SSC-108

NOTCH-TOUGHNESS PROPERTIES OF SHIP-PLATE STEEL AS EVALUATED BY THE VAN DER VEEN NOTCHED SLOW-BEND TEST

by

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and

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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.

August 31, 1959

Dear Sir:

Herewith is the Second Progress Report, SSC-108, entitled "Notch-Toughness Properties of Ship Plate Steel as Evaluated by the van der Veen Notched Slow-Bend Test" by E. A. Imbembo and F. Ginsberg, of Project SR-141, "Semikilled Steels over One Inch."

This portion of the project is being conducted at the Material Laboratory of the New York Naval Shipyard under the advisory guidance of the Committee on Ship Steel of the National Academy of Sciences-National Research Council.

This report is being distributed to individuals and groups associated with or interested in the work of the Ship Structure Committee. Please submit any comments that you may have to the Secretary, Ship Structure Committee.

Sincerely yours,

E. H. Thiele
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

Serial No. SSC-108

Second Progress Report
of
Project SR-141

to the

SHIP STRUCTURE COMMITTEE

on

NOTCH-TOUGHNESS PROPERTIES OF SHIP-PLATE STEEL AS EVALUATED BY THE VAN DER VEEN NOTCHED SLOW-BEND TEST

by

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Material Laboratory
New York Naval Shipyard

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ABSTRACT

This report describes the second stage of research work on a program designed to study the notch-toughness properties of semikilled ship-steel plate over one inch in thickness. The details set forth here are the results of tests on the fracture appearance and ductility transition temperatures of samples of 3/4 in., 1 1/4 in. and 1 3/4 in. thick plate, representing two heats of a low-carbon, high-manganese, semikilled experimental steel, as determined by means of the notched slow-bend test developed by J. H. van der Veen.

Observations made during this investigation seem to indicate that the van der Veen test provides an estimate of the fracture transition temperature similar to that obtained in the Navy tear test. However, more work remains to be done with regard to obtaining additional experience with the method and establishing its correlation with other techniques used for evaluating notch-sensitivity characteristics of ship-plate steels.

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INTRODUCTION

In November, 1955, the Material Laboratory of the New York Naval Shipyard commenced evaluating the notch-toughness properties of samples of experimental ship-plate steel by means of the van der Veen notched slow-bend test. This work is a phase of a comprehensive program (SR-141) which was originally set up by the Ship Structure Committee to investigate properties of semikilled steel plate in thicknesses over 1 in. that contain less carbon and more manganese than Class-B steel as specified in the 1955 ABS Rules for plate ranging in thickness from over 1/2 in. to 1 in. inclusive. It was felt that a semikilled, hot-rolled steel containing approximately 0.16% carbon and 1.00% manganese might serve as a possible emergency substitute for fully killed Class-C steel, currently specified by ABS Rules for ship plate over 1 in. in thickness. The program has been subsequently expanded to include a determination of the ductility and fracture-appearance transition temperatures of samples of steel plate by means of the van der Veen notched slow-bend test--an experimental technique developed in Europe by J. H. van der Veen.[1] Its application by the Material Laboratory represents the only known exploration of the method in this country.

Under arrangements made by the Ship Structure Committee, samples of plate rolled from two experimental heats of the proposed steel produced by the U. S. Steel Corporation were distributed to a number of laboratories for a comprehensive investigation of the characteristics of the material, with particular emphasis on notch-toughness properties as evaluated by various experimental techniques. These included Charpy drop-weight, explosion crack-starter, Robertson, Esso brittle temperature, and Navy tear tests. The groups participating in the program include the American Bureau of Shipping, Naval Research Laboratory, Admiralty Naval Construction Research Establishment, Esso Research and Engineering Company, Material Laboratory and the United States Steel Corporation. The project is of interest to the Department of the Navy in view of the fact that hull plate, 7/8 in. thick and over, is required under Military Specification MIL-S-16113B to be of the same type as ABS Class-C and, in addition, to be in the normalized condition.

The purpose of this report is to describe the technique, equipment and procedure used by the Material Laboratory in the van der Veen test. These data, together with those obtained by the various cooperating laboratories on the same steel, will be analyzed and correlated by R. W. Vanderbeck of the United States Steel Corporation; a first progress report on this analysis and correlation appeared in August, 1956.[2] An appraisal of the method as a means of determining the tendency of mild steel to brittle fracture may be found elsewhere.[3,4]

VAN DER VEEN TEST METHOD

Description: Specimens of the type shown in Fig. 1 are bent at various temperatures in a testing machine at a loading rate of 20 mm (0.8 in.) per min. The longitudinal axis of the specimen is taken perpendicular to the direction of rolling. In the middle of one of the two machined surfaces, a sharp 3-mm deep notch with an included angle of 45° is made with a hardened-steel knife, producing a radius in the order of 0.004 mm (0.00016 in.) at the root of the notch. After notching, the specimen is brought to the desired test temperature in a liquid bath, then removed from the conditioning bath and tested to failure within a minute. It is important that the testing be completed within 2 hr. of notching to minimize aging effects.[4]

Heat exchange with the surroundings is considered negligible; however, the temperature does rise as a result of deformation energy becoming in part frictional heat, which may influence the transition temperature. It is stated that the test thus acquires an adiabatic character. In this connection, it has been stated: "Whether service conditions are approximated more closely by an adiabatic than by an isothermal test is still an open question. In any case, the isothermal test is more difficult to perform, not only because during the test the specimen must be present in the cooling bath, but because the test would have to be carried out very slowly and with interruptions to permit dissipation of the heat locally generated."[3]

During the test, the changes in load as a function of the deflection of the specimen at its center are recorded automatically to produce a complete

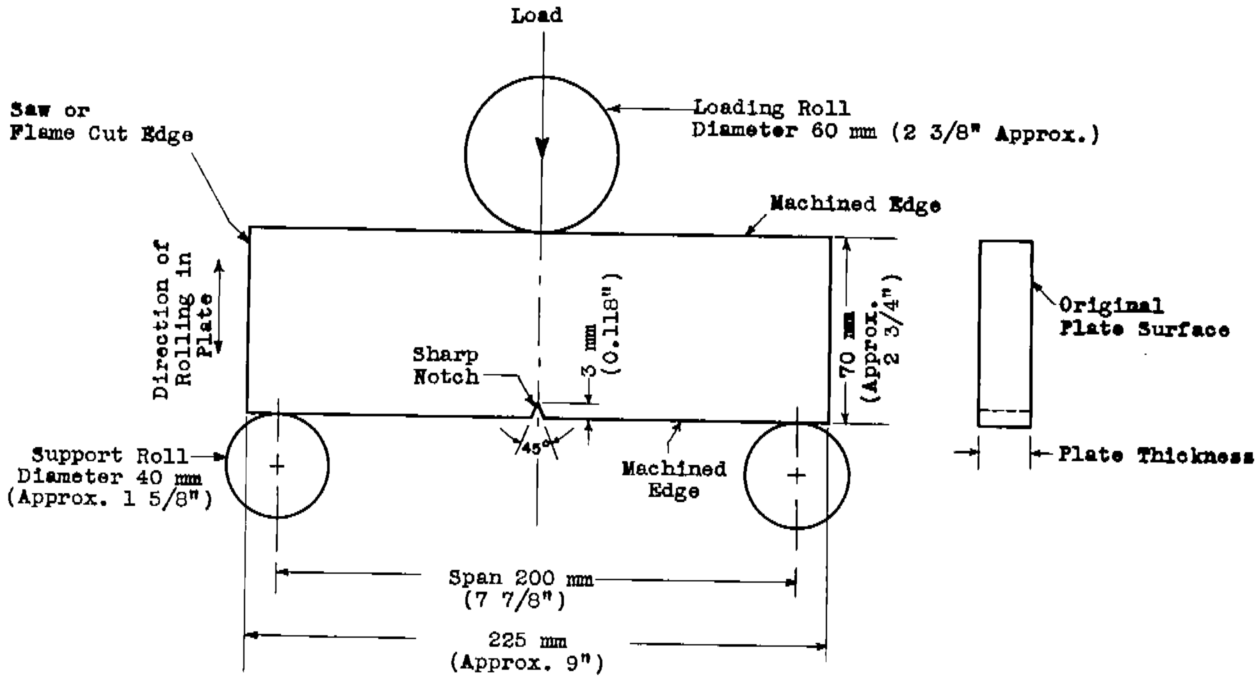

Fig. 1. Van der Veen Notched Slow-Bend Test Specimen.

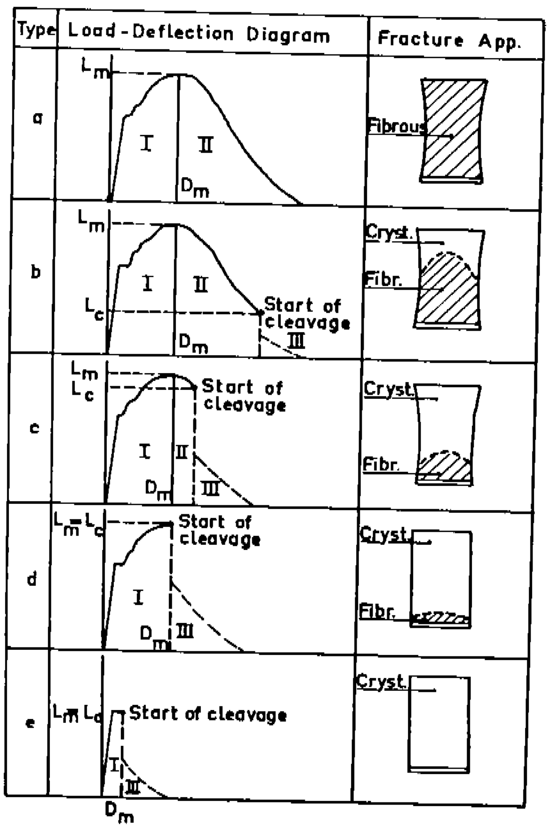

Fig. 2. Schematic Representation of Various Shapes of Load-Deflection Diagrams Obtained in the van der Veen Notched Slow-Bend Test.[3]

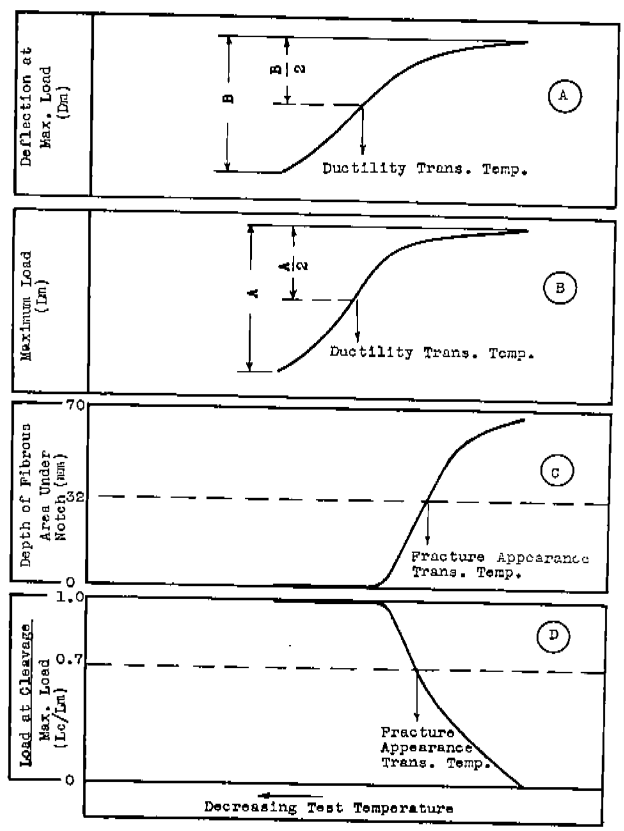

Fig. 3. Schematic Representation Showing Methods of Defining Transition Temperatures in the van der Veen Notched Slow-Bend Test.

load-deflection diagram. As will be shown later, it is not essential to obtain such diagrams since the test results may be evaluated by other means.

The various forms that may be assumed by the load-deflection curve are shown schematically in Fig. 2. Type "a" represents the behavior of a specimen failing entirely by shear, the fracture appearance being totally fibrous. Types "b," "c," "d," and "e" show the behavior of the specimen under the conditions that tend to promote increased brittleness, such as would be obtained by lowering the testing temperature. After the start of cleavage, a measurable (though small) amount of work may be absorbed in some cases, despite the fact that the fracture path is almost fully crystalline. In these cases, the fracture surface usually shows about 1- or 2-mm wide fibrous edges bordering on the plate surfaces. In addition, these fibrous edges may occasionally widen and join to form a so-called thumbnail of parabolic shape. At times, this thumbnail condition may lead to a sequence of alternate fibrous and crystalline areas in the fracture. In all of these instances, the energy included under Area III is greater than zero and the load-deflection diagrams occasionally show a "tail," which is indicated by the dashed lines in Fig. 2.

Two transition temperatures are usually determined by testing a number of specimens at each of a series of test temperatures 10 C (18 F) apart. These temperatures are the fracture-appearance transition temperature and the ductility transition temperature.

1. The fracture-appearance transition temperature is obtained by measuring the depth of fibrous area beneath the notch and plotting the value for each specimen tested as a function of the test temperature. Since in all fractures of a mixed type the fibrous portion has a parabolic boundary, measurement of fibrous areas can be avoided by simply taking a scale measurement of the distance between the notch root and the vertex of the parabola.[3] The curve drawn through the average value of "mm fibrous" at each test temperature is the transition curve. The fracture-appearance transition temperature is the temperature at which this average curve intersects the 32-mm line, as illustrated schematically in graph C of Fig. 3. An equivalent criterion for determin-

TABLE I - IDENTIFICATION OF U. S. STEEL (GARY WORKS) SAMPLE MATERIAL

1. Heat No.		2G 2850				2G 2883	
2. Ladle Analyses, %							
a. Carbon		0.16				0.15	
b. Manganese		1.30				1.04	
c. Phosphorous		0.010				0.013	
d. Sulfur		0.021				0.022	
e. Silicon		0.08				0.021	
3. Plate Thickness	3/4 in.	1 1/4 in.	1 3/4 in.	3/4 in.	1 1/4 in.	1 3/4 in.	1 3/4 in.
4. Slab Code	B	C	D	B	C	A	D
5. Sample Size							
a. Tear Test (in.)	36 x 45	36 x 45	36 x 45	18 x 45	18 x 45	18 x 45	18 x 45
b. VDV Test (in.)	*	*	*	18 x 48	18 x 48	18 x 48	18 x 48
6. Direction of Rolling in Sample for							
a. Tear Test	Parallel to 36 in. dimension				Parallel to 18 in. dimension		
b. VDV Test	Parallel to 36 in. dimension				Parallel to 48 in. dimension		
7. Approximate Location of Sample with Respect to Length of Original Plate							
a. Tear Test	Bottom	Bottom	Top	Top	Top	Top	Bottom
b. VDV Test	Bottom	Bottom	Top	Center	Center	Center	Center

* One sample piece for both tear and van der Veen tests.

ing this temperature uses Lc/Lm = 0.7, where Lc represents the load at cleavage and Lm is the maximum load. The fracture-appearance transition through use of this alternate criterion is obtained from the average curve of Lc/Lm vs. test temperature at a point where the curve intersects the 0.7 line of Lc/Lm, as illustrated schematically in graph D of Fig. 3. The use of "mm fibrous" as a criterion is preferred by van der Veen[1] because of somewhat greater accuracy in its measurement. This temperature is related to the transition from type "b" to "c" fractures (Fig. 2) and "therefore may be considered to be a measure of the tendency to start cleavage from a fibrous crack propagating in material that has been slightly deformed in tension."[1]

2. The ductility transition temperature is related to the transition from type "d" to "e" fractures (Fig. 2). Van der Veen has found that in the type "d" fracture, the depth of fibrous area under the notch amounts to 7 mm average. In type "e," the crystalline fracture starts immediately at the root of the notch in the vicinity of the "yield point" of the load-deflection diagram at a load and deflection considerably less than those at which the fibrous incipient crack would otherwise have started. On the basis of previous reports[1, 3] and information obtained in correspondence with van der Veen, the ductility transition temperature is taken as the temperature at which the value of Dm (deflection at maximum load) is about half-way between the extremes of the average curve of Dm vs. test temperature, as illustrated schematically in graph A of Fig. 3. (A recent IIW report[4] takes the ductility transition temperature at a value of Dm = 6 mm). A similar alternative procedure for determination of the ductility transition temperature is illustrated in graph B of Fig. 3. In this case, the transition temperature is defined as that temperature at which the maximum load is about half-way between the extremes of the average curve of Lm vs. test temperature. However, van der Veen[1] considers the ductility transition temperature using the criterion of Dm to be more convenient and reliable.

Ship-Plate Material Under Test: A detailed description of the ship-plate material under investigation is contained in the First Progress Report on this project.[2] In brief, one 30-in. x 64-in. x 89-1/2-in. ingot was cast from each of two heats. Four slabs, coded A, B, C, and D, were produced from each ingot.

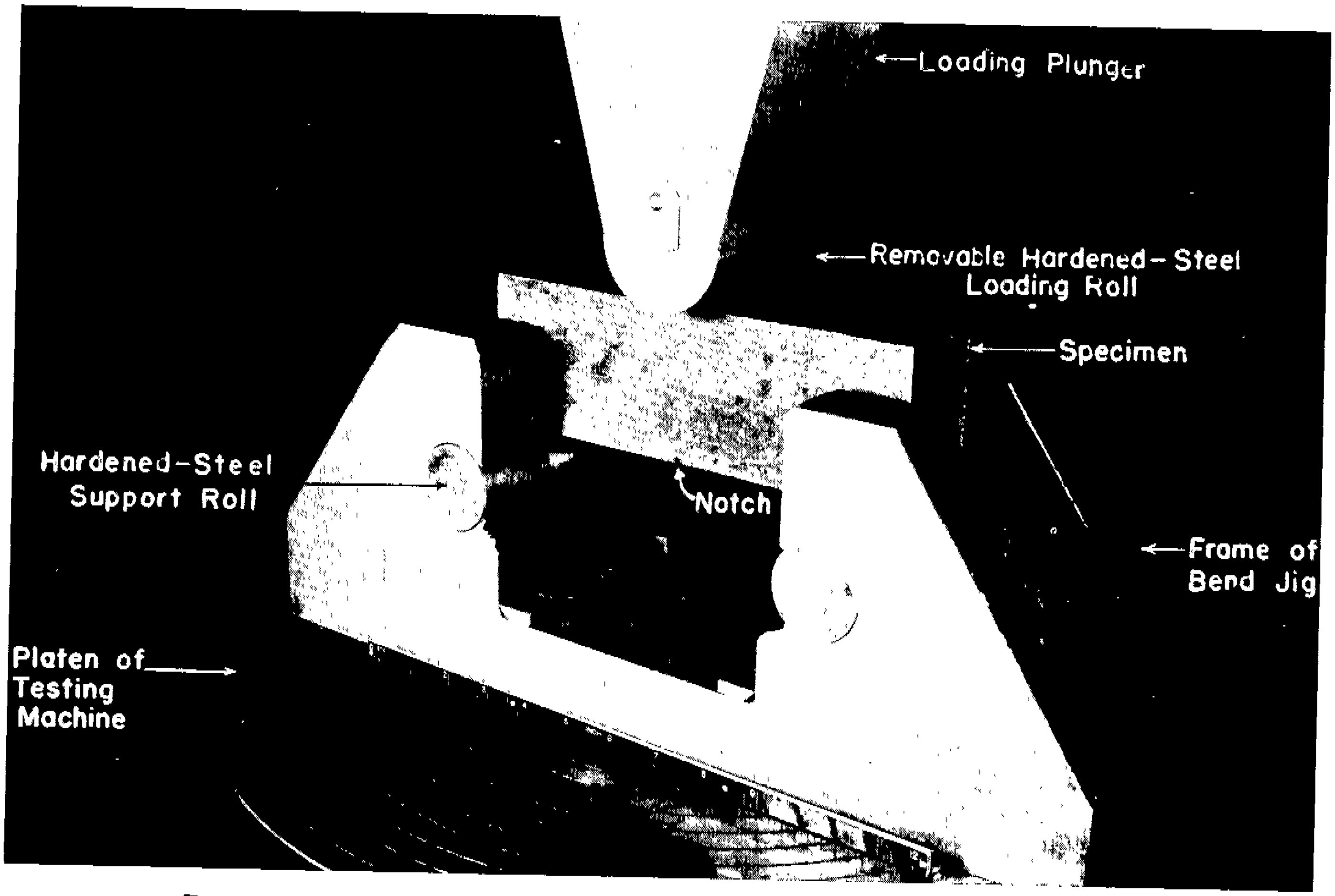

Fig. 4. Jig for Performing van der Veen Notched Slow-Bend Test.

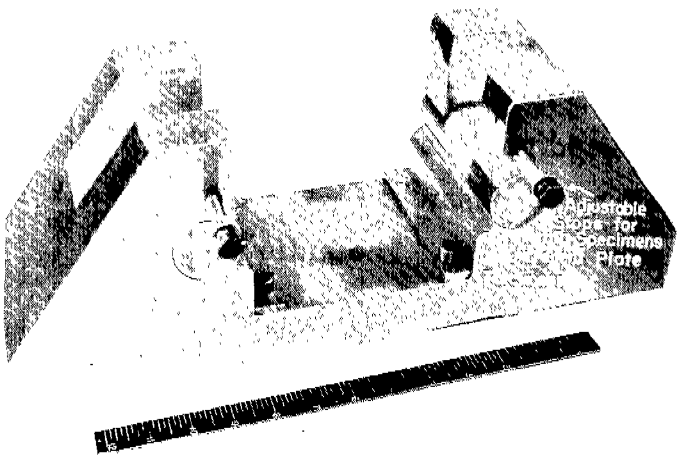

Fig. 5. Rear View of Frame of Bend Jig.

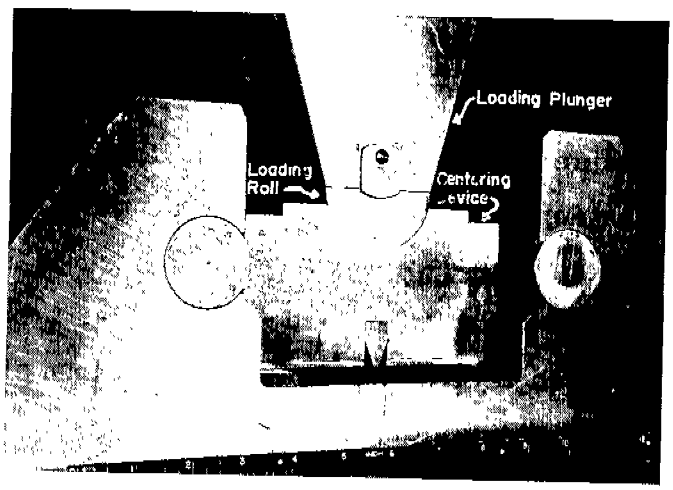

Fig. 6. Arrangement for Centering Loading Roll.

Slab A was the top slab of the ingot. In the first heat (No. 2G 2850), the top cut was lost because of pipe and, as a result, slab A was not obtained. The slabs were rolled to plate thicknesses of 3/4 in., 1-1/4 in. and 1-3/4 in.

A description of the sample material is given in Table I, which also shows the size and relative location of the sample material subjected to tear tests. It is to be noted that in the case of heat No. 2G 2850, the tear and van der Veen tests were made on the same sample of plate, while in the case of heat No. 2G 2883, tests were made on samples taken from different locations in the original plate.

EXPERIMENTAL EQUIPMENT

Figure 4 shows the jig that was constructed to perform the notched slow-bend tests. The dimensions of the loading and support rolls, as well as those of the span between centers of the support rolls, were made to conform to the dimensions given in Fig. 1. The jig was designed with adjustable stops (shown in Fig. 5) for centering specimens of different plate thicknesses up to 2 in. in thickness. A disadvantage of the test with respect to the testing of mild steel plate is that it requires a minimum plate thickness of approximately 1/2 in.[3] Thinner specimens tend to tilt and become unstable when loaded, which unduly affects the test results or may even render performance of the test impossible.

Figure 6 indicates the arrangement for locating the loading roll midway between the support rolls and, simultaneously, for lateral centering. The centering template is also utilized in the inverted position to serve as the hardened-steel knife holder. Figure 7 shows how the hardened-steel knife is used to cold-press the 45° V-notch in the test specimen. The knife is made of 52100 steel, hardened to Rc 63/64, ground and hand-honed to a sharp edge. The edge of the knife is located 3 mm above the top surface of the knife holder, a close-up view of which is shown in Fig. 8. In applying the load for cold-pressing, the loading roll is removed to prevent deformation of the specimen edge opposite the notch. The load is applied until the bottom edge of the specimen contacts the upper surface of the knife holder (as evidenced by sudden in-

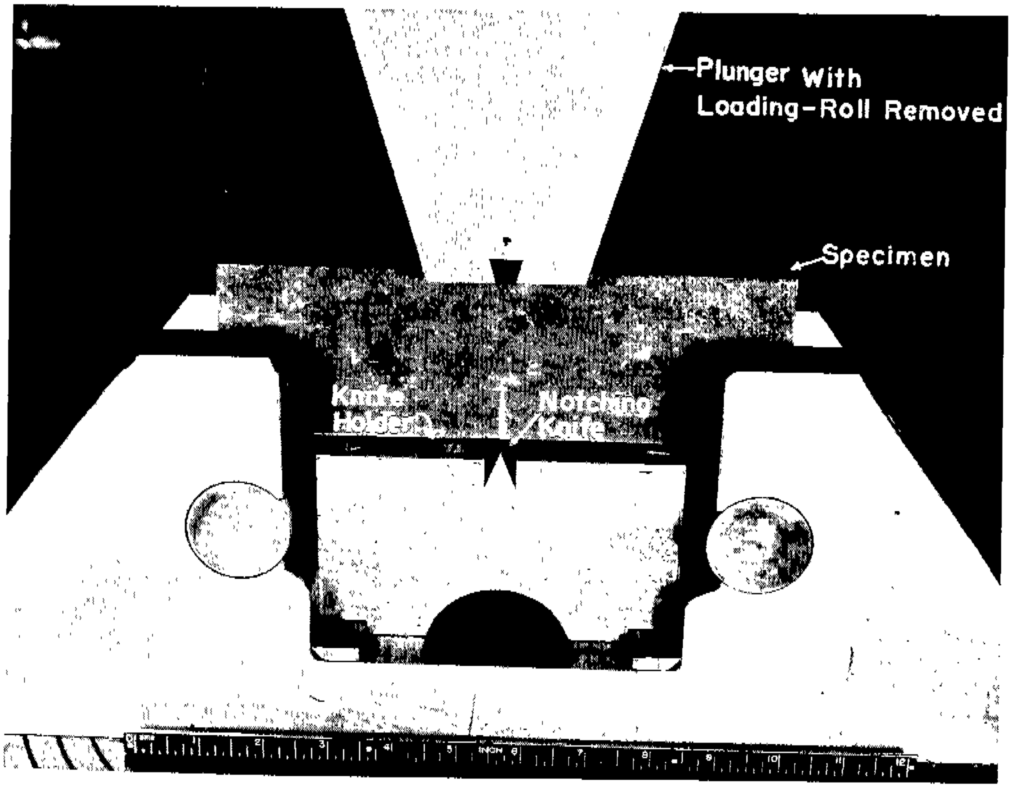

Fig. 7. Arrangement for Cold-Pressing 45° V-Notch in Test Specimen with Hardened Steel Knife.

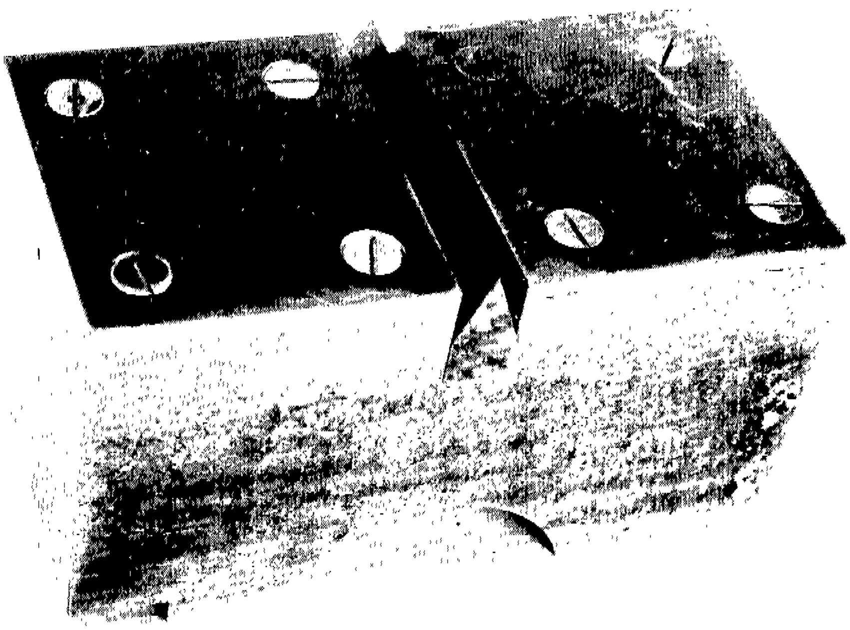

Fig. 8. Close-up View of Knife Holder and Centering Device.

crease in load), thus automatically pressing the notch to the required depth of 3 mm. A close-up view of a specimen in the process of being notched is shown in Fig. 9.

In order to avoid excessive change in temperature of a specimen during the interval between removal from the conditioning bath and application of load, it is considered desirable to have some means of quickly centering the specimen in the bending jig with subsequent immediate application of load. Therefore, a specimen, upon being removed from the conditioning bath, is banked against the specimen thickness stops (previously described) with the notch simultaneously centered midway between the support rolls by means of the index point shown in Fig. 10; the load is then immediately applied.

PROCEDURE

For each sample plate, three specimens were tested at each of seven or eight temperatures, selected so as to provide the necessary data for development of the transition curves. The longer dimension of the specimen was taken perpendicular to the direction of rolling.

Some preliminary experiments were conducted to determine whether it was necessary to machine the longer edges of the specimen. It was found that a carefully made saw-cut was adequate. The shorter edges were flame-cut. In this connection, van der Veen recommends that when the longer edges have been flame-cut, the width of the specimen blank should be 100 mm so as to provide an allowance of 15 mm on each side for subsequent removal by machining to the finished dimension of 70 mm.

The mechanism of cold-pressing the notch has been previously described. The necessary loads to fully form the notch to the required depth in the 3/4-in., 1-1/4 in. and 1-3/4 in. thick plates were in the ranges of 20,000--25,000, 30,000--35,000, and 40,000 to 50,000 lb, respectively. As a precaution against using a dull knife edge, no more than 10 pressings were made on the same area of the knife before the knife was hand-honed for subsequent pressings. Microscopic examination at 500 diam. of several notches showed no measurable radius at the

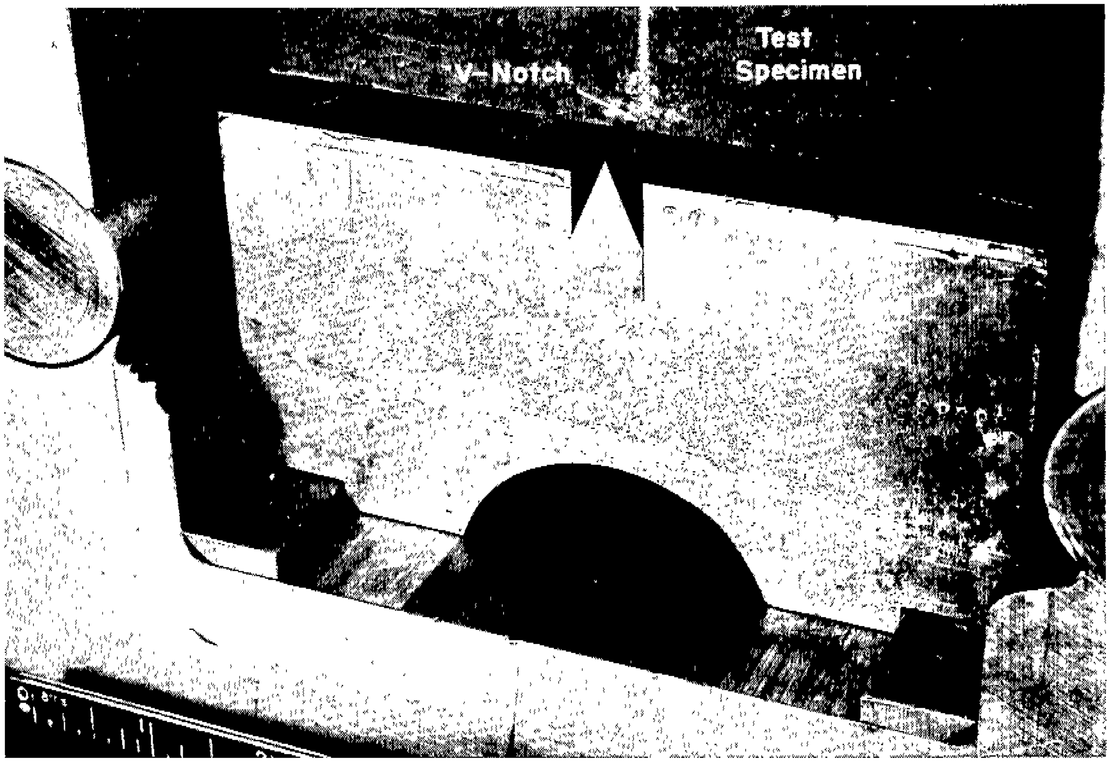

Fig. 9. Close-up View Showing Cold-Pressing of V-Notch.

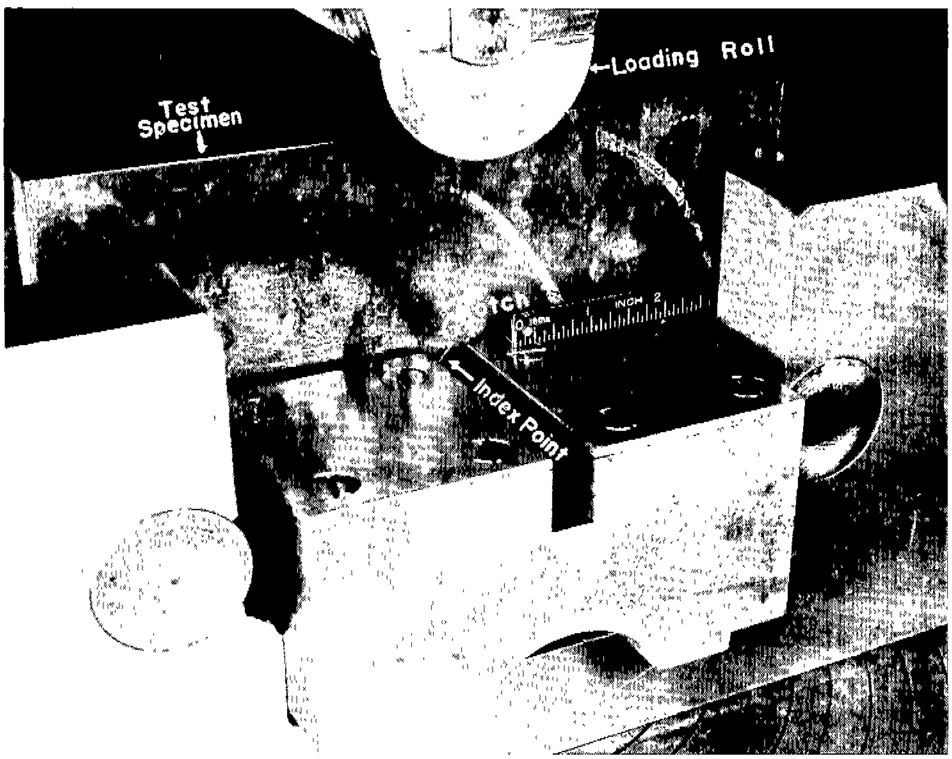

Fig. 10. Arrangement for Centering Notched Specimen for Loading.

root. The literature available on the van der Veen test does not contain direct references on the effects of the cold-pressed notch on test results. However, it indicates two advantages for the cold-pressed notch, namely: 1) such a notch simulates as nearly as possible the action of a natural fracture and 2) the transition temperature determined by this notch is relatively independent of notch root radius.[3]

Specimens of the 3/4-in. and 1-1/4-in. plates were tested in full plate thickness in a 120,000-lb capacity hydraulic testing machine equipped with a pacing device for controlling the speed of the loading ram. A microformer-type deflectometer and automatic recorder were employed to obtain the load-deflection diagrams. The deflection under load was not measured directly beneath the specimen because of possible damage to the deflectometer, particularly in the case of brittle failures; rather the deflection was measured as the change in distance between the loading heads, which is considered substantially equivalent to measurement of specimen deflection. This is especially true in view of the relatively large magnitude of this quantity. Because of insufficient load capacity of the testing machine described above, it was necessary to test specimens of the 1-3/4-in. thick plate in a 600,000-lb hydraulic testing machine. However, this machine is not equipped with apparatus for automatic recording of the load-deflection diagram. As a result, the evaluation of the data was based on the criteria of "mm fibrous beneath notch" and maximum load. In all cases, the cross-head speed was 0.5 in./min, since it was found difficult to control the test at a speed of 0.8 in./min as used by van der Veen.

For test temperatures below atmospheric temperature, the specimens were conditioned in an alcohol bath contained in an insulated tank and refrigerated by direct addition of dry ice. For test temperatures above atmospheric temperature, a water bath heated with an electric immersion heater was employed. The 3/4-in. and 1-1/4-in. thick specimens were held at temperature at least 30 min and the 1-3/4-in. thick specimens 45 min before transfer to the testing machine.

TABLE II - RESULTS OF VAN DER VEEN TESTS ON 3/4 INCH THICK STEEL PLATES

Test Temp. F	3/4 IN. THICK PLATE, HEAT 2G2850: Load, Lbs. Maximum Lm	Load, Lbs. At Cleavage Lc	Lc/Lm	Deflection at Max. Load, In. Dm	Depth of Fibrous Area Beneath Notch, mm	3/4 IN. THICK PLATE, HEAT 2G2883: Load, Lbs. Maximum Lm	Load, Lbs. At Cleavage Lc	Lc/Lm	Deflection at Max. Load, In. Dm	Depth of Fibrous Area Beneath Notch, mm
	52800	5000	0.09	0.32	60.0					
100	59000	0	0	0.41	67.0					
	54500	12200	0.22	0.36	56.0					
Avg.	55400	5700	0.10	0.36	61.0					
	53700	5000	0.09	0.34	61.0	54400	18000	0.33	0.43	55.0
80	52200	0	0	0.34	67.0	54500	19000	0.35	0.46	54.0
	53800	8000	0.15	0.36	58.0	55300	20000	0.36	0.45	55.0
Avg.	53200	4300	0.08	0.35	62.0	54700	19000	0.35	0.45	54.7
	53000	53000	1.00	0.34	6.0					
70	54000	14500	0.27	0.35	52.0					
	54500	8100	0.15	0.35	58.0					
Avg.	53800	25200	0.47	0.35	38.7					
	56800	21500	0.38	0.36	48.0	54100	18800	0.35	0.45	51.0
60	56200	20000	0.36	0.36	47.0	54200	18500	0.34	0.44	52.0
	50700	50700	1.00	0.23	1.0	51300	17000	0.33	0.40	52.0
Avg.	54600	30700	0.58	0.32	32.0	53200	18100	0.34	0.43	51.7
						55200	13200	0.24	0.44	59.0
50						55300	40500	0.73	0.47	33.0
						56500	27600	0.49	0.47	47.0
Avg.						55700	27100	0.49	0.46	46.3
	55900	39000	0.70	0.36	30.0	52400	26700	0.51	0.43	44.0
40	57200	57200	1.00	0.36	8.5	53200	53200	1.00	0.39	7.0
	56900	38000	0.67	0.36	32.0	44000	44000	1.00	0.22	1.0
Avg.	56700	44700	0.79	0.36	23.5	49900	41300	0.84	0.35	17.3
						47700	47700	1.00	0.24	1.0
30						47500	47500	1.00	0.25	1.0
						54500	28000	0.51	0.43	44.0
Avg.						49900	41100	0.84	0.31	15.3
	55300	55300	1.00	0.30	3.5	47200	47200	1.00	0.24	1.0
20	55800	55800	1.00	0.31	4.0	46800	46800	1.00	0.23	0.5
	58600	58600	1.00	0.34	6.5	42000	42000	1.00	0.18	0
Avg.	56600	56600	1.00	0.32	4.7	45300	45300	1.00	0.22	0.5
	52500	52500	1.00	0.25	2.0	40900	40900	1.00	0.15	0
0	55800	55800	1.00	0.29	3.5	40200	40200	1.00	0.15	0
	51400	51400	1.00	0.23	1.0	47900	47900	1.00	0.26	1.0
Avg.	53200	53200	1.00	0.26	2.1	43000	43000	1.00	0.19	0.3
	47500	47500	1.00	0.17	0					
-20	51200	51200	1.00	0.20	0					
	56000	56000	1.00	0.27	3.0					
Avg.	51600	51600	1.00	0.21	1.0					

TABLE III - RESULTS OF VAN DER VEEN TESTS ON 1 1/4 INCH THICK STEEL PLATES

Test Temp. F		1 1/4 IN. THICK PLATE, HEAT 2G2850					1 1/4 IN. THICK PLATE, HEAT 2G2883			
	Load, Lbs. Maximum Lm	Load, Lbs. At Cleavage Lc	Lc/Lm	Deflection at Max. Load, In. Dm	Depth of Fibrous Area Beneath Notch, mm	Load, Lbs. Maximum Lm	Load, Lbs. At Cleavage Lc	Lc/Lm	Deflection at Max. Load, Inc. Dm	Depth of Fibrous Area Beneath Notch, mm
						84700	32000	0.38	0.49	52.0
120						84300	0	0	0.46	67.0
						87500	34000	0.39	0.50	50.0
Avg.						85500	22000	0.26	0.48	56.3
	87600	0	0	0.40	67.0	89000	26500	0.30	0.53	56.0
100	85400	13200	0.16	0.42	59.0	85600	41500	0.49	0.50	49.0
	86000	30000	0.35	0.43	53.0	88800	39000	0.44	0.53	50.0
Avg.	86300	14400	0.17	0.42	59.7	87800	35700	0.41	0.52	51.7
						94000	73000	0.78	0.54	28.2
90						91100	56900	0.63	0.53	42.0
						94200	94200	1.00	0.55	11.0
Avg.						93100	74700	0.80	0.54	27.1
	93900	28000	0.30	0.46	51.5	91200	91200	1.00	0.53	7.0
80	93500	50000	0.53	0.46	47.0	94800	48000	0.51	0.54	49.5
	89000	31000	0.35	0.43	48.5	94000	94000	1.00	0.57	9.0
Avg.	92100	36300	0.39	0.45	49.0	93300	77700	0.84	0.55	21.8
	93400	74000	0.79	0.42	28.0					
70	93200	50000	0.54	0.46	18.0					
	104100	104000	1.00	0.45	8.0					
Avg.	96900	76000	0.78	0.44	18.0					
	94700	68700	0.73	0.45	33.0	90600	42500	0.47	0.49	51.0
60	86400	55000	0.64	0.43	39.0	86300	86300	1.00	0.40	2.5
	92400	92400	1.00	0.47	7.0	94100	90500	0.96	0.48	16.5
Avg.	91200	72000	0.79	0.45	26.3	90300	73100	0.81	0.46	23.3
	102800	102200	1.00	0.46	10.0	94700	94700	1.00	0.55	7.0
40	92600	62000	0.67	0.46	27.5	94700	94700	1.00	0.51	5.5
	88100	88100	1.00	0.40	2.0	95300	95300	1.00	0.46	5.5
Avg.	94500	84100	0.89	0.44	13.2	94900	94900	1.00	0.51	6.0
	89900	88000	0.98	0.45	19.0	78000	78000	1.00	0.29	0
20	90400	90400	1.00	0.36	4.0	81500	81500	1.00	0.34	2.0
	93500	92500	0.99	0.40	11.0	89800	89800	1.00	0.43	2.0
Avg.	91300	90300	0.99	0.40	11.3	83100	83100	1.00	0.35	1.3
	89600	89600	1.00	0.36	3.0	66800	66800	1.00	0.19	0
0	98300	98300	1.00	0.41	2.5	78600	87600	1.00	0.26	0
	76600	76600	1.00	0.22	0	59400	59400	1.00	0.12	0
Avg.	88200	88200	1.00	0.33	1.8	68300	68300	1.00	0.19	0
	101200	101200	1.00	0.43	7.8					
-20	69700	69700	1.00	0.15	0					
	87000	87000	1.00	0.32	0					
Avg.	86000	86000	1.00	0.30	2.6					

TABLE IV - RESULTS OF VAN DER VEEN TESTS ON 1 3/4 INCH THICK STEEL PLATES.

Test Temp., F	-20	0	20	40	60	70	80	90	100	120	140
1 3/4 IN. THICK PLATE, HEAT 2G2850											
Maximum	84800	96000		145600			135800		130200	130000	134000
load, lbs.	118200	148600		154000			154800		146000	140800	130400
Lm	131800	129400		153600			142000		135200	127800	141600
Average	111600	124700		151100			144200		137100	132900	135300
Depth of	0	0		7.0			29.0		35.0	67.0	67.0
fibrous area	0	2.5		16.0			32.0		4.0	33.0	67.0
beneath notch, mm	0	2.0		11.5			32.0		34.0	67.0	67.0
Average	0	1.5		11.5			31.0		24.3	55.7	67.0
1 3/4 IN. THICK PLATE, HEAT 2G2883, SLAB A											
Maximum	99200	117600	93000	128600			129000		124800	121600	118800
load, lbs.	110400	79000	129400	130000			127400		131600	125000	126000
Lm	94200	122800	107800	128800			133000		125600	123200	124000
Average	101300	106500	110100	129100			129800		127300	123300	122900
Depth of	0	1.0	0	5.0			15.0		45.0	50.0	56.0
fibrous area	0	0	2.0	3.5			19.0		39.0	49.0	62.0
beneath notch, mm	0	1.5	0	2.0			16.0		44.0	67.0	67.0
Average	0	0.8	0.7	3.5			16.7		42.7	55.3	61.7
1 3/4 IN. THICK PLATE, HEAT 2G2883, SLAB D											
Maximum	79000	106000		108400	123000	110200	120800	111000	104400		
load, lbs.	86600	107400		112800	110600	112600	125200	105600	103000		
Lm	91200	85400		121200	114000	120000	125600	114000	112400		
Average	85600	99600		114100	115900	114200	123900	110200	106600		
Depth of	0	0		10.5	11.0	60.0	44.5	53.5	67.0		
fibrous area	0	0		20.0	63.0	61.0	51.5	67.0	67.0		
beneath notch, mm	0	9.0		13.0	60.0	16.0	55.0	47.0	67.0		
Average	0	3.0		14.5	44.7	45.7	50.3	55.8	67.0		

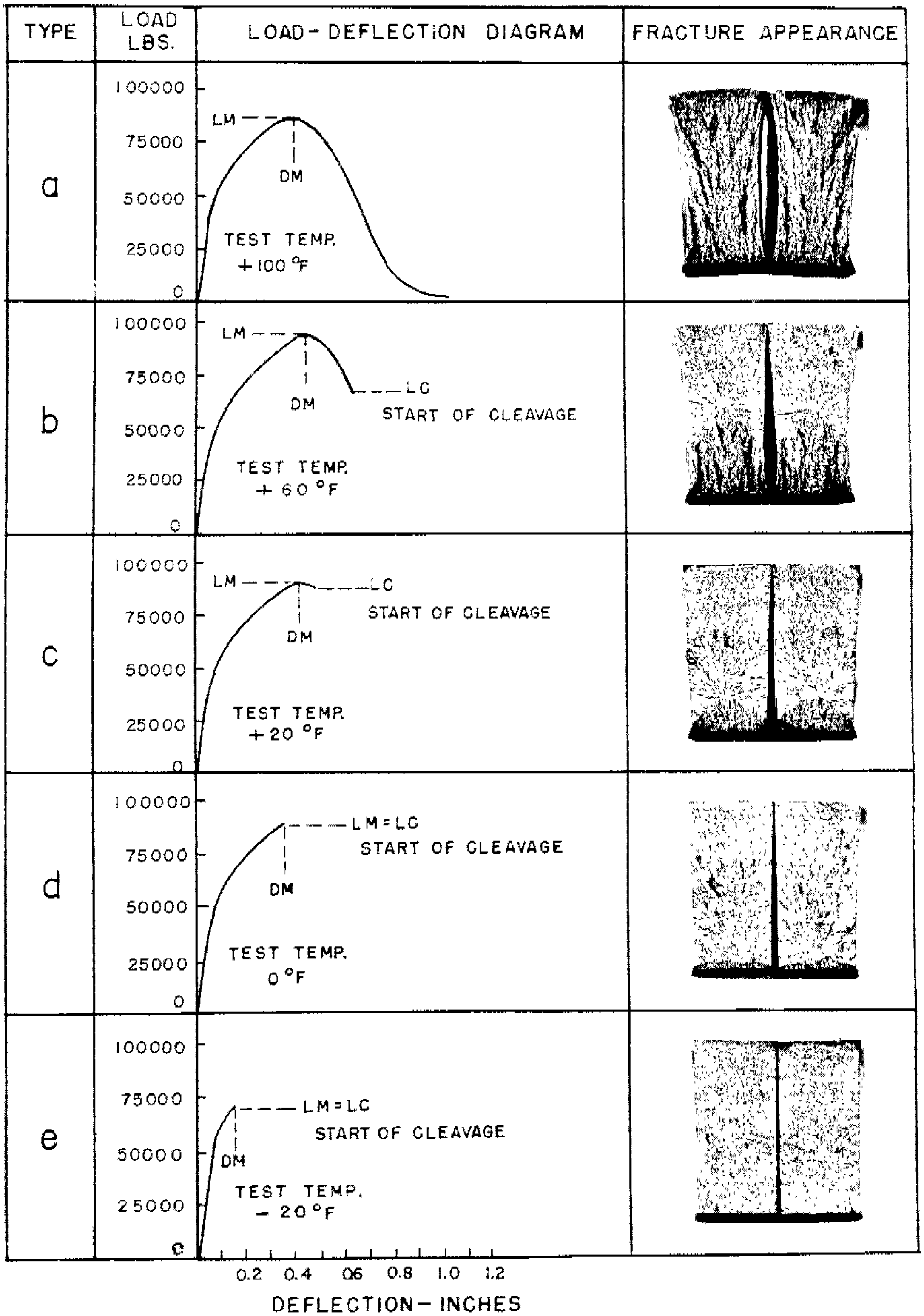

Fig. 11. Typical Load-Deflection Diagrams and Fractures.
(1 1/4 in. Thick Plate, Heat 2G2850, Lab. Code 241C)

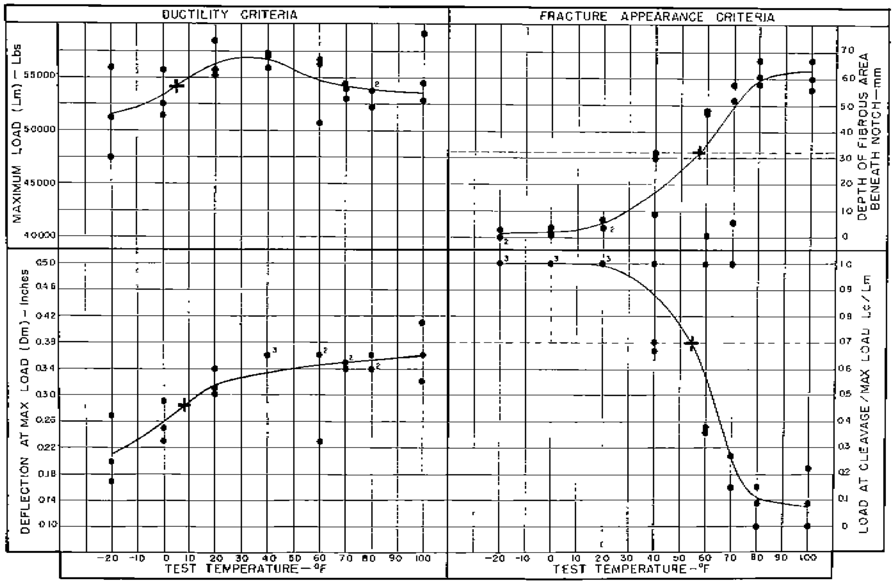

Fig. 12. Transition Curves as Determined by van der Veen Notched Slow-Bend Test. (3/4 in. Thick Plate, Heat 2G2850)

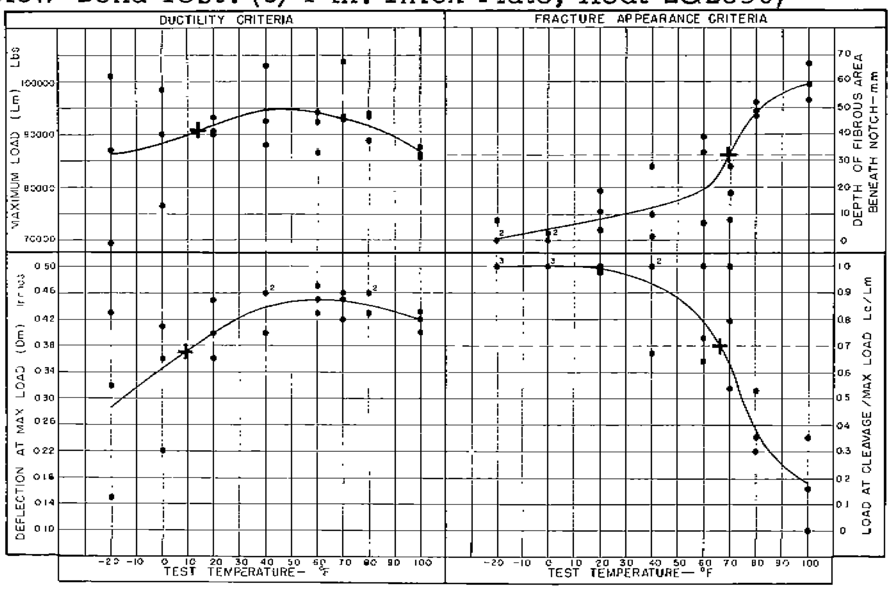

Fig. 13. Transition Curves as Determined by van der Veen Notched Slow-Bend Test. (1 1/4 in. Thick Plate, Heat 2G2850)

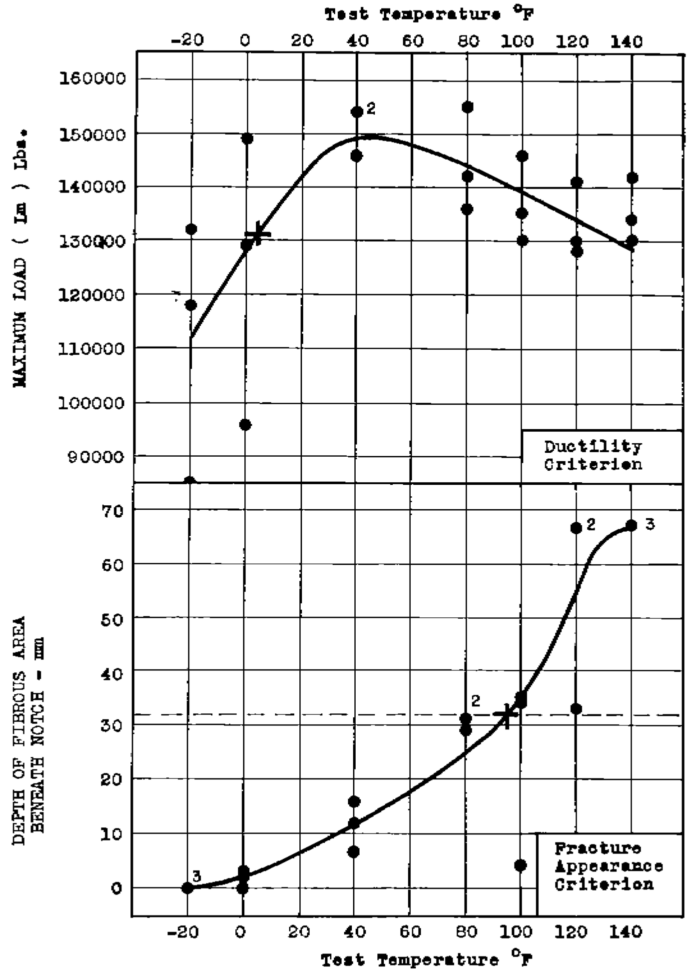

Fig. 14. Transition Curves as Determined by van der Veen Notched Slow-Bend Test. (1 3/4 in. Thick, Heat 2G2850)

TABLE V - SUMMARY OF TRANSITION TEMPERATURES AS DETERMINED BY TEAR TESTS AND VDV SLOW-BEND TESTS

	Transition Temperatures (°F)					
	Tear Test		van der Veen Test			
	Fracture Transition		Fracture Transition		Ductility Transition	
	Start of Trans.	Middle of Scatter Band	32 mm Fibrous	0.7 Lc/Lm	Max. Load	Dm
Heat No. 2G 2850						
3/4 in. (Slab B)	70	60	57	54	5	8
1 1/4 in. (Slab C)	70	55	69	67	14	9
1 3/4 in. (Slab D)*	90	75	95	-	4	-
Heat No. 2G 2883**						
3/4 in. (Slab B)	60	50	42	40	33	35
1 1/4 in. (Slab C)	90	85	87	85	17	22
1 3/4 in. (Slab A)*	120	105	91	-	7	-
1 3/4 in. (Slab D)*	90	65	61	-	1	-

* Tear specimens of 1 3/4-in. thick plate reduced in thickness to 1 1/4 in. for testing.

**Samples for tear and VDV tests were from different portions of plate (see Table I).

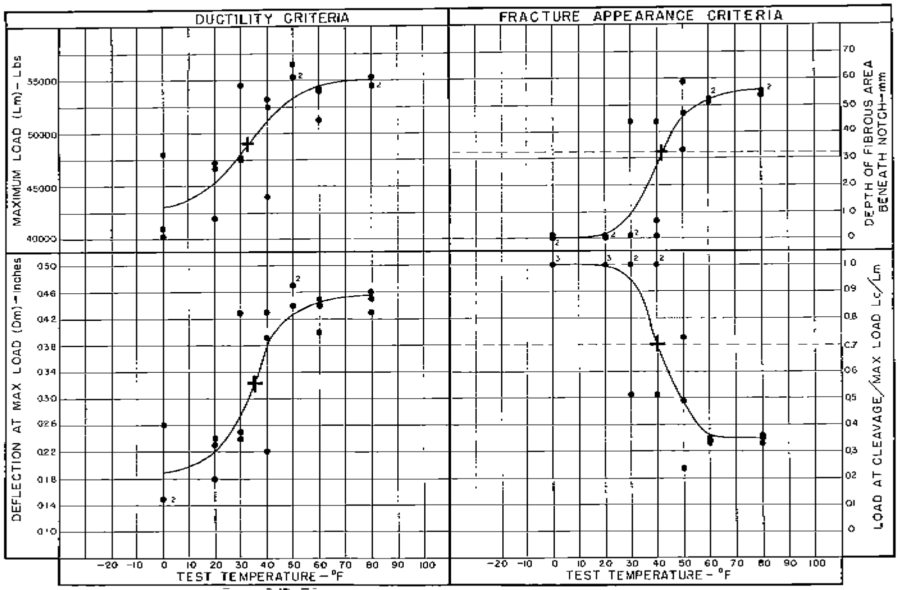

Fig. 15. Transition Curves as Determined by van der Veen Notched Slow-Bend Test. (3/4 in. Thick Plate, Heat 2G2883)

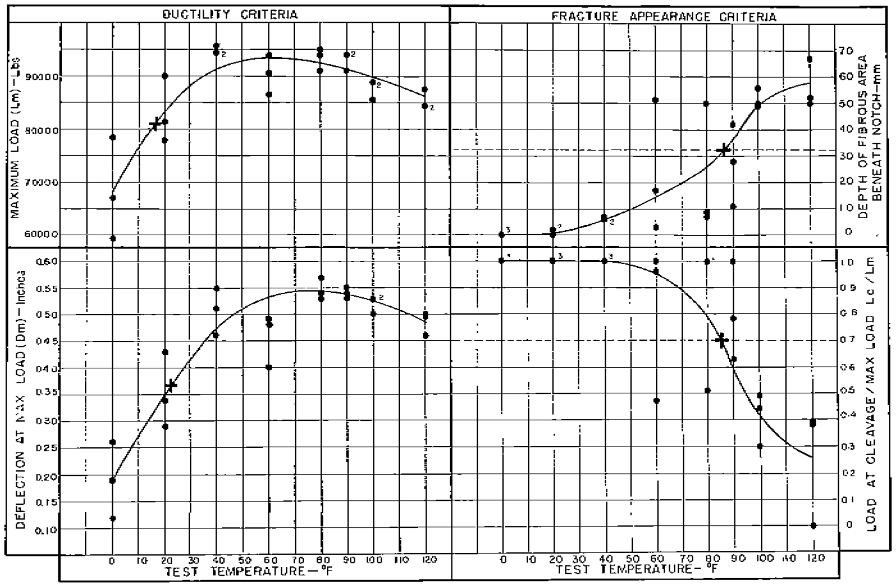

Fig. 16. Transition Curves as Determined by van der Veen Notched Slow-Bend Test. (1 1/4 in. Thick Plate, Heat 2G2883)

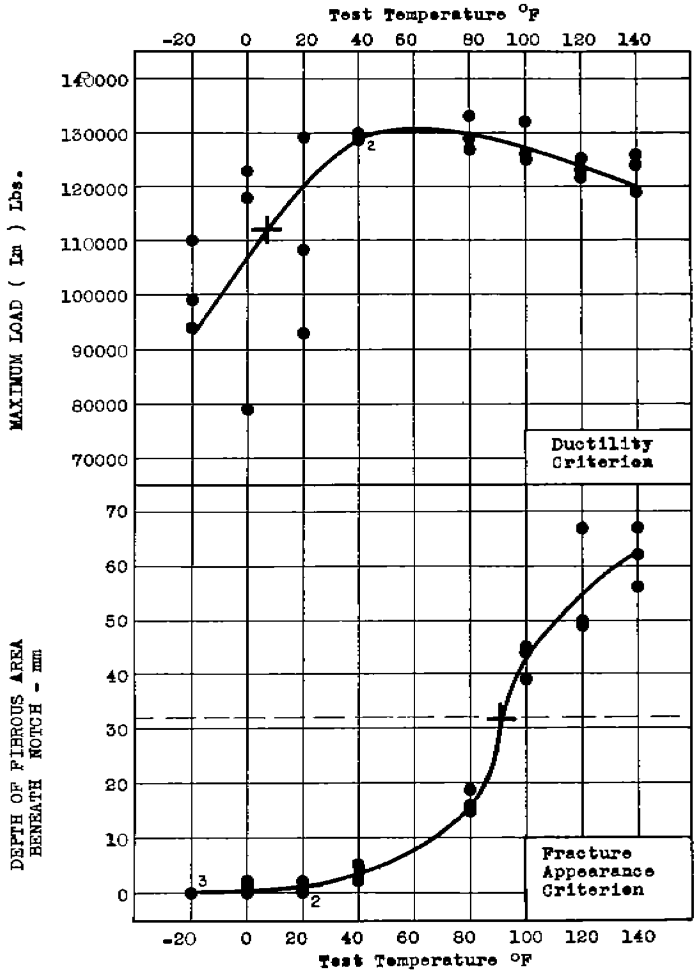

Fig. 17. Transition Curves as Determined by van der Veen Notched Slow-Bend Test. (1 3/4 in. Thick Plate, Heat 2G2883)

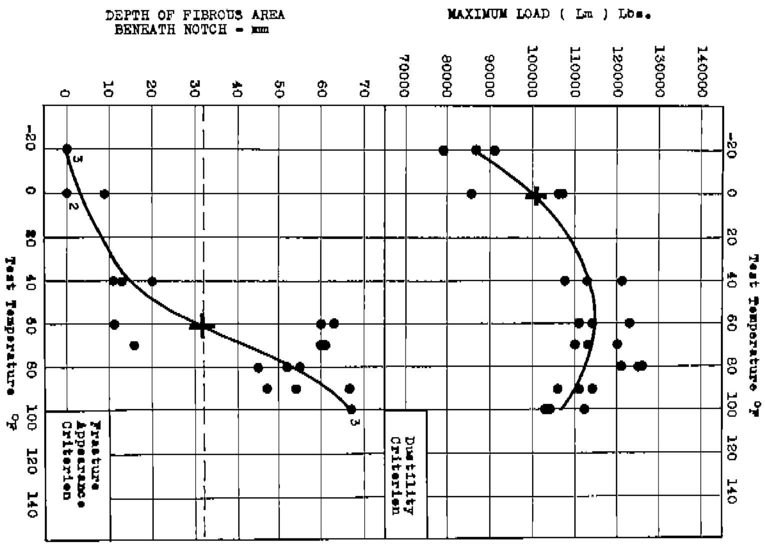

Fig. 18. Transition Curves as Determined by van der Veen Notched Slow-Bend Test.

(1 3/4 in. Thick Plate, Heat 2G2883, Lab. Code 41D.)

RESULTS

Results of tests are given in Tables II, III, and IV. Typical load deflection diagrams and fractures are shown in Fig. 11. The transition curves based on the data of Tables II, III, and IV are presented in Fig. 12 through 18. The transition temperatures, as previously defined, have been indicated by heavy crosses on the transition curves. It is to be noted from Fig. 12, 13, 15 and 16 that the alternative methods of determining transition temperature for either ductility or fracture-appearance criteria yield substantially the same results. In determining the ductility transition temperatures, considerable scatter of the Lm and Dm values was encountered at the lower test temperatures. In future work, it is planned to conduct a greater number of tests in this region in order to better define the lower end of the transition curve.

A summary of the VDV and tear-test transition temperatures is given in Table V. The fracture-appearance transition temperatures derived by both methods show fairly close agreement, particularly if the middle of the scatter band in the tear test is used as the basis of comparison.

Further analysis of the data will be made by R. W. Vanderbeck of the United States Steel Corporation who has accepted the task of compiling and correlating all data obtained on the same steel by the various cooperating laboratories.

CONCLUSIONS

On the basis of the limited amount of work reported here, the van der Veen notched slow-bend test appears to provide an estimate of the fracture transition temperature similar to that obtained in the Navy tear test. A ductility transition temperature can also be evaluated by the van der Veen test, but during the present study it appeared that more tests should have been conducted at lower temperatures in order to permit more suitable selections of the ductility transition temperature. Increased use of the van der Veen test should establish its correlation with the other tests that have been used to evaluate the notch-sensitivity characteristics of ship-plate steels. In this connection, the Material Laboratory is currently applying the van der Veen test to samples of ABS ship plate under investigation at the National Bureau of Standards as part of Ship Structure Committee Project SR-139, "Joint SSC-AISI Study."

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*Presented originally as part of the Symposium on Notch Bar Testing and Its Relation to Welded Construction, organized by the IIW in association with the Joint Committee on Materials and their Testing and held in London, December 5, 1951.

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