLATE THICK -NESS (in.)	TEST* LOCATION	YIELD** STRENGTH (psi)	TENSILE STRENGTH (psi)	ELONGATION IN 2" (%)	REDUCTION OF AREA (%)	CHARPY V-NOTCH ENERGY ABSORBED AT -50° F. (ft.-lb.)
1/2	LB	111,000	119,000	32.0	58.2	17 - 17 - 19
	LT	115,700	123,300	30.0	60.0	
3/4	LB	107,800	117,450	36.0	59.2	17 - 17 - 19
	LT	111,400	119,650	36.0	59.3	
1	LB	108,450	122,900	20.0	64.2	49 - 52 - 58
	LT	107,450	122,000	20.0	65.2	
2	LB	108,050	117,400	22.0	63.9	26 - 31 - 41
	LT	110,500	119,400	19.0	66.3	

*LB = Longitudinal specimen from bottom end of plate edge
LT = Longitudinal specimen from top end of plate edge
**0.5 percent Extension Under Load

TABLE 7. CHARPY V-NOTCH TRANSITION TEMPERATURES FOR ABS - C STEEL

	PLATE THICKNESS (inches)	TRANSITION TEMPERATURES 10 ft.-lb.	15 ft.-lb.	15 mil	20 mil	50% Fib.
	3/4	-70° F.	-50° F.	-35° F.	-25° F.	+30° F.
Van der Veen Test Plates	1	-70° F.	-60° F.	-65° F.	-60° F.	0° F.
	1-1/2	-60° F.	-50° F.	-60° F.	-50° F.	+10° F.
	2	-60° F.	-45° F.	-60° F.	-55° F.	+ 5° F.
	3	-60° F.	-50° F.	-60° F.	-50° F.	+10° F.
Bagsar Test Plates	1	-70° F.	-65° F.	-60° F.	-45° F.	-15° F.
	2	-50° F.	-40° F.	-35° F.	-30° F.	-15° F.
	3	-55° F.	-45° F.	-45° F.	-40° F.	-15° F.
	3*	-55° F.	-45° F.	-50° F.	-40° F.	+10° F.
Drop-Weight Test Plates	3/4	-70° F.	-50° F.	-35° F.	-25° F.	+30° F.
	1*	-50° F.	-45° F.	-50° F.	-45° F.	+ 5° F.
	1-1/2	-60° F.	-50° F.	-60° F.	-50° F.	+10° F.
	2*	-55° F.	-35° F.	-30° F.	-15° F.	+10° F.
	3*	-55° F.	-50° F.	-55° F.	-50° F.	+15° F.

*Specimens prepared from Heat No. 2

TABLE 8. CHARPY V-NOTCH TRANSITION TEMPERATURES FOR "T-1" STEEL

PLATE THICKNESS (inches)	TRANSITION TEMPERATURES 10 ft.-lb.	15 ft.-lb.	15 mil	20 mil	50% Fib.
1/2	-105° F.	- 95° F.	- 90° F.	- 55° F.	-45° F.
3/4	-120° F.	-105° F.	- 85° F.	- 45° F.	-40° F.
1	-165° F.	-140° F.	-120° F.	-100° F.	-80° F.
2	-115° F.	- 95° F.	- 90° F.	- 85° F.	-35° F.

steel was used only for the 1-inch and 2-inch thick drop-weight tests.

The van der Veen Test

The van der Veen test(10) is a notched slow-bend test. In this test, a concentrated load is applied at the midpoint of a notched beam so that the load is applied directly above the notch, thus putting the notched side of the specimen in tension as shown in Figure 1.

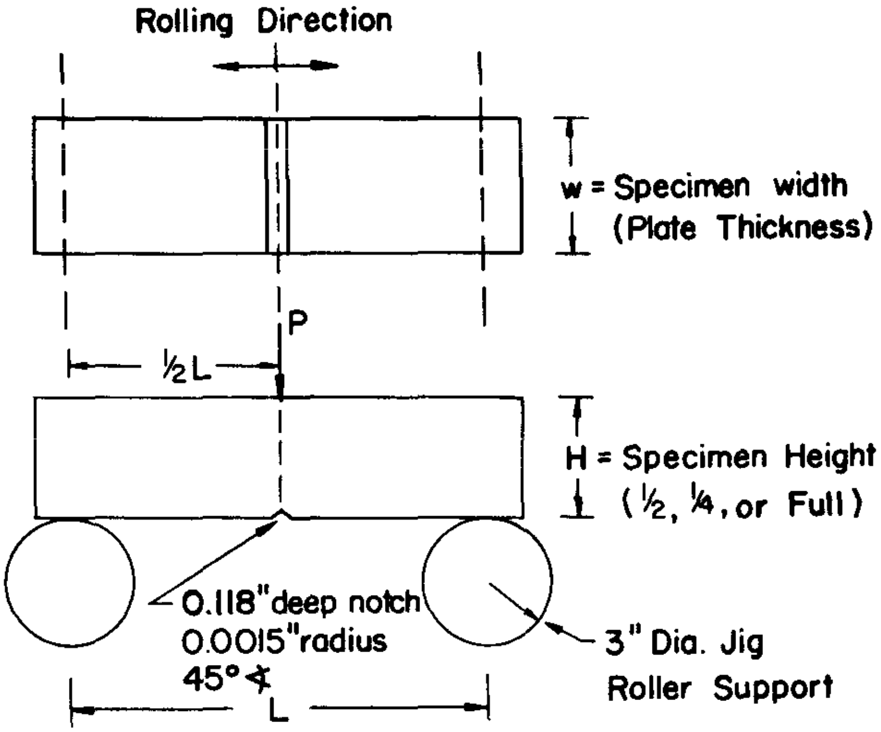


FIG. 1. DIMENSIONS OF THE VAN DER VEEN TEST.

Test dimensions were as follows: the specimen width was the plate thickness. The standard height specimen was 2.76 inches; the 1/2-height specimen was 1.38 inches; and the 1/4 -height specimen was 0.69 inch. The standard span was 9.5 inches, while the long span was 16.5 inches. Testing was performed with a special jig set up in a 300,000 pound universal testing machine, and the specimen was loaded at a deflection rate of one inch per minute.

Each van der Veen series consisted of fifteen test specimens. All specimens were cut from the plate with their longitudinal axis in the direction of rolling so that the notch was perpendicular to the rolling direction of the plate. This relation between the notch and rolling direction was maintained in all tests, including the Charpy test.

The specimen notch was 0.118 inch (3mm) deep with a radius of 0.0015 inch and an included angle of 45°. The root radius was less sharp than that used by van der Veen but the same as that used by Bagsar in his bend test(11). This notch was pressed to the required depth in the test specimen by means of a tool steel die. The depth was controlled during pressing by a dial gauge mounted on the movable head of the testing machine. After notching, the specimens were filed on both sides of the notch to obtain a smooth surface for taking lateral measurements. These lateral measurements were taken before and after testing to determine the percent lateral contraction.

The van der Veen specimens for each series were tested over a range of temperatures to obtain the transition temperature for each criterion selected. The specimens were cooled to a predetermined temperature in a bath of alcohol and dry ice. For the tests run at temperatures below -100°F, the specimens were immersed in a bath of methyl butane cooled with liquid nitrogen.

The minimum holding time needed for each specimen to cool uniformly to the bath temperature was determined by running a temperature versus time test. A thermocouple was inserted into a hole drilled to the center of a 3-inch x 2.76-inch cross section van der Veen specimen. The time for the center of the specimen to reach the bath temperature was found to average 13 minutes for bath temperatures from -30°F to -75°F. In practice this time was doubled to insure a uniform temperature throughout the specimen. The holding times for the smaller cross sections were estimated from the measurements on the 3-inch x 2.76-inch cross section. A time of approximately 10-15 seconds was taken to remove the specimen from the bath, center it on the jig and begin the testing. Deflection readings were taken from an Ames dial gauge.

Both fracture appearance and ductility criteria were used to evaluate the transition temperature. These criteria were as follows:

Fracture appearance:

a. 50% shear depth
b. 8 mm shear depth

Ductility:

a. 2% lateral contraction at the root of the notch
b. ½ the deflection observed at maximum load in the shear range

The shear depth was obtained by measuring the maximum distance from the root of the pressed notch to which the shear type fracture penetrated before brittle fracture occurred. (Figure 2).

The lateral contraction was determined by measuring the width of the specimen at the root of the notch before and after testing. The specimen deflection at maximum load was measured with a dial gauge.

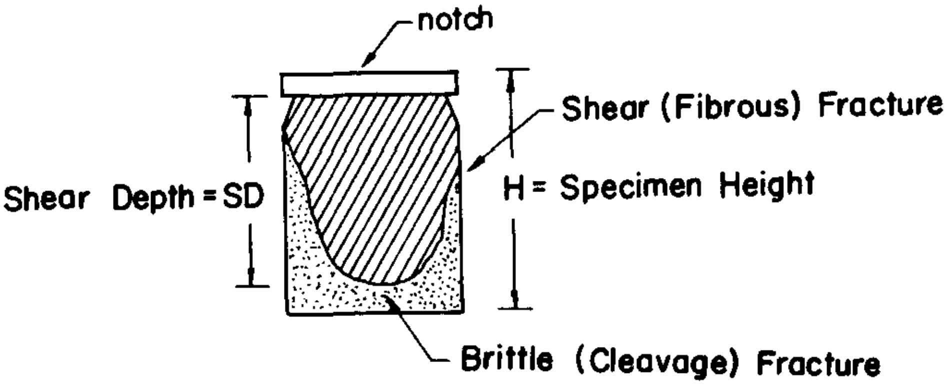


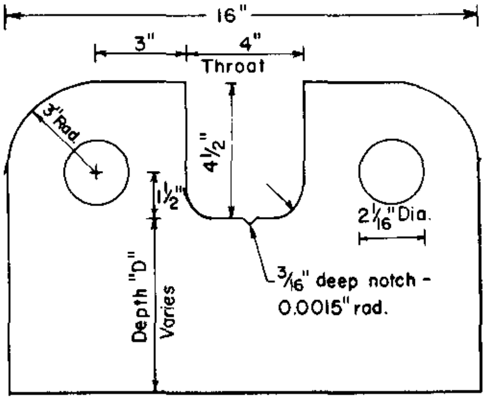
FIG. 2. SHEAR TO CLEAVAGE TRANSITION IN THE VAN DER VEEN TEST.

<u>The Bagsar Test</u>

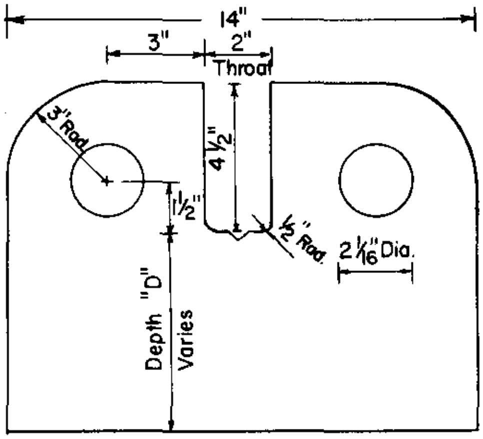
The Bagsar test(11) utilizes a notched tensile-bend specimen. The test coupon can be considered as a notched beam of rectangular cross section subjected to combined axial tensile and transverse bending stresses induced by eccentric loading. The geometry of the specimen is shown in Figure 3.

The test coupon has a U-shaped recess on one side, and the notch is pressed at the center of the base of this recess. The parts of the specimen forming the arms of the U contain the loading holes and provide the desired eccentricity of loading. The tensile load is applied through a clevis and pin arrangement.

The notch was pressed mechanically into the Bagsar test specimens by the same procedure as that used for the van der Veen test specimens. In the Bagsar test the notch depth was 3/16 inch with an included angle of 45° and a notch radius of 0.0015-inch. After notching, the ends of the notch were filed down to produce a smooth surface for measuring the lateral dimension before and after testing.

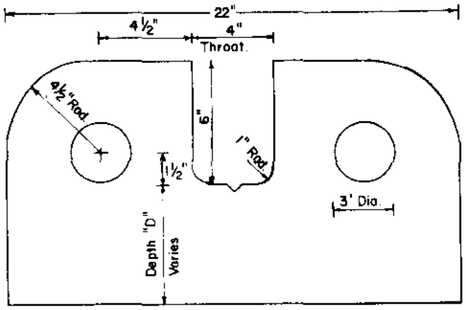


STANDARD THROAT SPECIMEN

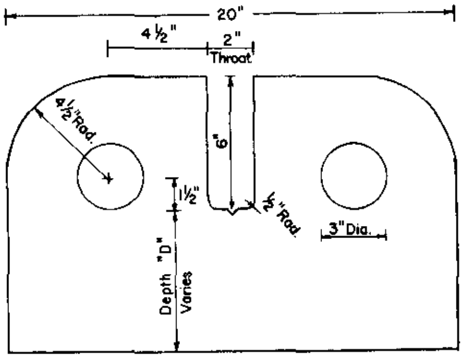


NARROW THROAT SPECIMEN

FIG. 3a DIMENSIONS OF THE 1 AND 2 INCH BAGSAR TESTS.



STANDARD THROAT SPECIMEN



NARROW THROAT SPECIMEN

FIG. 3b. DIMENSIONS OF THE 3 INCH PLATE BAGSAR TESTS.

Ten test specimens were used for each Bagsar test series, except for the 3-inch plate where only 6 to 8 specimens per series were available. Table 10 lists the variations of geometry introduced into the Bagsar specimens.

The Bagsar tests were carried out with the specimens immersed in a bath of alcohol cooled by adding dry ice. Thus the specimens were kept at the desired temperature throughout the test. The bath was supported in the lower head of an 800 kip universal screw type testing machine. The lower part of the Bagsar specimen was pinned to a clevis arrangement in the bottom of the bath.

The top hole of the specimen was attached by means of a pin to a similar clevis arrangement in the upper head of the testing machine.

The load was then applied through the pins at a cross-head separation speed of one inch per minute.

The criteria used to evaluate the transition temperatures were similar to those used for the van der Veen test.

Bagsar Transition Temperature Criteria

Fracture Appearance Criteria:

a. 50% shear depth

Ductility Criteria:

a. 2% lateral contraction
b. drop in maximum load

The Drop-Weight Test

In the drop-weight test(12) a known free falling weight strikes the center of a special test specimen supported at its ends in a jig. The impact energy is controlled by the choice of the weight and the distance of fall.

The drop-weight test specimens were cut from plate with their longitudinal axis parallel to the rolling direction. Figure 4 shows the dimensions of these specimens.

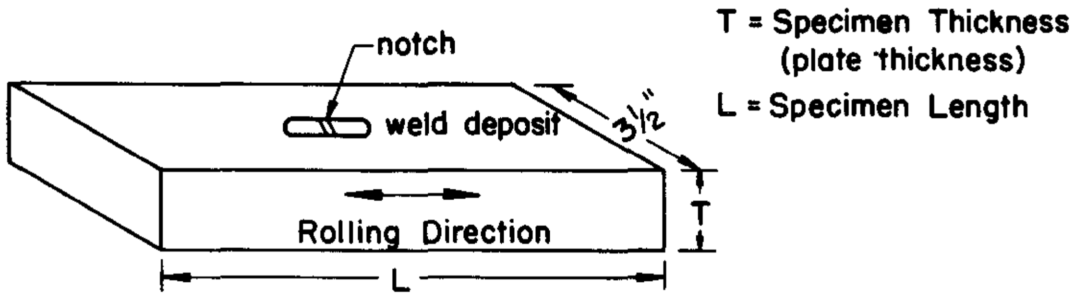


FIG. 4. DIMENSIONS OF THE DROP-WEIGHT TEST.

A crack starter weld was placed centrally on the surface of the specimen as shown in Figure 4. This weld bead was approximately 2 inches long and 1/2 inch wide and had a hardness of Rockwell C 40-45. Murex Hardex N electrodes of 3/16 inch diameter were used to deposit the weld bead on the tension side of the test specimen.

The welding conditions were as follows:

22 volts, 180-200 amperes, travel speed 5 inches per minute except for the 3/4 inch plate for which a travel speed of 8 inches/min was used. For the thinner plate,

a faster travel speed was necessary to meet the hardness requirements.

A notch was machined in the weld bead using a 45° angle cutter with a radius of 0.010 inch. The notch was machined to a depth such that the root of the notch was 0.070 inch above the specimen surface. The purpose of the notch was to initiate brittle fracture in the weld bead directly below the line of impact.

The specimens were brought to the desired temperatures in a bath of alcohol cooled by dry ice additions. After the required period the specimen was removed from the bath and centered on the jig supports so that the notch on the tension side of the specimen was directly below the line of impact. The weight was then dropped on the specimen from a height necessary to give the required impact energy.

This impact energy value was determined by trial. The impact energy for each specimen thickness and span length was determined as that energy which would produce a minimum crack opening of 0.015 inch at the base of the notch at room temperature. The impact energy chosen for each test series initiated brittle fracture at room temperature in the hard weld bead. At low temperatures the brittle crack initiated in the weld bead was propagated into the test specimen.

A specimen was considered broken (a "Go" specimen) if the brittle crack propagated to one or both edges of the tension surface. If the brittle crack did not propagate this amount, the specimen was considered unbroken (a "No Go" specimen).

Duplicate specimens were tested at 10°F intervals in the expected transition temperature range. The nil ductility transition temperature (NDT) for a test series was defined as the highest temperature at which a "Go" specimen was obtained, providing duplicate "No-Go" specimens were obtained at a temperature 10°F higher. This was the only transition temperature criterion used for this test, and it is essentially a criterion of the ability of the specimen material to stop a running cleavage crack.

EXPERIMENTAL DATA

An illustration of the data collected for the determination of transition temperatures is given in Figure 5. The scatter exhibited by the data is typical of that observed in the tests and represents an uncertainty of about ± 10°F.

A complete listing of the transition temperatures obtained from the several testing methods is presented in the tables.

Table 7 contains the Charpy V-notch test results on the plates of ABS Class C steel and Table 8 the results for the T-1 steel. While these data indicate a general uniformity among the thicknesses, several plates deviated enough from the average to require adjustment before interpreting results. The method of adjustment is discussed below.

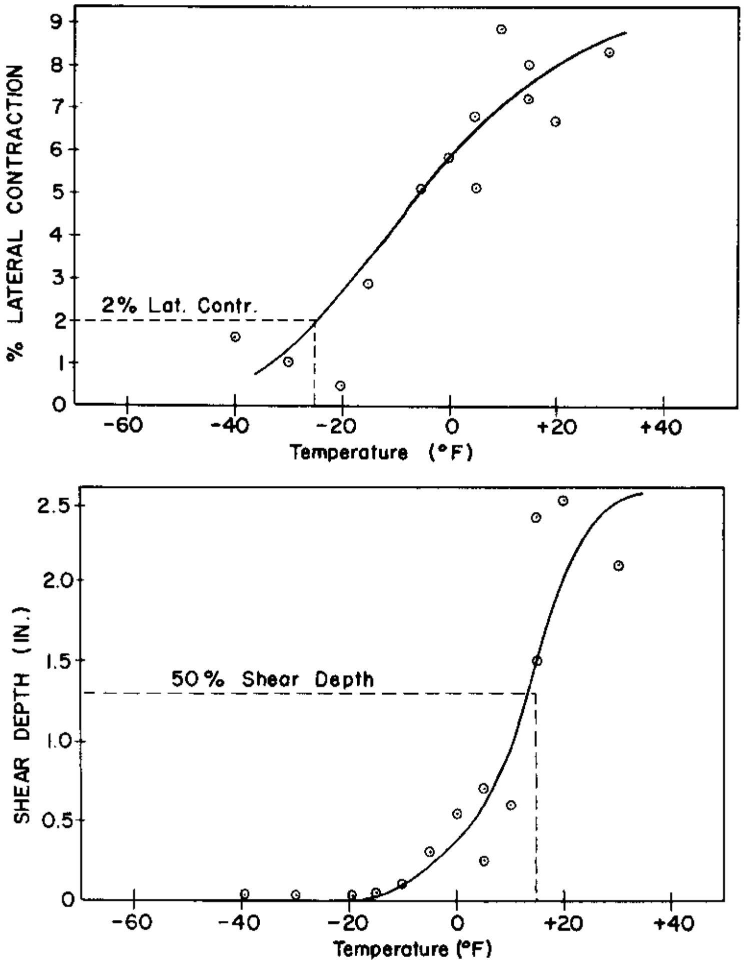


FIG. 5. TYPICAL TRANSITION CURVES OBTAINED IN THE VAN DER VEEN TEST FOR A 3-INCH STANDARD SPECIMEN.

For the ABS Class C steel, Table 9 lists the van der Veen test results, Table 10 the Bagsar test data, and Table 11 the drop-weight NDT data. For T-1 steel, Table 12 contains the van der Veen test data. An analysis of these data is presented in the next section.

DISCUSSION OF RESULTS

Before an attempt was made to analyze the data obtained from the testing program, it was essential to minimize masking effects produced by metallurgical variations among the plate thicknesses.

TABLE. 9. VAN DER VEEN TRANSITION TEMPERATURES OF ABS CLASS C STEEL- DETERMINED BY VARIOUS CRITERIA.

TEST SERIES			SHEAR	DEPTH	DEFLECTION AT FAILURE	LATERAL CONTRACTION
Plate	Height	Span	50%	8mm	1/2 Ductile Value	2%
3/4"	Stnd.	9.5"	-20° F.	-25° F.	-55° F.	-60° F.
3/4"	1/2	9.5"	-25° F.	-30° F.	-50° F.	-55° F.
3/4"	1/4	9.5"	+35° F.	+35° F.	-40° F.	-40° F.
1 "	Stnd.	9.5"	-25° F.	-45° F.	-55° F.	-55° F.
1 "	1/2	9.5"	-45° F.	-45° F.	-50° F.	-50° F.
1 "	1/4	9.5"	-75° F.	-75° F.	-85° F.	-75° F.
1 "	Stnd.	16.5"	-55° F.	-70° F.	-85° F.	-90° F.
1-1/2"	Stnd.	9.5"	-10° F.	-45° F.	-55° F.	
1-1/2"	1/2	9.5	-35° F.	-40° F.	-50° F.	-50° F.
1-1/2"	1/4	9.5"	-40° F.	-40° F.	-40° F.	-50° F.
2 "	Stnd.	9.5"	+ 5° F.	-20° F.	-35° F.	-50° F.
2 "	1/2	9.5"	-10° F.	-20° F.	-30° F.	-30° F.
2 "	1/4	9.5"	-25° F.	-25° F.	-30° F.	-30° F.
2 "	Stnd.	16.5"	+15° F.	-20° F.	-50° F.	-45° F.
3 "	Stnd.	9.5"	+15° F.	0° F.	-15° F.	-15° F.
3 "	1/2	9.5"	+15° F.	0° F.	-30° F.	-30° F.
3 "	1/4	9.5"	-20° F.	-20° F.	-30° F.	-25° F.
3 "	Stnd.	16.5"	+20° F.	-10° F.	-30° F.	-30° F.
1* "	Stnd.	9.5"	-10° F.	-25° F.	-35° F.	-45° F.
2* "	Stnd.	9.5"	0° F.	-15° F.	-20° F.	-20° F.

*These specimens were split from 3-inch thick plates

TABLE 10. BAGSAR TEST RESULTS ON ABS CLASS C STEEL - TEST SERIES.

TEST SERIES

PLATE THICK -NESS	SPECIMEN DEPTH	50% SHEAR	2% LATERAL CONTRACTION	DROP IN MAXIMUM LOAD
1"	1.5"	-25° F.	-50° F.	-45° F.
1"	3 "	-25° F.	-45° F.	-50° F.
1"	6 " (Standard)	-30° F.	-70° F.	-70° F.
1"	6 " (Narrow Throat)	-25° F.	-70° F.	-65° F.
2"	1.5"	+ 5° F.	-40° F.	-40° F.
2"	3 "	+20° F.	-55° F.	-30° F.
2"	6 " (Standard)	+30° F.	-55° F.	-50° F.
2"	6 " (Narrow Throat)	+35° F.	-60° F.	-55° F.
3"	1.5"	+40° F.	-	-
3"	3 "	+50° F.	-	-
3"	6 " (Standard)	+45° F.	-45° F.	-

TABLE 11. RESULTS OF DROP-WEIGHT TESTS ON ABS CLASS C STEEL.

PLATE THICKNESS (inches)	SPAN LENGTH (inches)	NDT
3/4	6	-20° F.
3/4	9	-40° F.
3/4	12	-40° F.
1*	9	-20° F.
1*	12	-20° F.
1*	16	-20° F.
1-1/2	9	+10° F.
1-1/2	12	0° F.
1-1/2	20	-10° F.
2*	12	+20° F.
2*	16	+20° F.
2*	20	+10° F.
3	12	+30° F.

*Specimens prepared from Heat No. 2

TABLE 12. VAN DER VEEN TEST TRANSITION TEMPERATURES FOR "T-1" STEEL.

SERIES	SHEAR DEPTH		2% LATERAL CONTRACTION
	8mm	50%	
1/2" Pl. Std. ht.	-95° F.	-65° F.	-145° F.
1/2" Pl. 1/2 ht.	-80° F.	-75° F.	-145° F.
1/2" Pl. 1/4 ht.	-70° F.	-70° F.	- 95° F.
3/4" Pl. Std. ht.	-75° F.	-60° F.	-110° F.
3/4" Pl. 1/2 ht.	-65° F.	-60° F.	- 90° F.
3/4" Pl. 1/4 ht.	-40° F.	-40° F.	- 55° F.
1 " Pl. Std. ht.	-85° F.	-60° F.	-130° F.
1 " Pl. 1/2 ht.	-90° F.	-80° F.	-140° F.
1 " Pl. 1/4 ht.	-50° F.	-50° F.	- 65° F.
2 " Pl. Std. ht.	-35° F.	0° F.	- 90° F.
2 " Pl. 1/2 ht.	-15° F.	-10° F.	- 60° F.
2 " Pl. 1/4 ht.	0° F.	0° F.	-

A first-order correction was applied to the observed transition temperatures on the basis of deviations observed in the Charpy test results. For fracture transition temperatures, the Charpy 50% shear criterion was used, and for ductility transition temperatures, the Charpy 15 mil lateral expansion criterion was used. The adjustments applied to the data of Tables 9 to 12 for presentation in the figures were estimated from Tables 7 and 8 as follows:

		CORRECTION APPLIED	
STEEL	THICKNESS	FRACTURE TRANSITIONS	DUCTILITY TRANSITIONS
ABS Class C (Heat 1)	3/4 inch	-15°F	-15°F
	1	+10	+15
	1 1/2	0	0
	2	0	0
	3	0	0
"T-1" Steel	1/2	0	0
	3/4	0	0
	1	+40	+30
	2	0	0

Except for the 1 inch "T-1" steel, these corrections could be omitted without disturbing the clear trends shown by the results. Heat No. 2 of the ABS Class C steel did not require any corrections.

The primary point of interest was the effect of plate thickness on transition temperature indicated by the three testing methods. Figures 6, 7, and 8 summarize this effect. In Figure 6, the 50% shear fracture transition temperatures of ABS Class C steel determined by all three tests are shown as a function of plate thickness. There is obvious agreement among the tests in indicating a strong effect of thickness in thinner gages and a flattening of the curve at greater thicknesses. This trend is confirmed by the 2% lateral contraction transition temperatures of the van der Veen

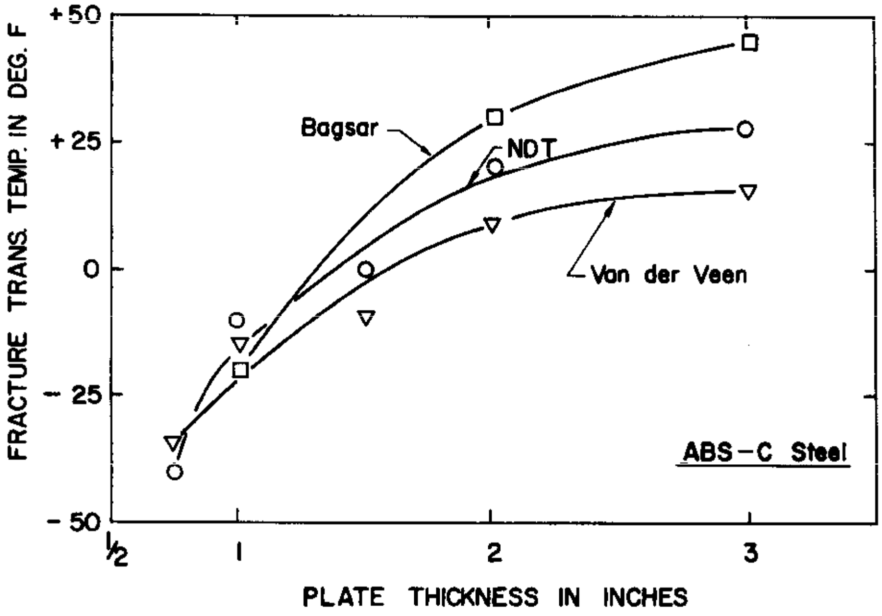


FIG. 6.

EFFECT OF PLATE THICKNESS ON FRACTURE TRANSITION TEMPERATURE OF ABS - CLASS C STEEL.

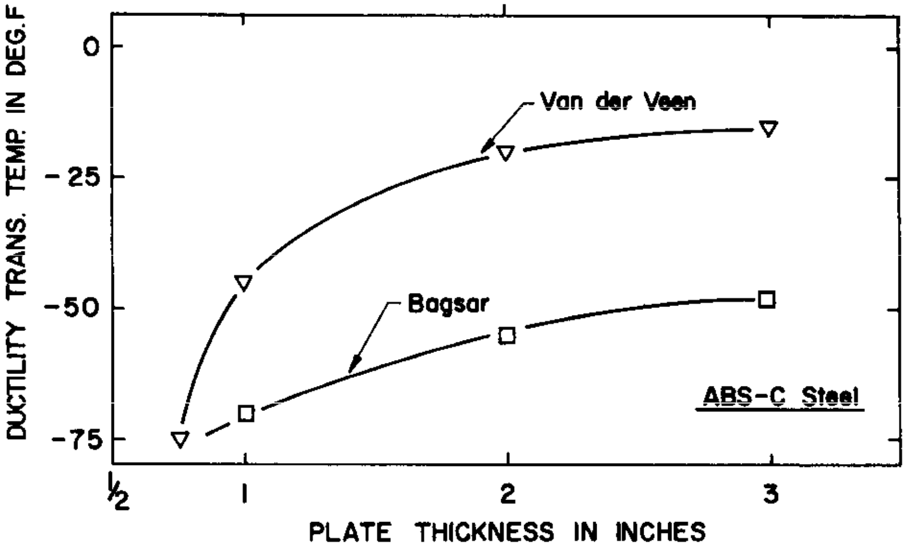


FIG. 7.
EFFECT OF PLATE THICKNESS ON DUCTILITY TRANSITION TEMPERATURE OF ABS - CLASS C STEEL.

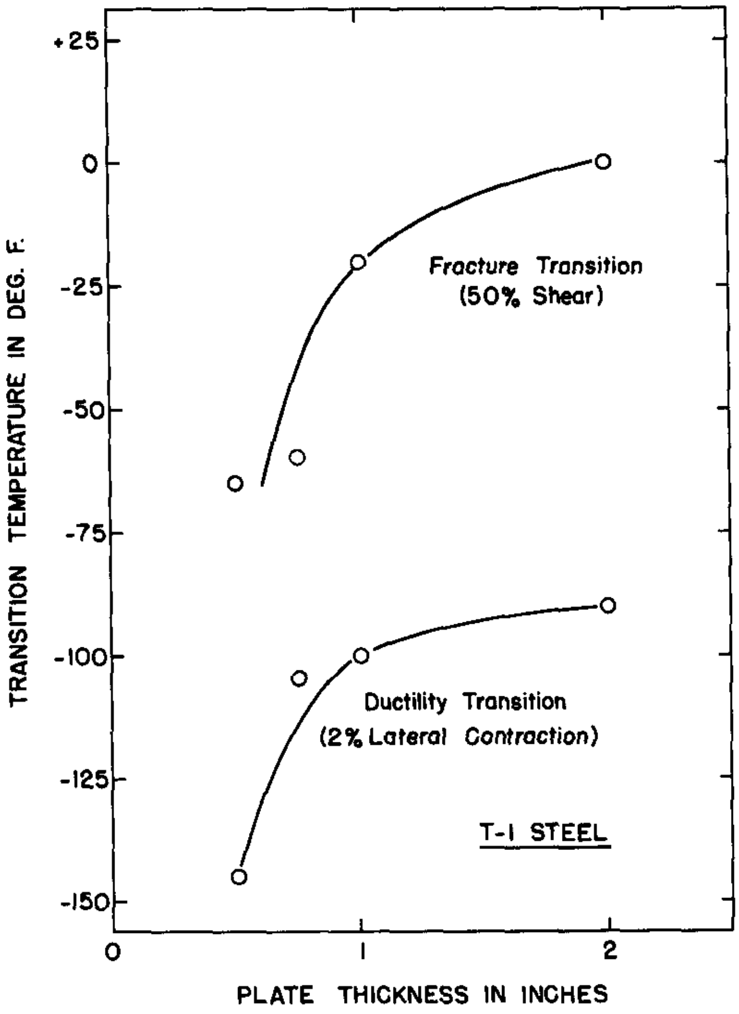


FIG. 8. EFFECT OF PLATE THICKNESS ON THE TRANSITION TEMPERATURES OF "T-1" STEEL IN THE VAN DER VEEN TEST.

test and Bagsar test shown in Figure 7. A similar behavior is suggested by both the fracture and 2% lateral contraction transition temperature curves for "T-1" steel shown in Figure 8. The tendency for the change in transition temperatures to be small for plate thicknesses above 2 inches has been shown for several steels. There is lack of evidence, however, that the rise in transition temperature with thicknesses up to 2 inches is a purely geometrical effect and therefore the same for all steels. It is concluded on the basis of Figures 6, 7, and 8 that the geometrical effect of plate thicknesses above 2 inches can be expected to be relatively small.

The experimental data obtained from the van der Veen tests also furnish information about the direct influence of the other lateral dimension of the specimens on transition temperature, and more importantly its influence on the plate thickness effects reported above. Figures 9 and 10 illustrate the results obtained. In Figure 9, it is seen that the reduction of the van der Veen specimen height from full to half height (1.38 inches) lowers the fracture transition temperature of ABS Class C and "T-1" steels an average of 10°F. The effect of height on the ductility transition shown in Figure 10 was smaller than its effect on fracture transition, and it produced a reverse effect in two cases (possibly due to scatter). The quarter-height specimens produced rather erratic results, in many cases showing higher transition temperatures than the standard-height specimens. Some of the anomaly may arise from the relatively large deflections required to produce failure in these shallow specimens. In any event, the effect observed for plate thickness in full-height specimens was reproduced for the most part in the half-

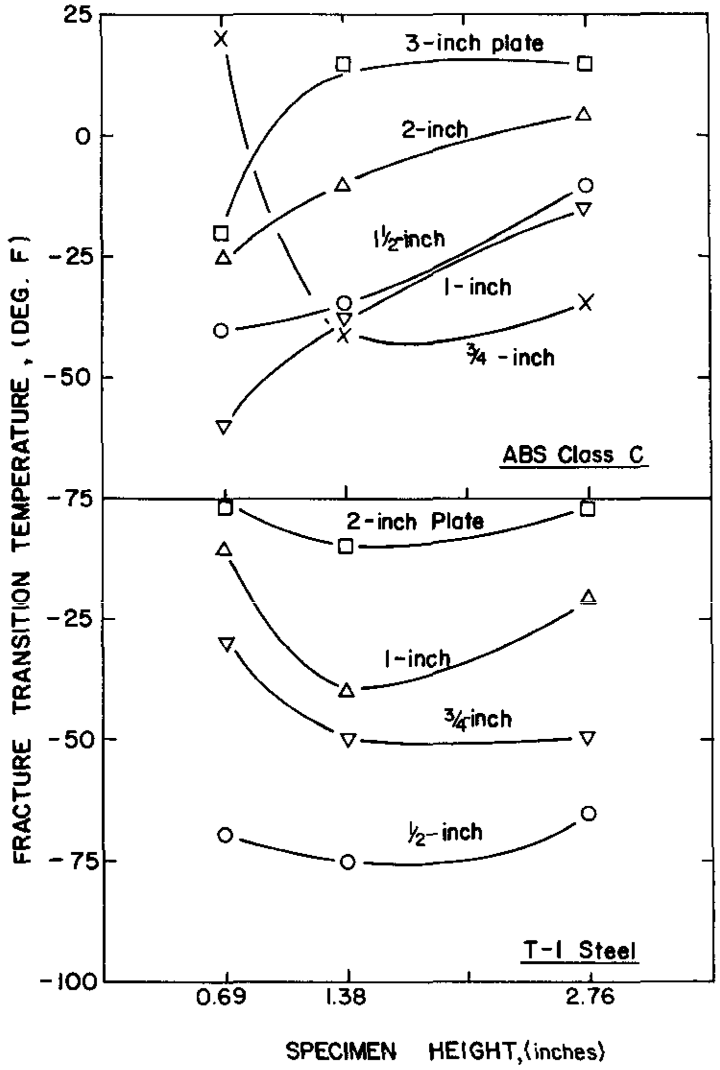


FIG. 9. EFFECT OF VAN DER VEEN SPECIMEN HEIGHT ON FRACTURE TRANSITION TEMPERATURES OF ABS - CLASS C AND "T-1" STEELS.

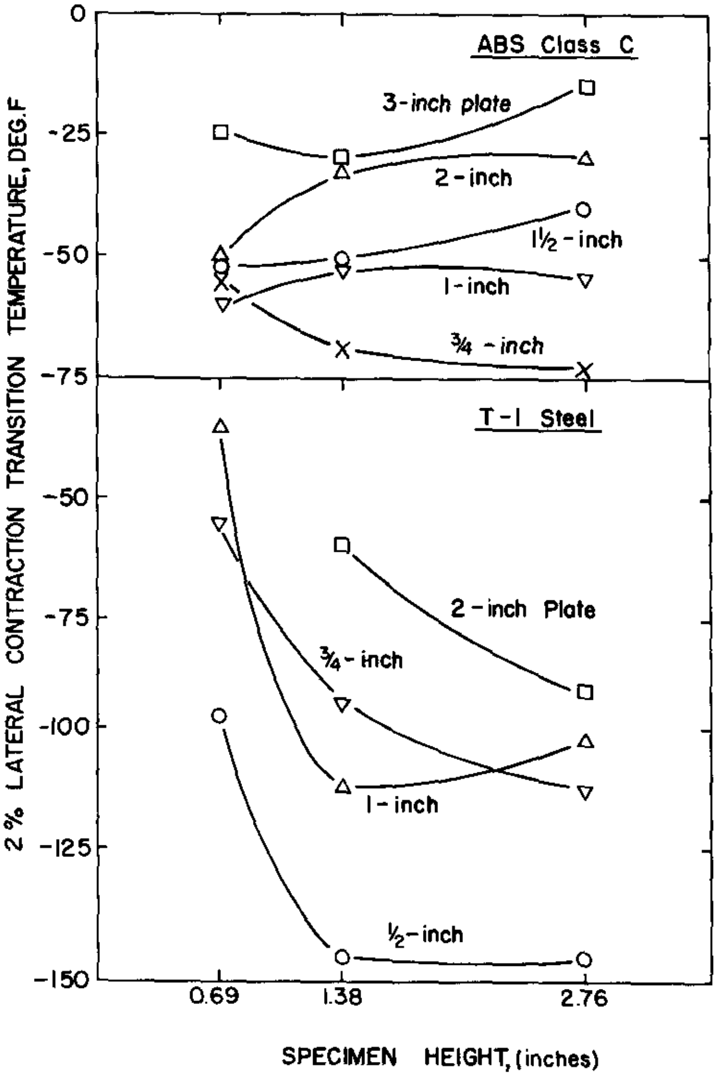


FIG. 10. EFFECT OF VAN DER VEEN SPECIMEN HEIGHT ON DUCTILITY TRANSITION TEMPERATURES OF ABS - CLASS C AND "T-1" STEELS.

height specimens. Some deviation was evident in the fracture transition temperatures for ABS Class C steel, but the other data were consistent. These results suggest that the standard-height specimen is large enough to avoid an interaction between height and width in the specimen. The results of the Bagsar tests showed no discernible trend as the specimen width was varied from 1 1/2 to 6 inches, as can be seen from Table 10.

The effect of plate thickness on the drop-weight test NDT observed in the present tests is contrary to that generally stated. The NDT has been assumed to be independent of plate thickness, but several investigators have recently shown that the NDT rises with plate thickness. The similarity of the drop-weight test to the van der Veen and Bagsar tests in its response to plate thickness is more useful and comprehensible to the investigator than would be a total insensitivity to thickness.

An increase of the length of span generally lowered the fracture transition temperatures in the van der Veen and drop-weight specimens. Figure 11 illustrates that the effects were not very consistent but averaged about 10^{O}F drop when the span was doubled.

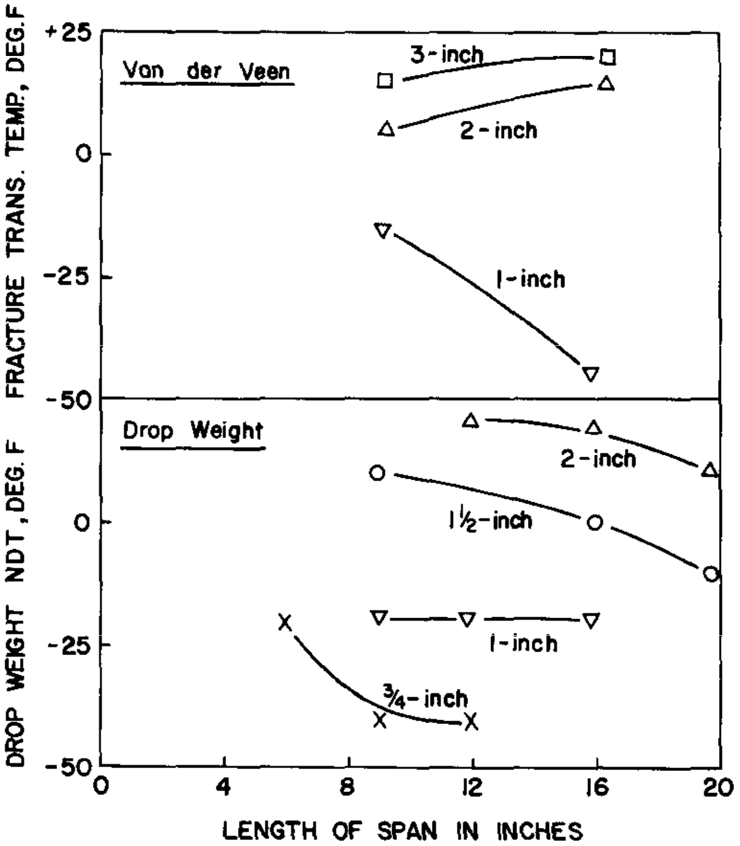


FIG. 11. EFFECT OF SPECIMEN SPAN ON TRANSITION TEMPERATURES IN VAN DER VEEN AND DROP-WEIGHT TESTS.

As a general conclusion, the experimental results suggest that the size effect in very sharply notched specimens becomes relatively small when both the width and depth dimensions are increased beyond 2 inches.

CHOICE OF TESTING METHOD FOR PHASE TWO

From the experimental evidence it appears that any of the three testing methods could be used in carrying out Phase Two of the program. There are several advantages, however, to the choice of the van der Veen test for this purpose. First, it can be applied to thicknesses up to 4 inches without requiring special testing equipment other than readily available universal testing machines. Secondly, it permits the use of a variety of criteria of transition temperature to assess the merits of steel compositions and heat treatments. Third, it is free of the interfering action of the welding heat-affected zone which sometimes produces spurious transition temperatures in the drop-weight test.

It is therefore planned to adopt the van der Veen test as the primary testing method for the second phase of the investigation.

SUMMARY

The results of the investigation can be summarized as follows:

1. The van der Veen test, the Bagsar test, and the drop-weight test showed general agreement in their response to changes in plate thickness ranging from 3/4 to 3 inches.

2. The dimensional effect of plate thickness, with metallurgical variables held constant, was to raise the transition temperature markedly as the plate thickness was increased from 1/2 to 1 1/2 inches. Above 2 inches, thickness appeared to have much less effect on the transition temperature observed in these sharply-notched specimens. ABS Class C and "T-1" steels behaved similarly in this respect.

3. In the presence of a severe notch, specimen widths and heights of 2 inches or greater appear adequate to determine the sensitivity of heavy-section steel plate to brittle fracture.

4. The van der Veen specimen is recommended as the testing method for the second phase of the program because of its testing convenience and its suitability for determining transition temperatures by a variety of criteria.

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