PROGRESS REPORT

on

CORRELATION OF LABORATORY TESTS WITH FULL SCALE SHIP PLATE FRACTURE TESTS: SLOW NOTCH BEND TEST

by

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Under Navy Contract NObs-31217

COMMITTEE ON SHIP CONSTRUCTION
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
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Date: December 31, 1947

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December 31, 1947

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Dear Sir:

Attached is Report Serial No. SSC-15 entitled "Correlation of Laboratory Tests with Full Scale Ship Plate Fracture Tests: Slow Notch Bend Test." This report has been submitted by the contractor as a progress report on the work done on Research Project SR-96 under Contract NObs-31217 between the Bureau of Ships, Navy Department and Pennsylvania State College.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Inudstrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

Frederick M. Feiker

Frederick M. Feiker, Chairman
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Enclosure

Preface

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals that were actively associated with this research program. This report represents a part of the research work contracted for under the section of the Navy's directive "to investigate the design and construction of welded steel merchant vessels."

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PROGRESS REPORT

Navy Bureau of Ships Contract NObs-31217 Project SR-96

CORRELATION OF LABORATORY TESTS WITH FULL SCALE SHIP PLATE FRACTURE TESTS: SLOW NOTCH BEND TEST

Date: October 15, 1947

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SHIP PLATE FRACTURE TESTS:
SLOW NOTCH BEND TEST

INTRODUCTION

The present progress report is essentially a continuation of that released March 19, 1947[1]. The objective and outline of work were indicated in that place; the former consisting in the development of a test capable of conduction in the laboratory and which would correlate closely with the large plate test results which were obtained at the University of California[2] and at the University of Illinois[3]. The latter consisting in part in the examination of the Charpy test in the prescribed manner to ascertain if in this test the desired correlation could be obtained. Close correlation was not obtained in this test. In order to obtain the desired correlation, a slow-bend notched-bar test was developed and it is with the results of slow bend testing that this report is concerned.

The following persons have constituted the staff and have contributed to the various phases of the investigation:

M. Gensamer	Technical Representative
F. C. Wagner	Supervisor
E. P. Klier	Investigator
J. O. Mack	Investigator
Mary Ann Bishop	Research Assistant
Eunice Marks	Research Assistant
Selma Krause	Drafting
Mina Moessen	Technical Labor
Philip Vonada	Technical Labor
Herman Colyer	Technical Labor

1,2 & 3 - See Bibliography

STEELS

The steel designations are those used formerly[1]. No additional steels have been used to date.

SLOW BEND TESTING

Resume of Testing Program:

Specimens have, but for the indicated exceptions, been taken from the plate so that the long dimension was parallel to the rolling direction while the notch was parallel to the thickness direction. These are designated LH specimens. Similarly cut specimens with the notch in the plane of the plate are designated as LB specimens; while specimens taken from the plate so that the long dimension was parallel to the cross direction with the notch parallel to the thickness direction are designated as BH specimens.

(1) It was indicated[1] that the rate of testing could possibly be very important in determining the transition temperature. To determine this effect quantitatively, sets of steels A, C, D, and E were tested in a slow bend fixture for the standard LH V-notched Charpy bar.

(2) The results in (1) did not appear promising so a second series of tests were conducted for Steels A, Br, Bn, C, Dr, Dn, E, H, N and Q. The test bar was of standard Charpy V-notched test bar dimensions except for the height, which was .788 inches instead of .394 inches. The test data offered definite promise but were not fully correlative.

(3) The second modification of the slow bend test was again with reference to the specimen; in this instance the width was altered to full plate thickness, while the height and notch geometry were held the same. Tests were conducted on virgin plate stock from the project steels.

(4) Adequate correlation between the slow bend test results and the large plate test results were obtained in (3) except for steels Br and H. For these two steels the opening up of cracks on the central plane of the specimens perpendicular to the notch as noted elsewhere[2] appear to be effective in preventing the appearance of a brittle fracture except at much too low temperatures. In an effort to prevent this type of cracking an LB set of specimens and a BH set of specimens for steels Br and H were used.

(5) Some specimens as in (3) were also cut as in Figure 1 from the large plate sections originally studied[1].

Testing Procedure:

The fixture used for the conduction of the slow bend test has undergone several modifications. The alterations consisted in the construction of a more sturdy unit in each instance. The final form which now is in use together with complete instructions for the conduction of the test is presented in Appendix I.

The Representation of Test Data:

Several factors are available to allow differentiation between brittle and ductile failure of the test bar. Not all of these are equally convenient to use, however. Thus the customarily used energy absorption - temperature curve obtained in the standard impact test is not obtainable without an appreciable expenditure in time and effort in slow bend testing. It is estimated that the autographic recording of the load-bend diagram requires an increase in the time for the testing of one test bar by a factor of five, and with the present test procedure requires the time of two men as against one if the recording is not attempted. If the load-deflection diagram is not recorded, the time for the testing of one test bar is of the same order as that for the conduction of the standard impact test.

A factor which is a convenience in the conduction of the test but which cannot be recorded is the noise which accompanies a brittle failure. This is audible even when brittle failure progresses only a short distance through the bar. Accompanying brittle failure there is an immediate drop in load. The magnitude of this drop in load depends on the penetration of the brittle fracture, falling to zero when it passes essentially through the bar.

Two additional factors differentiate the brittle from the ductile fracture and are namely, the angle of bend of the test bar and the character of the fractured surfaces.

It has not appeared desirable to report in their entirety the experimental data which have been accumulated for the determination of energy absorption versus temperature curves. For this reason typical load-extension summary curves only are included. Energy absorption versus temperature curves for all steels tested are included.

The criterion for selecting a transition temperature was in most cases that of selecting the point at which a fracture of brittle appearance started to occur in the test piece. This is indicated on the temperature energy absorption diagrams for specimens from the large plate sections by a vertical dashed line separating brittle from ductile failures.

Results of Slow Bend Testing:

1. Standard V-notched Specimens: The standard LH Charpy V-notched test bar was used with the test being conducted to complete failure of the bar. In all instances therefore the load had passed through a maximum and had dropped to a very low value when the test was stopped. The load

deflection curve was recorded with the energy absorption being the area under the curve. The energy absorption versus temperature curves so obtained are presented in Figures 2a, 2b, 2c. These curves are not complete but it is evident that the transition temperatures for steels A and C are approximately equal. This test evidently is not selective, so was not prosecuted further.

2. Double Height V-Notched Specimens: The height of the LH Charpy V-notched bars was increased to 0.788 inches, other dimensions remaining standard. These specimens were tested at a no load head speed of 1 inch per minute. A correction factor of +10° to +20°F is required to obtain full correlation in all but two instances. In these two exceptions no correlation obtains.

3. Double Height, Plate Thickness Width, V-Notched Specimens

A-LH Orientation: The decision to increase the width of the specimens to full plate thickness was made upon obtaining slightly low transition temperatures from the double-height V-notched specimens as compared with the large-plate tensile tests.

Bend tests were run on all of the stock project steels, and gave quite good correlation with the large plate tests for all but steels Br and H as indicated in Table I. The energy-absorption versus temperature curves are shown in Fugures 3a to 3h with the exception of Br and H. For these particular steels, correlation was still not obtainable with this test presumably due to the fissuring at the fracture surface.

The small vertical arrows above certain points in the temperature - energy absorption diagrams indicate that the specimens corresponding to such points failed in a ductile manner with no abrupt drop in load. As pointed out in the appendix, the actual energy absorption value which is used in such a case is for a total deflection of 0.4 inches, and hence is not the total energy required for breaking the specimen.

Some points are also evident for specimens which showed low energy absorption and yet behaved in a ductile manner. The steels for which this occurred were previously observed to have internal flaws of major slag inclusions or actual voids in some cases.

<u>B-LB and BH Orientations</u>: The appearance of fissures in the fracture surfaces of the LH test bars led to an examination of the effect of specimen orientation for the Br and H steels.

Sets of LB and BH specimens were prepared and tested in the usual manner. The results obtained from the LB specimens were not satisfactory, as this orientation also permitted the opening up of fissures at the fracture surfaces. In this case, however, the fissures were parallel to the notch, instead of perpendicular to it as in the LH specimens.

This fissuring increased the scatter in results to such an extent as to make them of no value.

The BH specimens were tested and sharp transition zones were obtained in this case. The energy absorption curves for these sets of specimens are shown in the curves in Figures 4a and 4b.

4. <u>Specimens from large plate tests</u>: Sets of specimens were cut from the 72" wide fracture test specimens in relatively unstrained portions of the plates immediately adjacent to the internal notches. This position is shown in the sketch in Figure 1.

The results of the tests conducted on these specimens are tabulated in Table II, while the energy absorption versus temperature curves are shown in Figures 5a - 5v. In certain instances the transition temperature indicated by vertical dashed lines - could not be determined from the energy absorption curves. Brittlely breaking specimens required as much energy as did ductilly breaking ones. The transition temperature was taken as that temperature at which a sharp drop in load was consistently observed in the testing.

5. Specially machined specimens from steel C: These were prepared by shaping one surface only and notching in the sawed surface opposite (see Appendix I). Results are shown in Figure 6a. This test indicated the possibility of quite low specimen preparation cost.

DISCUSSION

The foregoing has been presented to show the various stages in the development of one type of small scale test for correlation with full-scale large ship plate fracture tests.

Of the many tests proposed for this correlation, the slow-bend test gives results which seem to be, in the steels tested to date, the most uniformly comparable with the large-plate tests.

The important points, then, in the selection of any one of these laboratory tests as a specifications test, are (1) thorough checking of results with a variety of steels to insure the absence of anomalies (2) consideration of the overall ease and economy with which the test may be conducted, i.e., time of specimen preparation, size of equipment necessary to conduct the test, time necessary to run the test, and time and skill necessary for the interpretation of results.

From this standpoint, there are certain things to be said in favor of the notched-bend test.

1. The specimen size is small, allowing more economy in the use of material and in equipment necessary for testing.

2. The necessary machining is little.

3. The conduction of the test requires a relatively short time and by use of the drop in load and examination of fracture surfaces, the time for interpretation of results is short.

4. In a like manner, the test requires only one person for its conduction.

The specific cases of the Br and H steels are matters for some concern. The results from the BH sets of specimens indicate good correlation with the 72" wide large-plate tests for the H steel and good correlation of Br steel with the 12" wide plate specimens. (Table I). For consistency in the procedure, it would seem a good plan to take specimens from all steels as both BH and LH orientation.

CONCLUSIONS

The conclusions to be drawn from the above results may be listed as follows:

(1) The development of a notched bend test has been attained which correlates well with 72" wide plate specimens in regard to the transition temperatures from ductile to brittle behavior.

(2) The orientation of specimens is of importance in two instances, those of the tests on Br and H steels. For these steels, it is necessary to use BH specimens for the satisfactory definition of the transition temperature.

(3) The notched-bend test is a fairly simple test to conduct, and the equipment involved is available in the usual testing laboratory or is easily constructed.

(4) The cost of specimen preparation is low as compared with a standard Charpy impact test specimen.

(5) The test bar is relatively small, permitting many tests to be run with economy of material.

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1. Research Project SR-96, "Correlation of Laboratory Tests with Full Scale Ship Plate Fracture Tests" Serial No. SSC-9, Contract NObs-31217, dated March 19, 1947.

2. Research Project SR-92, "Causes of Cleavage Fracture in Ship Plate, Flat Plate Tests and Additional Tests on Large Tubes" Serial No. SSC-8, Contract NObs-31222, dated January 17, 1947.

3. Research Project SR-93, "Cleavage Fracture of Ship Plates as Influenced by Size Effect" Serial No. SSC-10, Contract NObs-31224, dated June 12, 1947.

TABLE I

CHART SHOWING ESTIMATED TRANSITION TEMPERATURES OF STEELS FOR VARIOUS TYPES OF NOTCHED TESTS TEMPERATURES IN °F.

	STEEL CODE LETTER									
Type of Test	E	C	A	Bn	Dn	Dr	Br	Q	H	N
Charpy Impact Std. V-Notch	150	100	90	30	30	45	10	-5	0	-50
3/4" Tear Test Jeweler's Saw Cut	130		63							
3/4" Tear Test Keyhole	130	125	62				45		35	
3/4" Bend Test V-Notch	73	97	50	30	23	19	BH -4	-11	BH 18	-35
72" Wide Plate Internal Notch	100	90	35	31	23	30	32		20	-45
24" Wide Plate Internal Notch	100	About 88	-7 to 37	Below 32	35	35	Below 32			
12" Wide Plate Internal Notch	90	90	25	15	5	40	5	-10 + 5	-15	-65
3" Tension Edge Notched	120	90	45	-5	32		5	35	About 20	
Charpy Impact 10% Prestrain Keyhole	85	95	60	30	0	20	20		-20	
Charpy Impact 5% Prestrain Keyhole	60	65	45	0	-25	0	10		-35	
Charpy Impact 2% Prestrain Keyhole	70	55	40	0	-55	-30	-5		-55	
Charpy Impact Full Thickness Sawcut	75	50	60	35	-30	-20	10	15	0	-100
Charpy Impact Standard Keyhole	30	15	0	-20	-60	-60	-30	-55	-50	-220

TABLE I

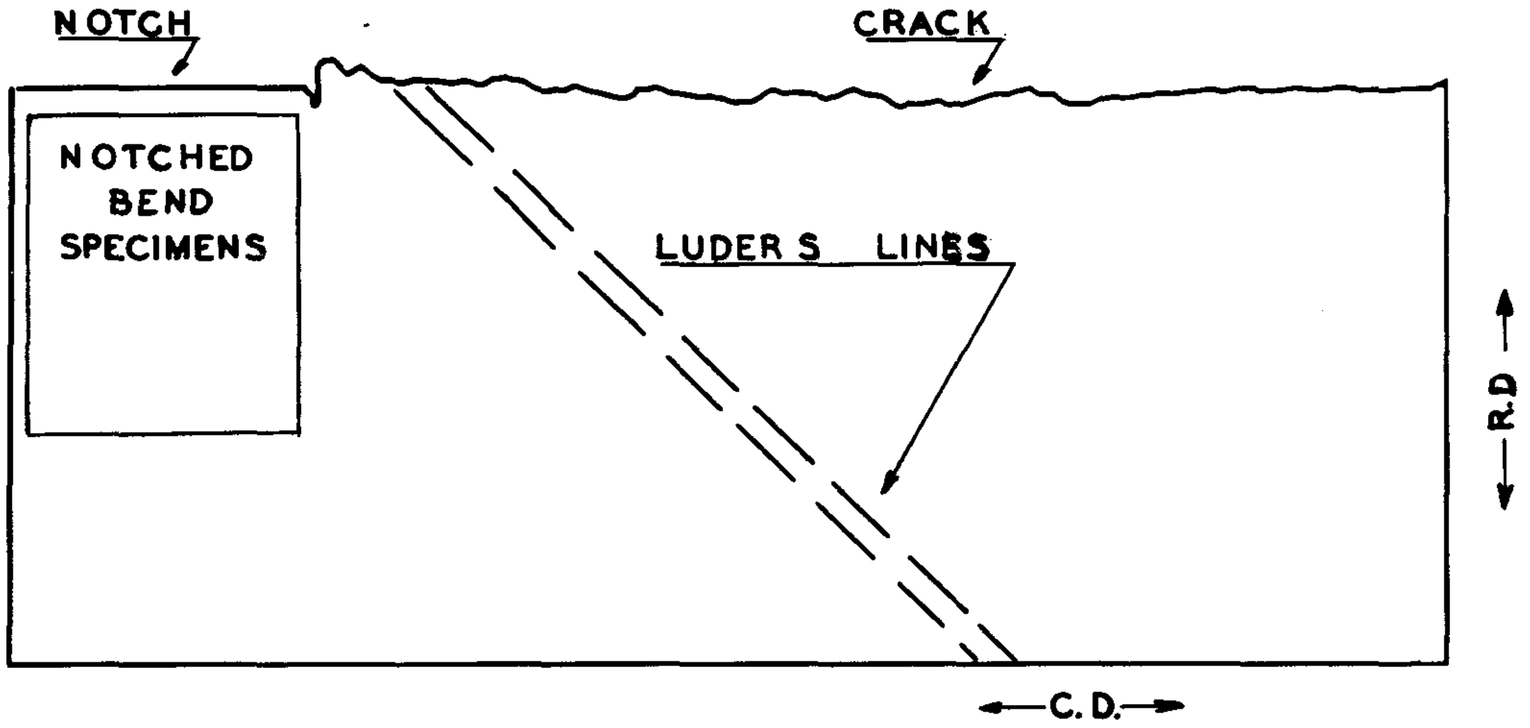
(Continued)

TYPE OF TEST	METHOD OF DETERMINING TRANSITION TEMPERATURE	REFERENCE
Charpy Impact Std. V-Notch	50% energy absorption	Progress Report SSC-9
3/4" Tear Test Jeweler's Sawcut	Intermediate temperature between all ductile and all brittle behavior	New York Shipyard Reports
3/4" Tear Test Keyhole	Intermediate temperature between all ductile and all brittle behavior	New York Shipyard Reports
3/4" Bend Test V-Notch	From energy absorption values	This report
72" Wide Plate Internal Notch	50% energy Absorption	California Report SSC-8 and Illinois Report SSC-10
24" Wide Plate Internal Notch	50% energy Absorption	California Report SSC-8 and Illinois Report SSC-10
12" Wide Plate Internal Notch	50% energy absorption	California Report SSC-8 and Illinois Report SSC-10
3" Tension Edge Notched	50% energy Absorption	California Report SSC-8 and Illinois Report SSC-10
Charpy Impact 10% Prestrain Keyhole	50% energy Absorption	Progress Report SSC-9
Charpy Impact 50% Prestrain Keyhole	50% energy Absorption	Progress Report SSC-9
Charpy Impact 2% Prestrain Keyhole	50% energy Absorption	Progress Report SSC-9
Charpy Impact Full Thickness Sawcut	50% energy Absorption	Progress Report SSC-9
Charpy Impact Std. Keyhole	50% energy Absorption	Progress Report SSC-9

TABLE II

STEEL	LARGE PLATE #	ESTIMATED TRANSITION TEMPERATURE	TEMPERATURE AT WHICH LARGE PLATE WAS TESTED
A	A1A	58°F	75°F
A	A2A	33°F	30 - 35°F
A	A3A	50°F	48 - 50°F
Bn	B2A	-2°F	29 - 32°F
Bn	B4A	-9°F	?
Bn	B5A	-13°F	49 - 52°F
Br	B1A	-13°F	30 - 35°F
Br	B3A	5°F	72°F
Br	B6A	-4°F	?
C	C1A	95°F	30 - 33°F
C	C2A	123°F	75 - 78°F
C	C4A	140°F	80 - 82°F
C	C3	103°F	100 - 104°F
Dn	5-7	8°F	0°F
Dn	14-7	5°F	-38°F
Dn	12A1KN	31°F	?
Dr	18A1K	30°F	18°F
Dr	221K	58°F	?
E	13A7	122°F	110°F
E	18A1R	132°F	141°F
E	CG1	137°F	74°F
N	N1A	-85°F	-51 - -55°F

FIG. I LOCATION OF NOTCHED-BEND SPECIMENS IN LARGE PLATE SECTIONS



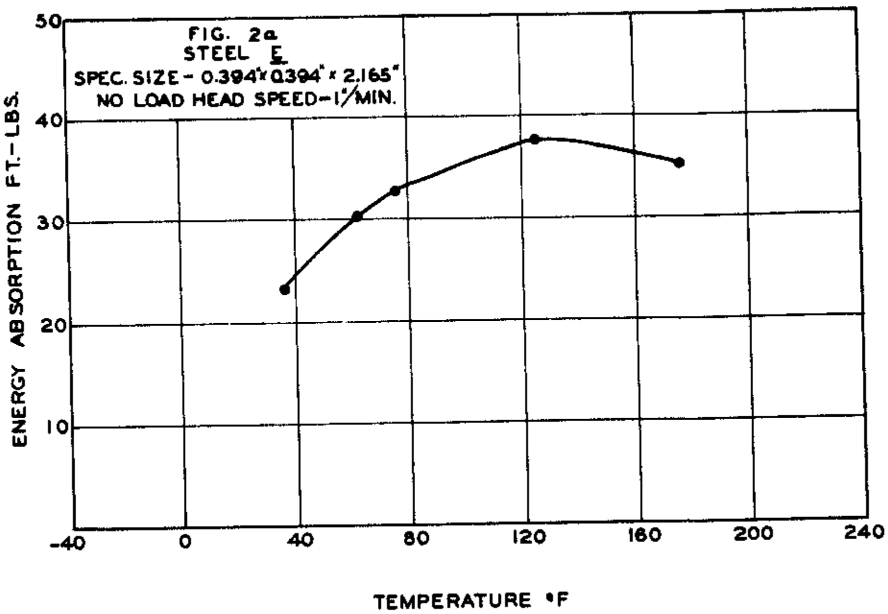


FIG. 2a
STEEL E
SPEC. SIZE - 0.394" x 0.394" x 2.165"
NO LOAD HEAD SPEED - 1"/MIN.
ENERGY ABSORPTION FT.-LBS.
50
40
30
20
10
-40
0
40
80
120
160
200
240
TEMPERATURE °F

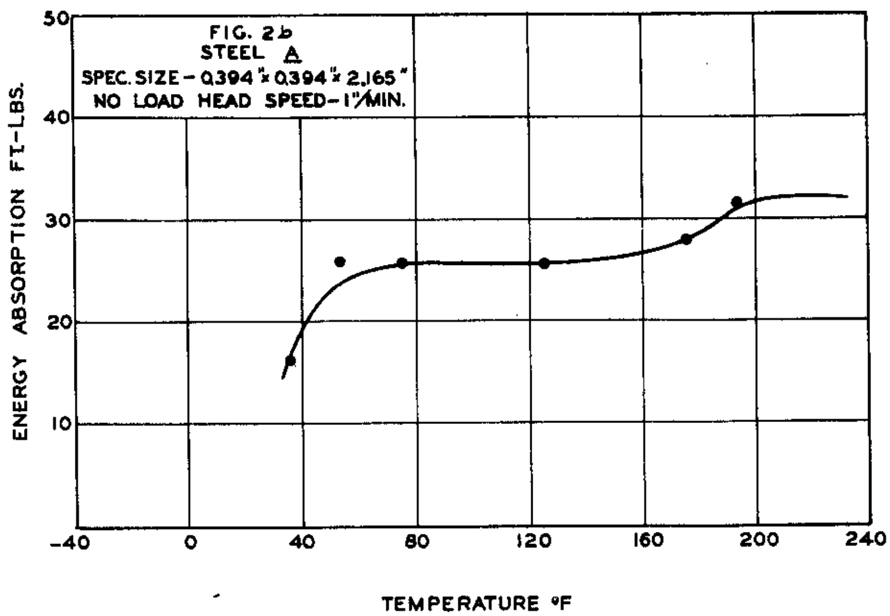


FIG. 2b
STEEL A
SPEC. SIZE - 0.394" x 0.394" x 2.165"
NO LOAD HEAD SPEED - 1"/MIN.
ENERGY ABSORPTION FT.-LBS.
50
40
30
20
10
-40
0
40
80
120
160
200
240
TEMPERATURE °F

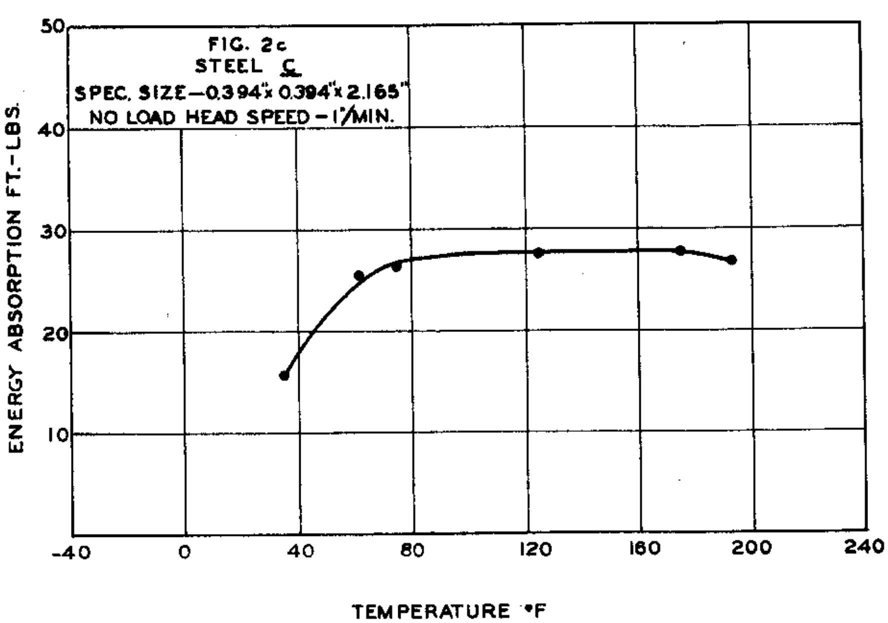


FIG. 2c
STEEL C
SPEC. SIZE - 0.394" x 0.394" x 2.165"
NO LOAD HEAD SPEED - 1"/MIN.
ENERGY ABSORPTION FT.-LBS.
50
40
30
20
10
-40
0
40
80
120
160
200
240
TEMPERATURE °F

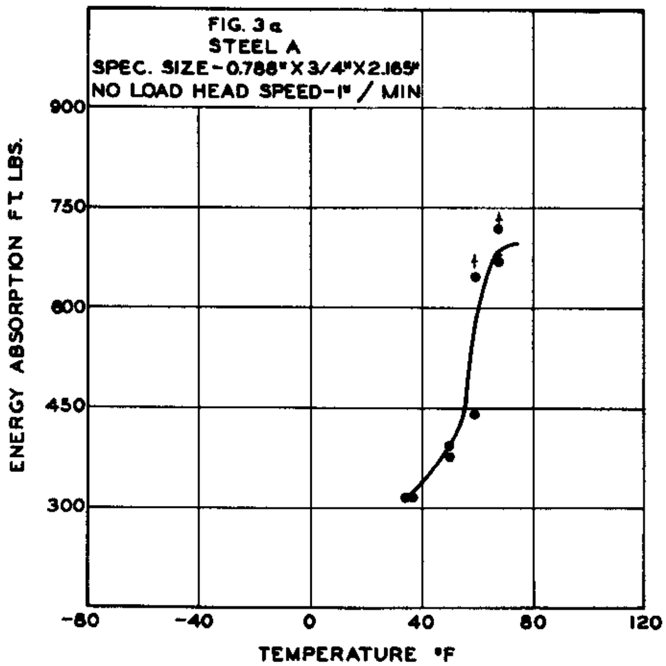


FIG. 3a
STEEL A
SPEC. SIZE-0.788"X3/4"X2.165"
NO LOAD HEAD SPEED-1"/MIN
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

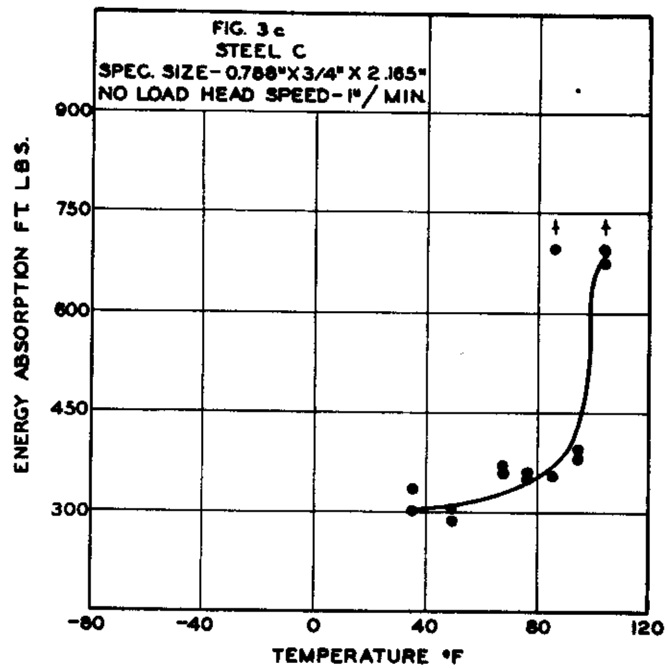


FIG. 3c
STEEL C
SPEC. SIZE-0.788"X3/4"X 2.165"
NO LOAD HEAD SPEED-1"/MIN
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

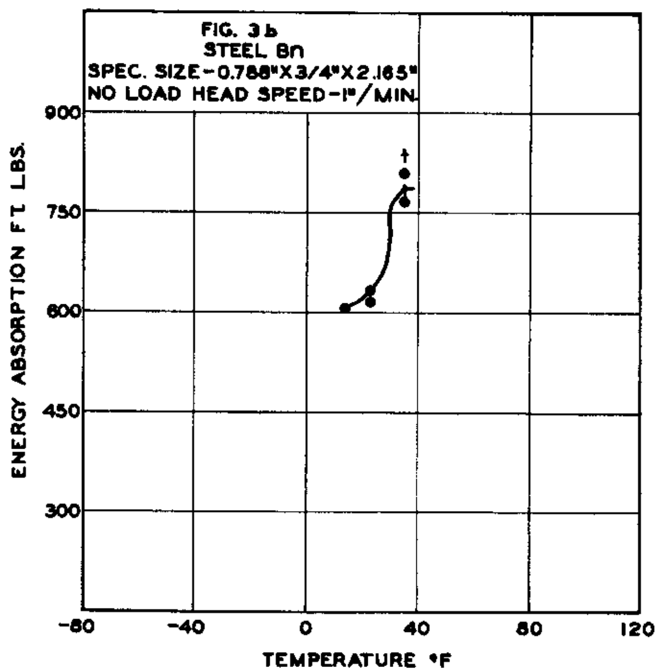


FIG. 3b
STEEL Bn
SPEC. SIZE-0.788"X3/4"X2.165"
NO LOAD HEAD SPEED-1"/MIN
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

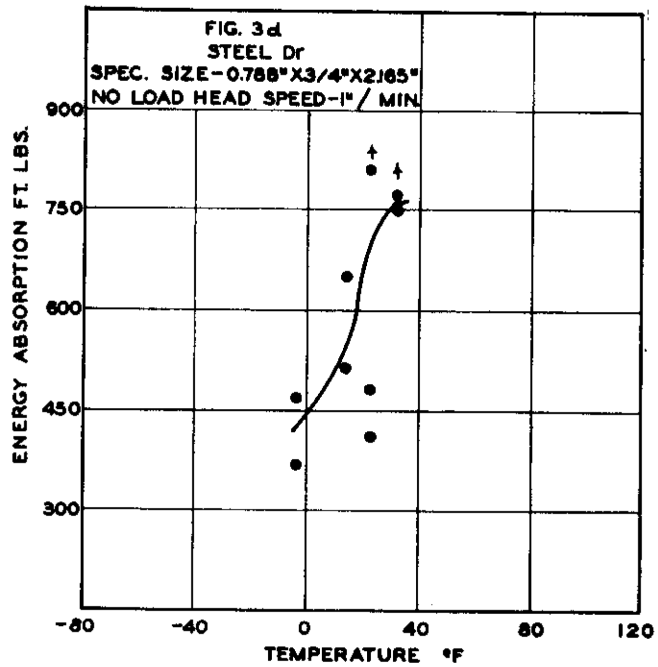


FIG. 3d
STEEL Dr
SPEC. SIZE-0.788"X3/4"X2.165"
NO LOAD HEAD SPEED-1"/MIN
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

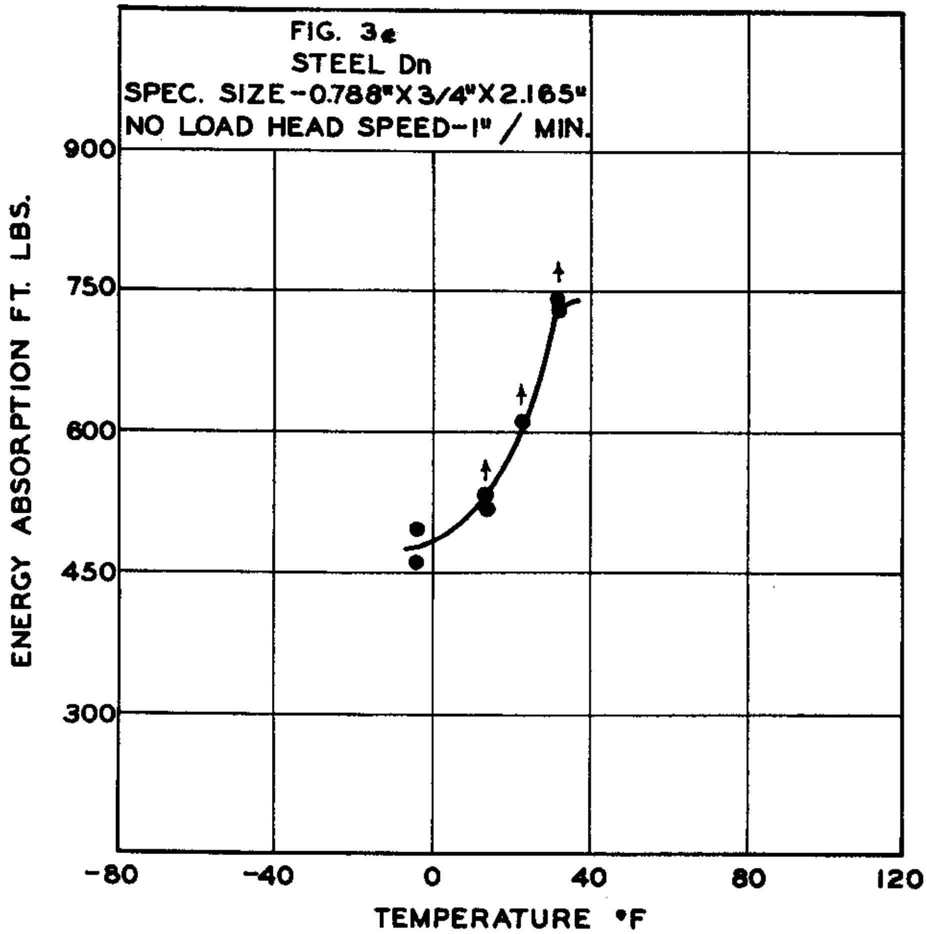


FIG. 3e
STEEL Dn
SPEC. SIZE-0.788"X3/4"X2.165"
NO LOAD HEAD SPEED-1" / MIN.
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-80
-40
0
40
80
120
TEMPERATURE °F

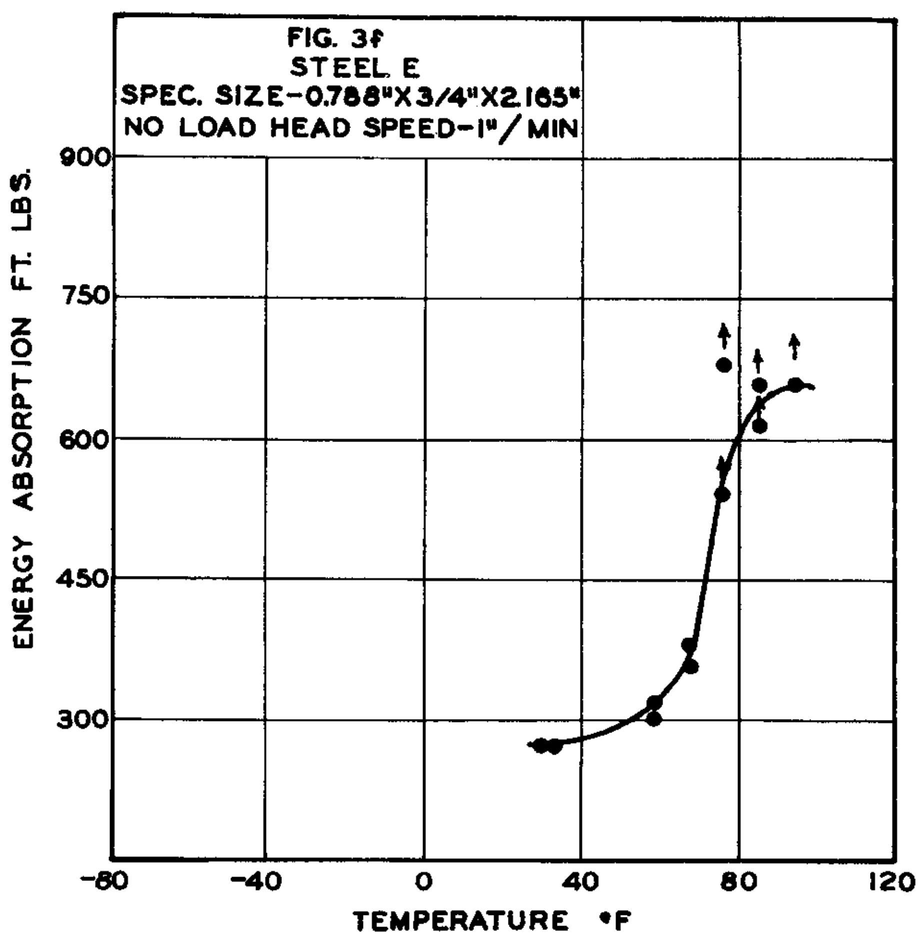


FIG. 3f
STEEL E
SPEC. SIZE-0.788"X3/4"X2.165"
NO LOAD HEAD SPEED-1"/ MIN
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-80
-40
0
40
80
120
TEMPERATURE °F

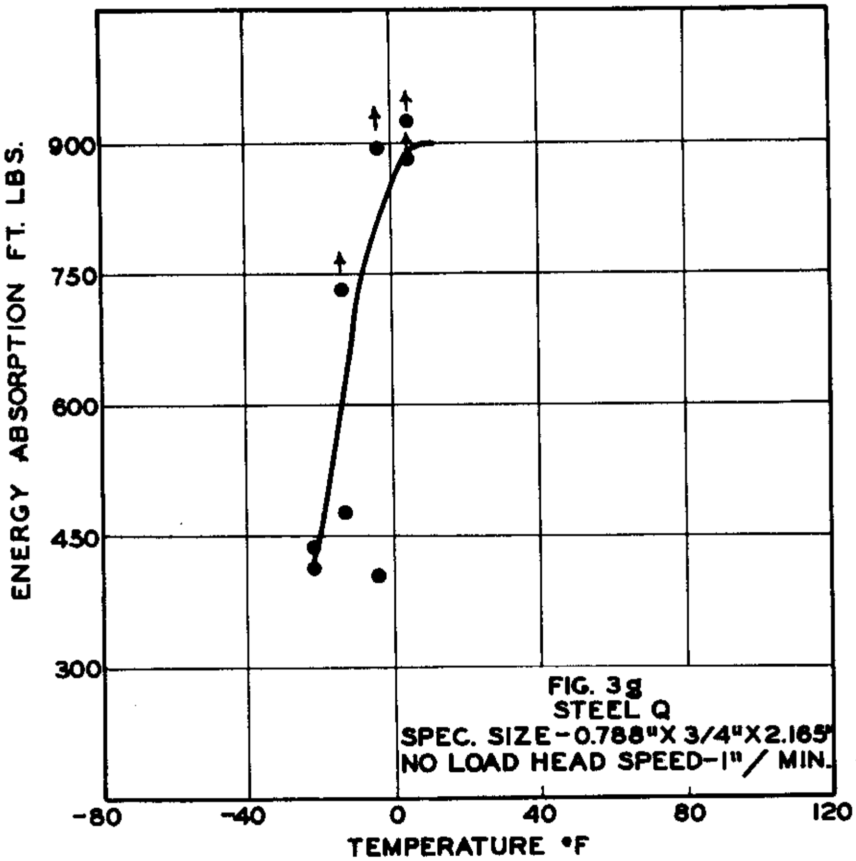


FIG. 3g
STEEL Q
SPEC. SIZE-0.788" X 3/4" X 2.165"
NO LOAD HEAD SPEED-1"/ MIN.

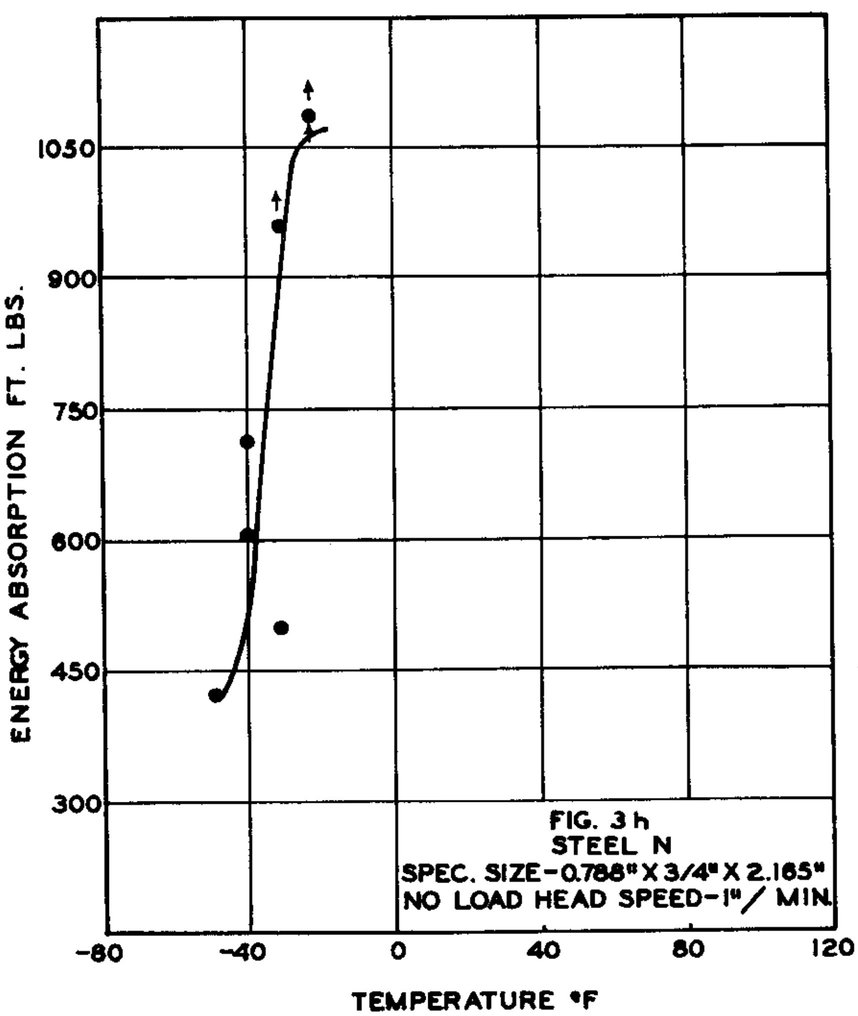


FIG. 3h
STEEL N
SPEC. SIZE-0.788" X 3/4" X 2.165"
NO LOAD HEAD SPEED-1"/ MIN.

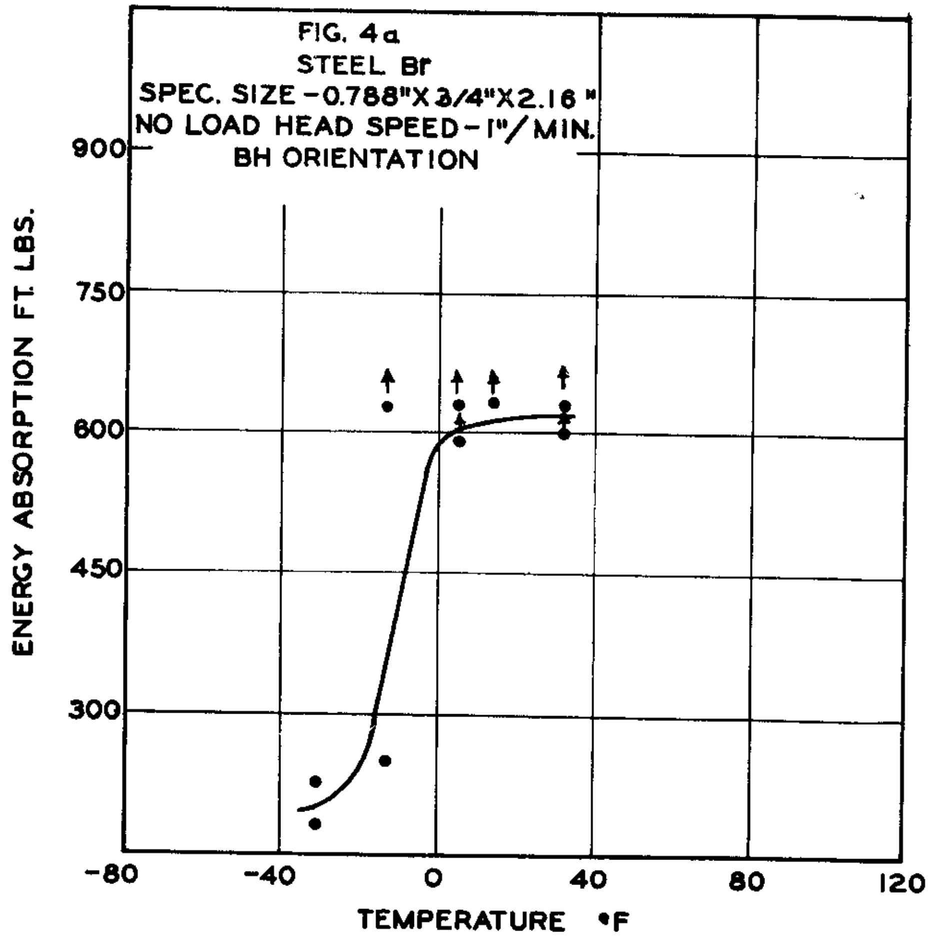


FIG. 4a
STEEL Br
SPEC. SIZE - 0.788" X 3/4" X 2.16"
NO LOAD HEAD SPEED - 1"/MIN.
BH ORIENTATION
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-80
-40
0
40
80
120
TEMPERATURE °F

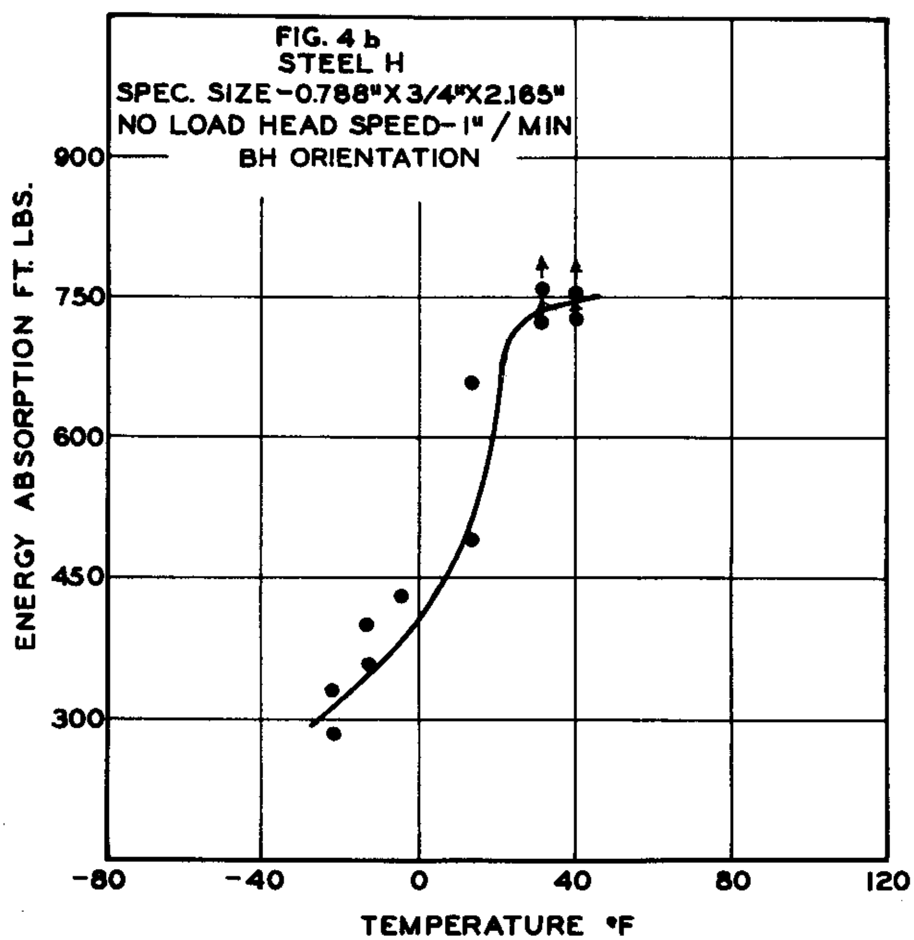


FIG. 4b
STEEL H
SPEC. SIZE - 0.788" X 3/4" X 2.165"
NO LOAD HEAD SPEED - 1" / MIN
BH ORIENTATION
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-80
-40
0
40
80
120
TEMPERATURE °F

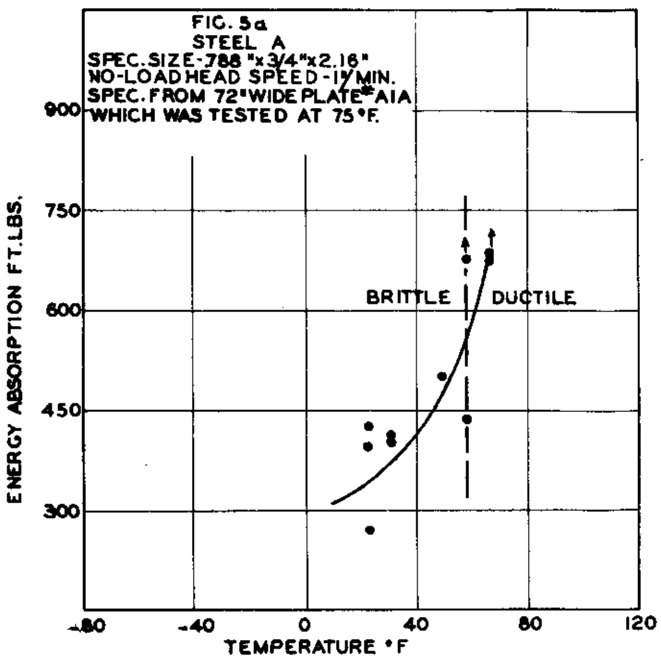


FIG. 5a
STEEL A
SPEC. SIZE-.788"x3/4"x2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE # A1A
WHICH WAS TESTED AT 75°F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

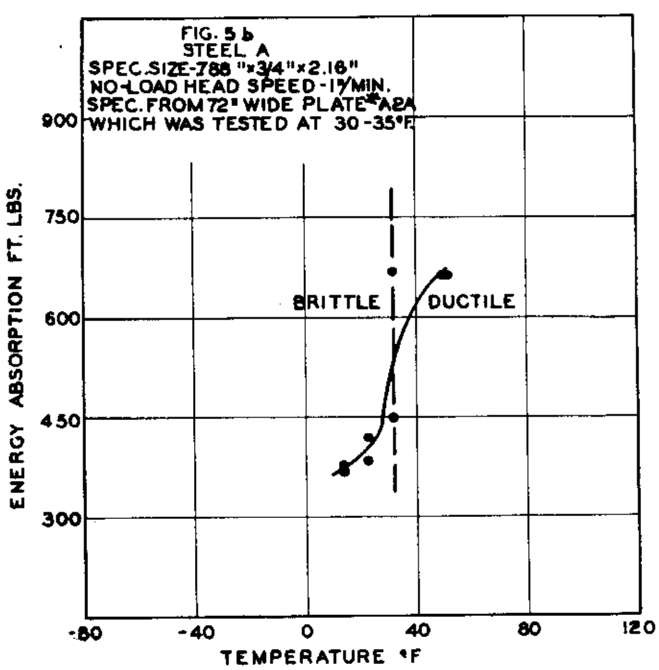


FIG. 5b
STEEL A
SPEC. SIZE-.788"x3/4"x2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE # A2A
WHICH WAS TESTED AT 30-35°F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

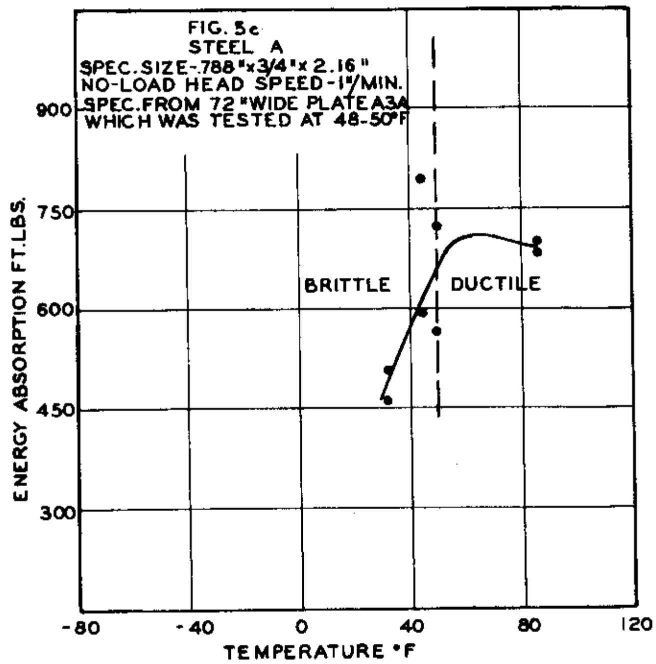


FIG. 5c
STEEL A
SPEC. SIZE-.788"x3/4"x2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE A3A
WHICH WAS TESTED AT 48-50°F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

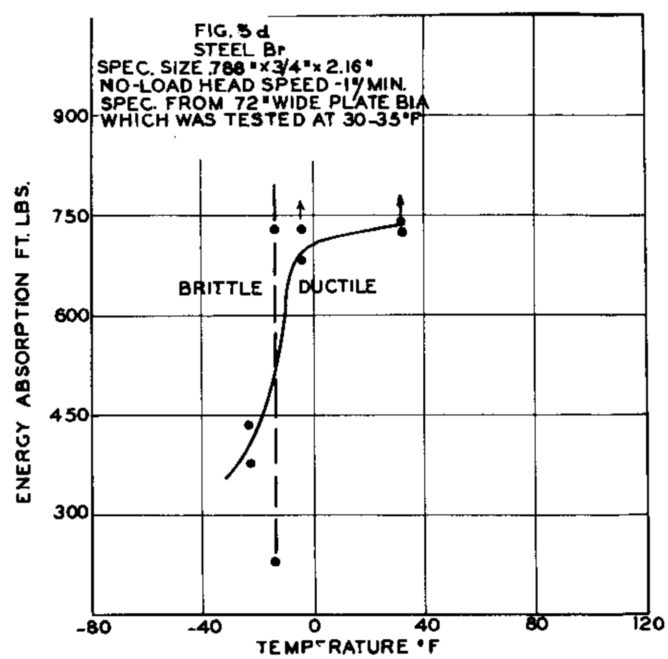


FIG. 5d
STEEL Br
SPEC. SIZE .788"x3/4"x2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE B1A
WHICH WAS TESTED AT 30-35°F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

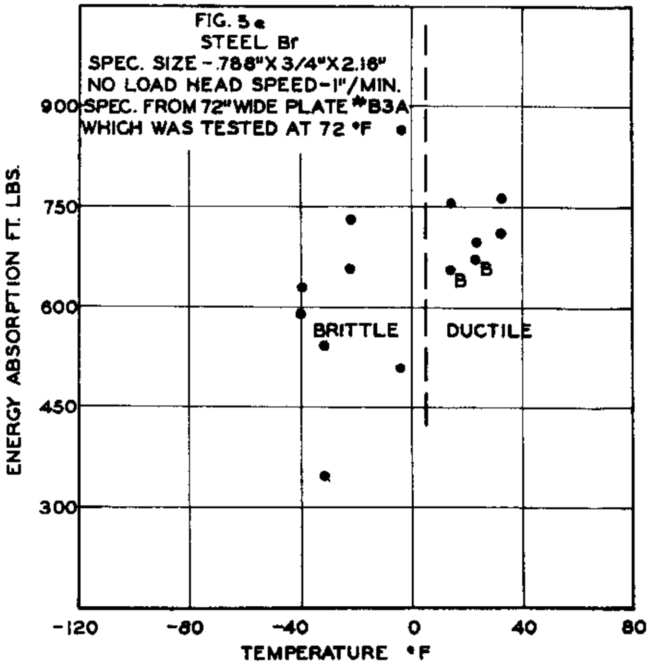


FIG. 5e
STEEL Br
SPEC. SIZE -.788"X 3/4"X 2.16"
NO LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE #B3A
WHICH WAS TESTED AT 72 °F
BRITTLE
DUCTILE
B
B
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-120
-80
-40
0
40
80
TEMPERATURE °F

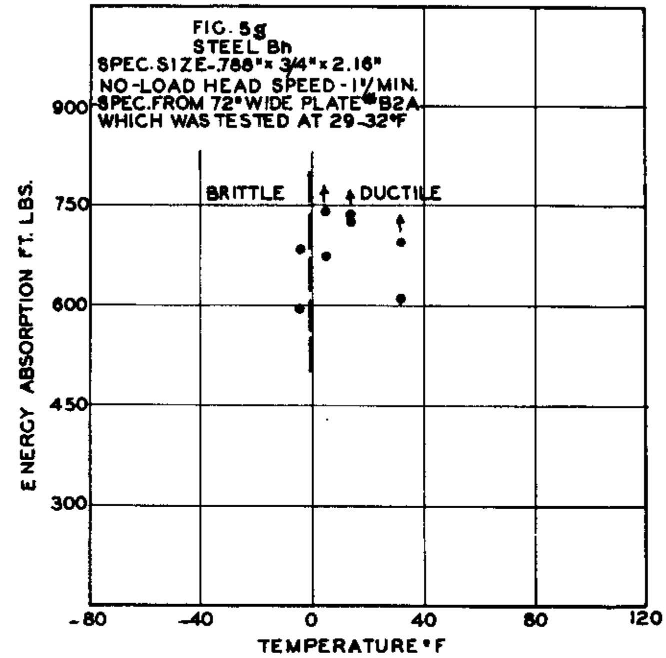


FIG. 5g
STEEL Bh
SPEC. SIZE-.788"x 3/4"x 2.16"
NO-LOAD HEAD SPEED - 1"/MIN.
SPEC. FROM 72" WIDE PLATE #B2A
WHICH WAS TESTED AT 29-32°F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-80
-40
0
40
80
120
TEMPERATURE °F

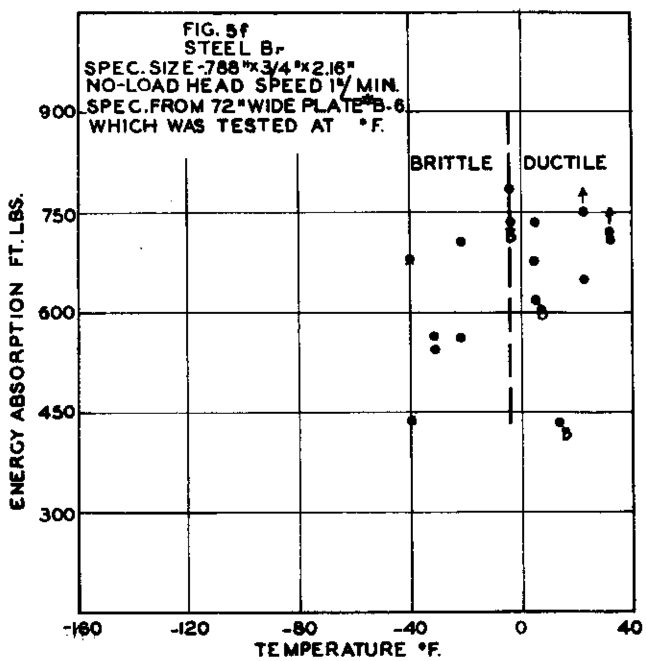


FIG. 5f
STEEL Br
SPEC. SIZE-.788"x 3/4"x 2.16"
NO-LOAD HEAD SPEED 1"/MIN.
SPEC. FROM 72" WIDE PLATE #B-6
WHICH WAS TESTED AT °F.
BRITTLE
DUCTILE
B
B
B
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-160
-120
-80
-40
0
40
TEMPERATURE °F.

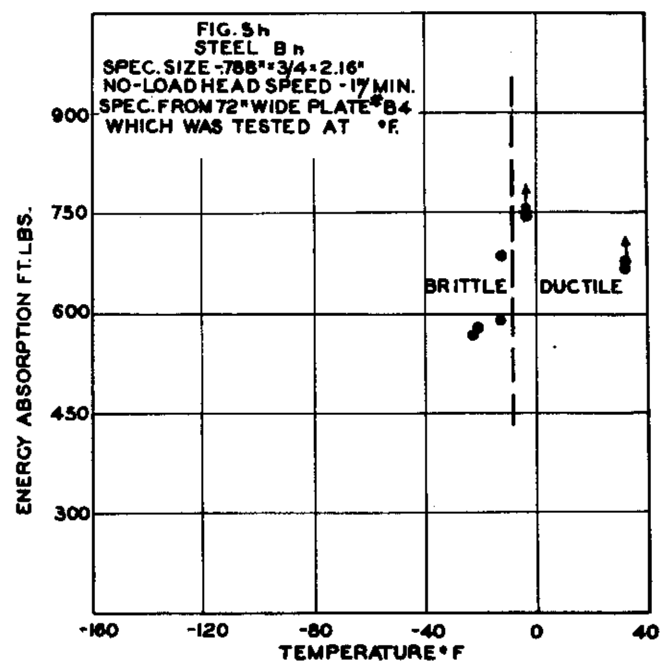


FIG. 5h
STEEL Bn
SPEC. SIZE-.788"x 3/4 x 2.16"
NO-LOAD HEAD SPEED - 1"/MIN.
SPEC. FROM 72" WIDE PLATE #B4
WHICH WAS TESTED AT °F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-160
-120
-80
-40
0
40
TEMPERATURE °F

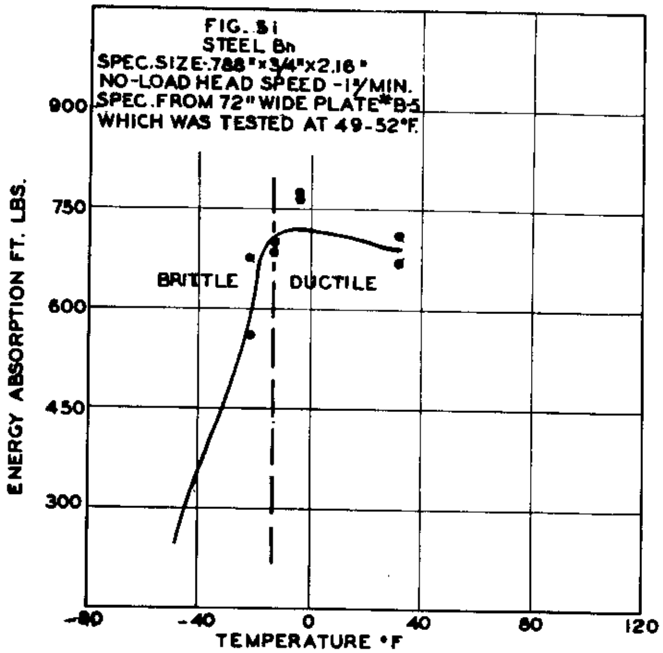


FIG. 5i
STEEL Bn
SPEC. SIZE-.788"x3/4"x2.16"
NO-LOAD HEAD SPEED -1"/MIN.
SPEC. FROM 72" WIDE PLATE #B5
WHICH WAS TESTED AT 49-52°F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

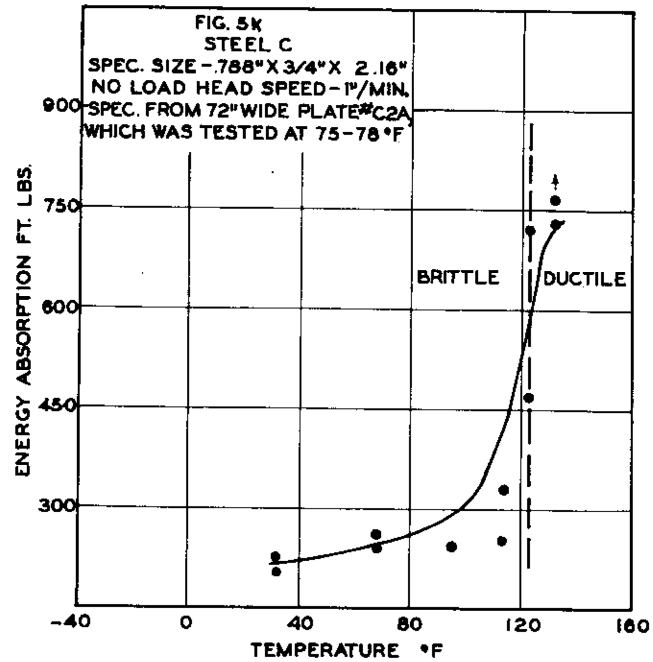


FIG. 5k
STEEL C
SPEC. SIZE -.788" X 3/4" X 2.16"
NO LOAD HEAD SPEED - 1"/MIN.
SPEC. FROM 72" WIDE PLATE #C2A
WHICH WAS TESTED AT 75-78 °F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

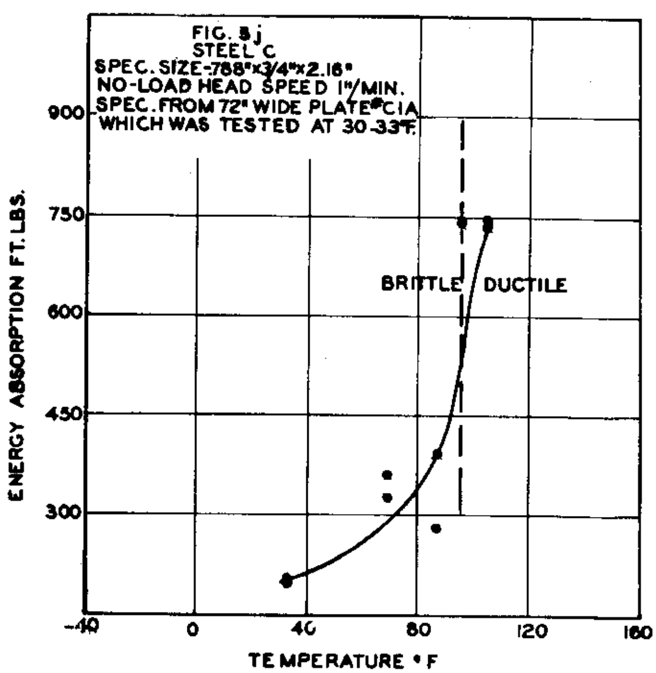


FIG. 5j
STEEL C
SPEC. SIZE-.788"x3/4"x2.16"
NO-LOAD HEAD SPEED 1"/MIN.
SPEC. FROM 72" WIDE PLATE #C1A
WHICH WAS TESTED AT 30-33°F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

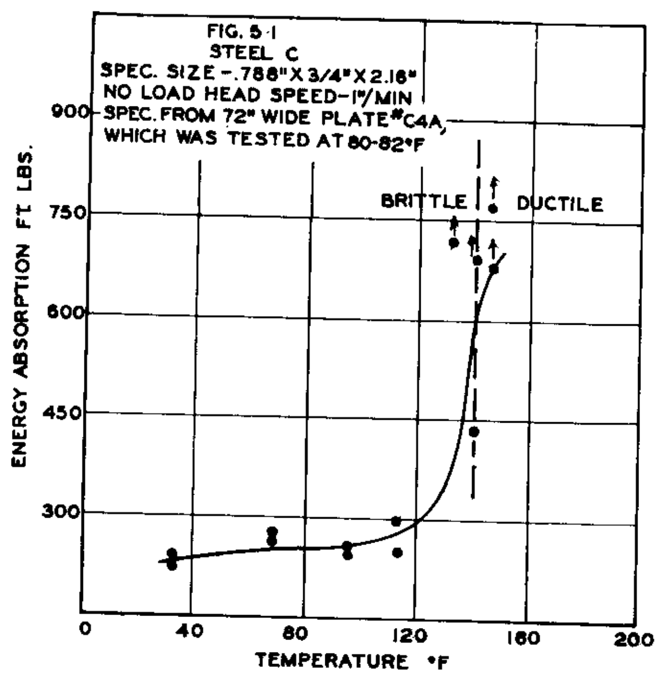


FIG. 5-l
STEEL C
SPEC. SIZE -.788" X 3/4" X 2.16"
NO LOAD HEAD SPEED - 1"/MIN
SPEC. FROM 72" WIDE PLATE #C4A
WHICH WAS TESTED AT 80-82°F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

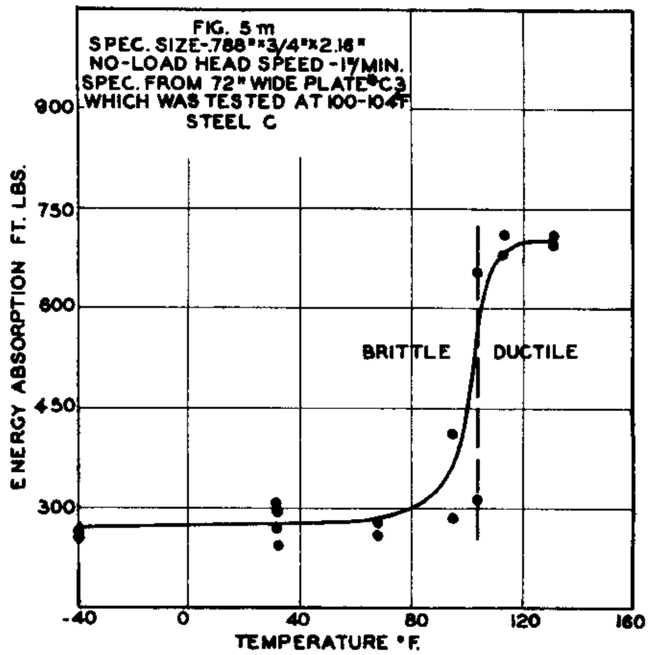


FIG. 5m
SPEC. SIZE-.788"×3/4"×2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE #C3
WHICH WAS TESTED AT 100-104°F
STEEL C
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F.

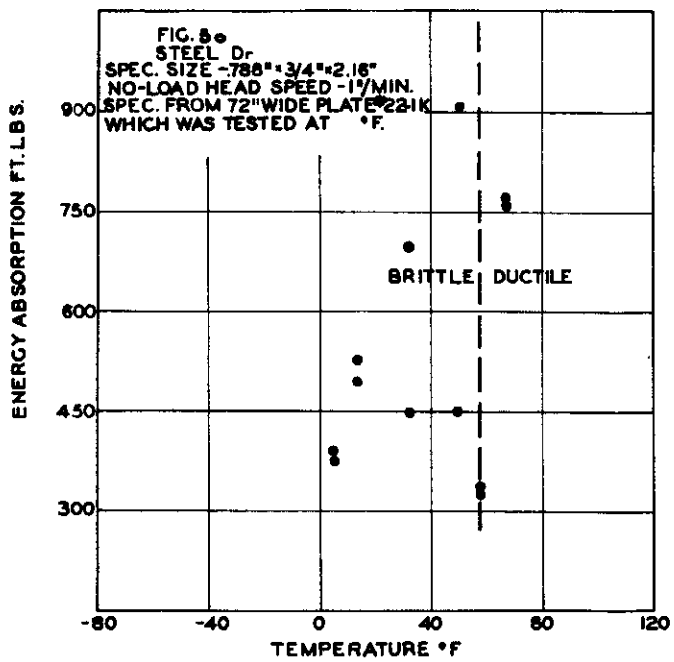


FIG. 5o
STEEL Dr
SPEC. SIZE-.788"×3/4"×2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE #22-1K
WHICH WAS TESTED AT °F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

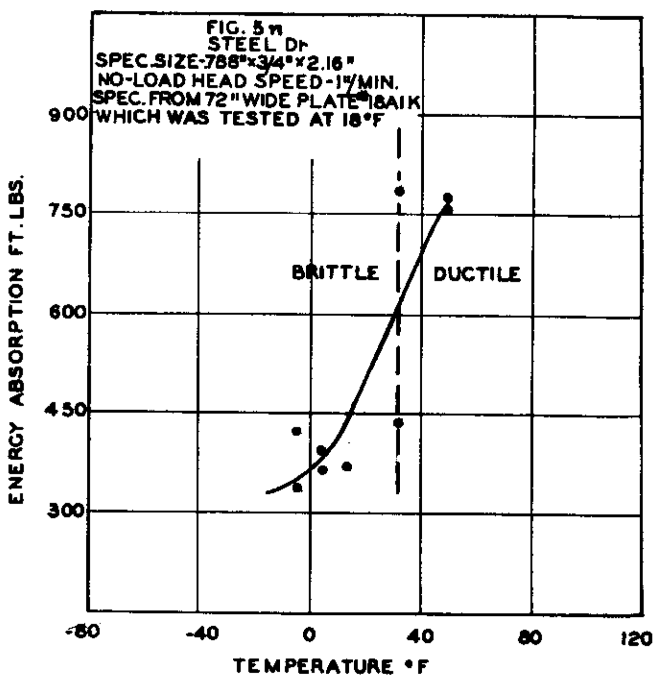


FIG. 5n
STEEL Dr
SPEC. SIZE-.788"×3/4"×2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE #18A1K
WHICH WAS TESTED AT 18°F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

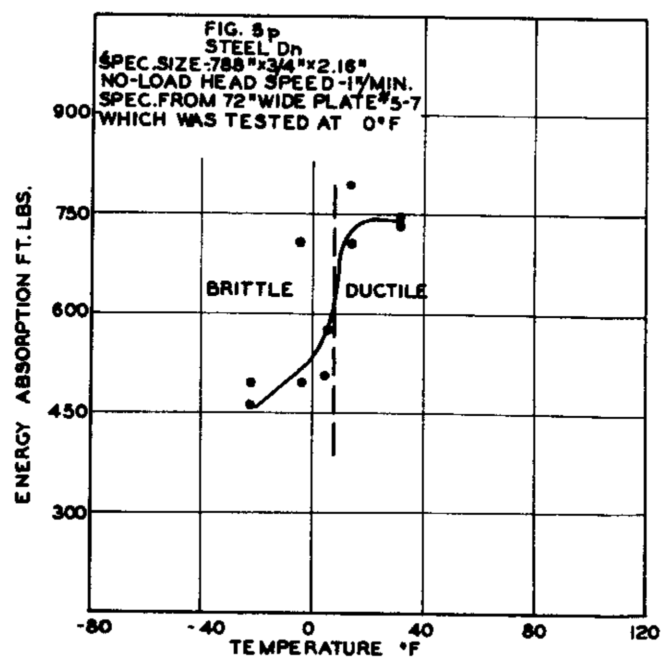


FIG. 5p
STEEL Dn
SPEC. SIZE-.788"×3/4"×2.16"
NO-LOAD HEAD SPEED-1"/MIN.
SPEC. FROM 72" WIDE PLATE #5-7
WHICH WAS TESTED AT 0°F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F

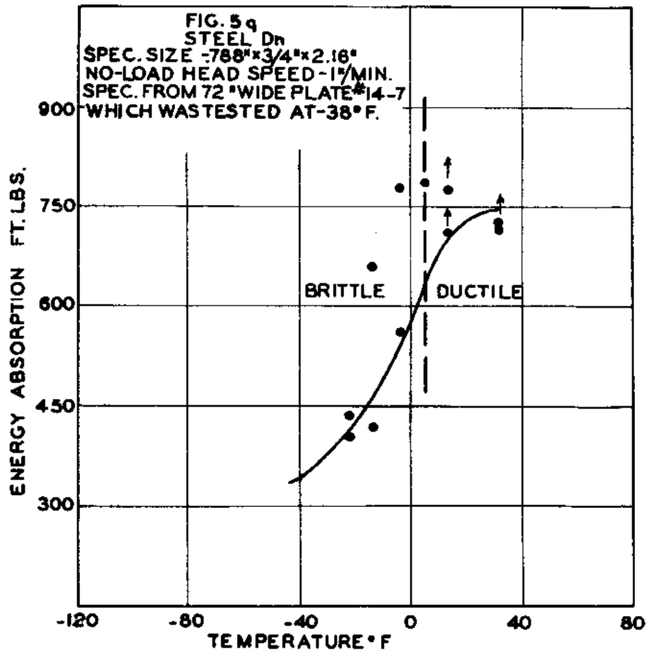


FIG. 5q
STEEL Dn
SPEC. SIZE -.788"x3/4"x2.16"
NO-LOAD HEAD SPEED - 1"/MIN.
SPEC. FROM 72" WIDE PLATE #14-7
WHICH WAS TESTED AT -38° F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-120
-80
-40
0
40
80
TEMPERATURE ° F

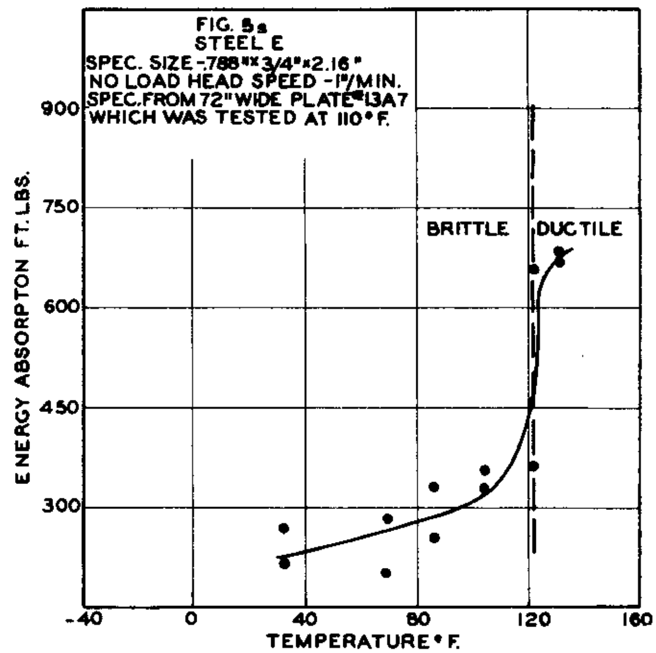


FIG. 5s
STEEL E
SPEC. SIZE -.788"x3/4"x2.16"
NO LOAD HEAD SPEED - 1"/MIN.
SPEC. FROM 72" WIDE PLATE #13A7
WHICH WAS TESTED AT 110° F.
BRITTLE
DUCTILE
ENERGY ABSORPTON FT. LBS.
900
750
600
450
300
-40
0
40
80
120
160
TEMPERATURE ° F.

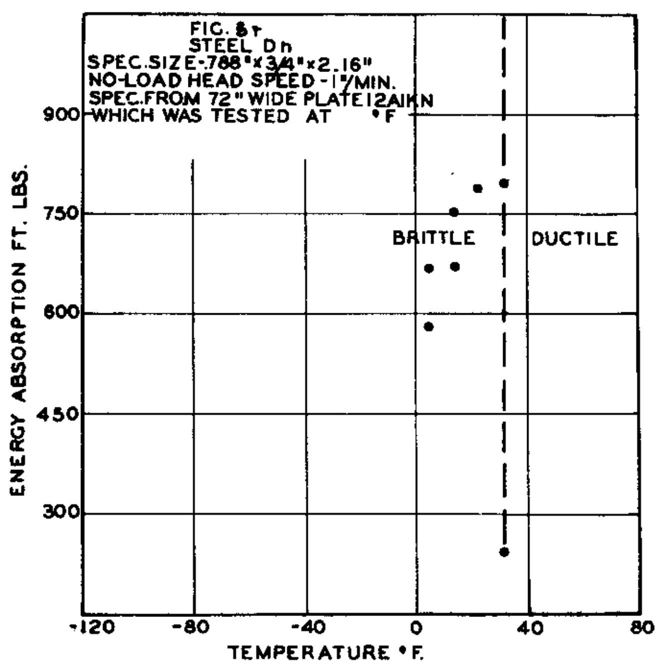


FIG. 5r
STEEL Dn
SPEC. SIZE -.788"x3/4"x2.16"
NO-LOAD HEAD SPEED - 1"/MIN.
SPEC. FROM 72" WIDE PLATE 12AIKN
WHICH WAS TESTED AT ° F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
-120
-80
-40
0
40
80
TEMPERATURE ° F.

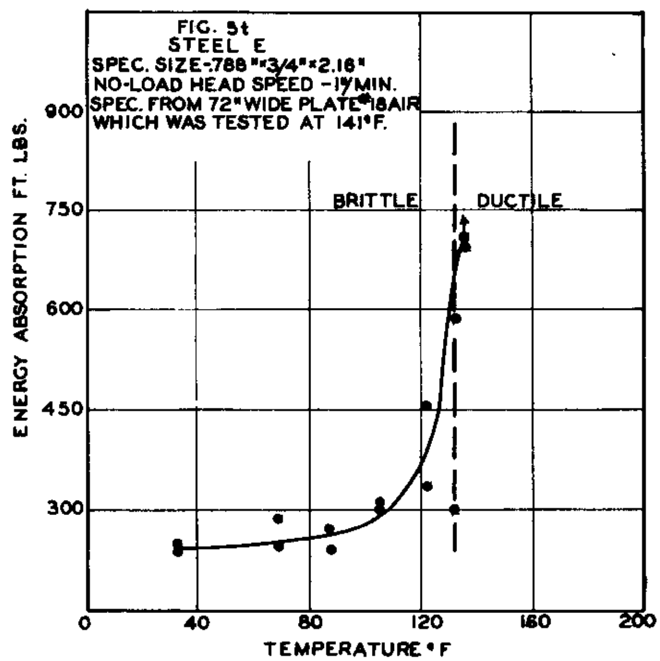


FIG. 5t
STEEL E
SPEC. SIZE -.788"x3/4"x2.16"
NO-LOAD HEAD SPEED - 1"/MIN.
SPEC. FROM 72" WIDE PLATE #18AIR
WHICH WAS TESTED AT 141° F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
900
750
600
450
300
0
40
80
120
160
200
TEMPERATURE ° F

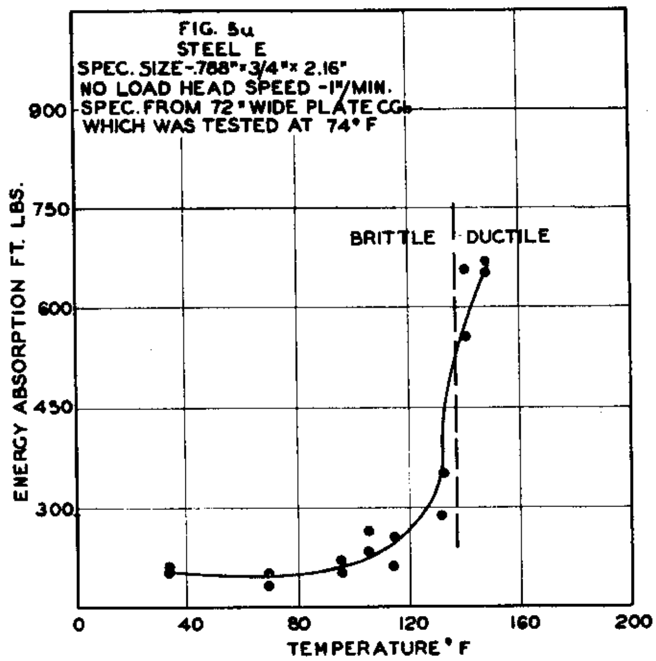


FIG. 5u
STEEL E
SPEC. SIZE-.788"x3/4"x 2.16"
NO LOAD HEAD SPEED -1"/MIN.
SPEC. FROM 72" WIDE PLATE CG
WHICH WAS TESTED AT 74° F
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE ° F
900
750
600
450
300
0
40
80
120
160
200

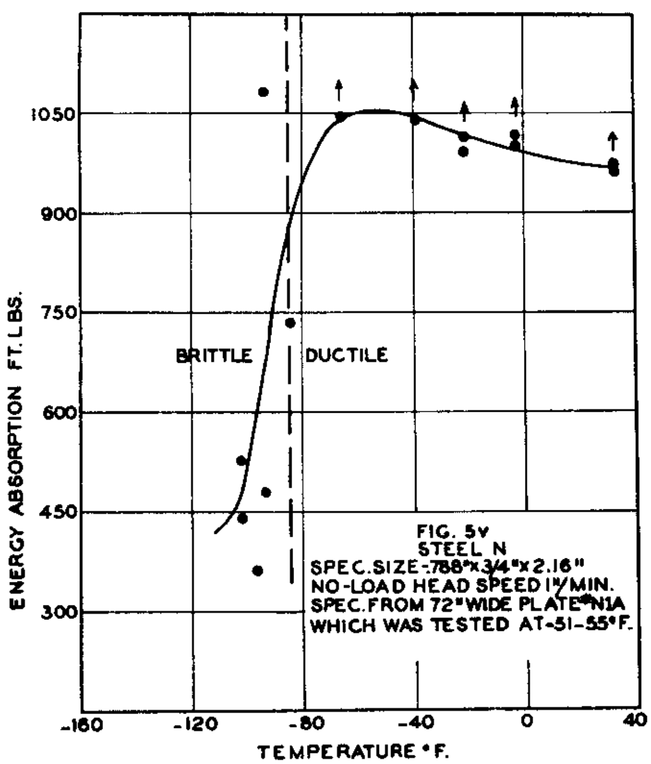


FIG. 5v
STEEL N
SPEC. SIZE-.788"x3/4"x2.16"
NO-LOAD HEAD SPEED 1"/MIN.
SPEC. FROM 72" WIDE PLATE N1A
WHICH WAS TESTED AT -51-55° F.
BRITTLE
DUCTILE
ENERGY ABSORPTION FT. LBS.
TEMPERATURE ° F.
1050
900
750
600
450
300
-160
-120
-80
-40
0
40

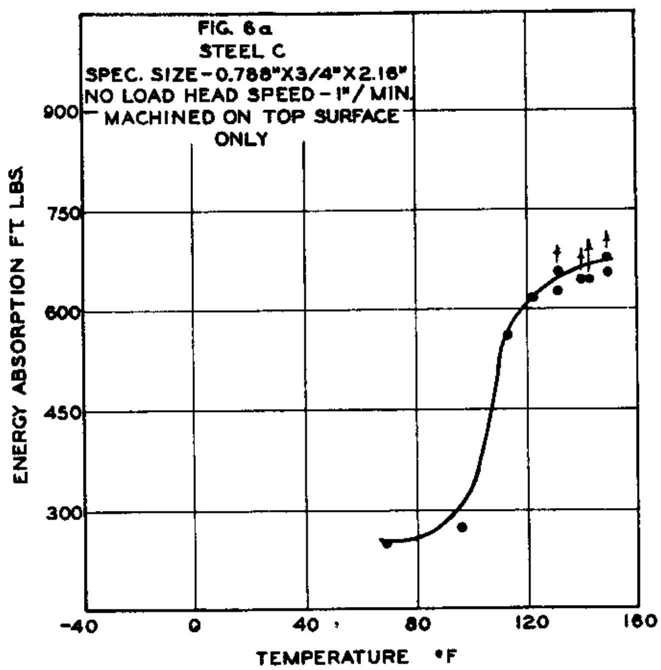


FIG. 6a
STEEL C
SPEC. SIZE-0.788"X3/4"X2.16"
NO LOAD HEAD SPEED-1"/MIN.
MACHINED ON TOP SURFACE
ONLY
ENERGY ABSORPTION FT. LBS.
TEMPERATURE °F
900
750
600
450
300
-40
0
40
80
120
160

APPENDIX I

In order to facilitate duplication of the bend test, detailed descriptions of specimen preparation, equipment construction, and testing procedure are given below.

Description of Test Specimen:

The photograph in Figure A-1 shows the type of notched-bend test specimen which is being used at present to determine correlation with large plate notched-tensile tests.

These specimens are of full plate thickness (3/4") in width and 0.788 inches in height, this latter dimension being just double that of a standard Charpy test bar. The length is 2.16 inches which is also the standard Charpy bar length; however, the allowable tolerance along this dimension is somewhat greater. The distance from the top of the specimen to the base of the notch is 0.709 inches. These dimensions are shown in Figure A-2.

The method used in machining of the test specimens depends, of course, on the available equipment and somewhat on personal preference. The general procedure is similar to that of preparing standard V-notch Charpy bars. Two methods of preparation which have been used and proved satisfactory are as follows:

Method 1.

(a) From the plate to be tested, a bar is cut which is slightly wider than the length of the finished specimens. This bar may be cut long enough to contain 15 or 20 specimens.

(b) The sides of this initial bar are shaped (or milled) to give the test bar a length of 2.16 inches, plus or minus .02 inches.

(c) The bar is sawed transversely into sections wide enough to allow:

(d) Finish machining on both sides to a .788 inches, plus or minus .002 inches, which may be done by milling, shaping or shaping and grinding.

(e) The V-notch is cut into one of the machined faces of the bar with a 45° included angle milling cutter having an 0.01 inch radius. The depth of this notch is the same as for the standard V-notch Charpy bar, being 0.079 inches in depth.

Method 2.

Steps (a), (b) and (c) are the same as in Method 1.

(d) The machining is done from one side only by shaping. In this case, some care must be used in making the sawed cut perpendicular to the ends of the test specimen.

(e) The V-notch is cut into the sawed face of the specimen, with the distance from the base of the notch to the machined side of the specimen being held at 0.709 inches, plus or minus 0.001 inches.

Description of Testing Equipmant:

The necessary apparatus for conducting the bend test consists of the usual supporting jig and bending punch, along with accessory equipment for cooling the specimen, centering the specimen in the jig, and measuring the deformation and load on the specimen.

Shown in Figure A-3 is the equipment as assembled before the testing operation. This photograph does not show the supporting jig within the container; however in Figure A-4 is a closeup view of this jig with the specimen in position for testing. The centering fixture which overhangs the specimen is used to center the specimen with respect to the supporting anvils, and to place the notch directly under the axis of the bending punch. The latter operation is carried out by matching the notch in the overhanging member of the centering fixture with scribed lines on the front and back of the punch.

Line drawings of the jig are shown in Figure A-5. As can be seen from the drawing of the jig, the dimensions of the jig are such as to allow a 40 mm. span between the anvils which support the specimen. This particular length was originally chosen from slow bend tests on standard Charpy specimens and has served satisfactorily for the present larger test specimens. The anvils are made of hardenable steel, and heat-treated to a hardness of 50 Rockwell C.

The punch is made of heat-treatable steel and the end is quenched and tempered to a hardness of 50 Rockwell C. The photograph in Figure A-6 shows this punch, while the line drawing in Figure A-7 gives the dimensions of it. The large 1/2" radius of curvature was found to be necessary to prevent excessive local compression of the specimen at the point of contact with the punch. In the method which is described here, the punch is fastened to the stationary head of a tensile testing machine by means of a bolt which is axially in line with the center of the punch. The supporting jig is placed on the movable platen and the specimen moved in relation to the punch, so that the specimen is submitted to a bending load opposite the notch.

<u>Description of Test Procedure</u>:

The step by step procedure for testing a specimen is as follows: The testing assembly is set up as in Figure A-3. The container is then filled with either acetone or water depending on the temperature at which the test is to be run.

By the use of dry ice with the acetone or by circulating water of the proper temperature through the container, the jig is brought to the desired temperature.

The specimen is then inserted and centered after which the punch is brought into light contact with the specimen to prevent any shifting which might occur while stirring the bath or adding dry ice.

The first specimen is held in the bath for a period of four minutes to reach the desired temperature, and additional specimens are added to the bath at this time, thus eliminating the waiting period before testing each bar. The holding period was checked by means of a thermocouple inserted in the specimen and was found to be adequate. The actual time required to cool the specimen to 0°C from room temperature was approximately one minute. The cooling curve for this specimen is shown in Figure A-8.

The speed at which the test is made is controlled by setting the no-load head speed of the tensile machine, at a predetermined value of about one inch per minute. Tests have been conducted through a range of speeds of from .01"/min. to 1"/min. to determine the effects of speed on the ductile to brittle transition temperature. This series of tests showed that the test was not sensitive to differences in speed in the neighborhood of 1"/min., so this has been the standard speed for subsequent testing.

If the specimen fails in a brittle manner, the load is immediately released at the point of failure. If the specimen behaves in a ductile manner, the bending is continued to slightly more than 0.4 inches deformation. In the case of the drilled specimens, the bending is continued to fracture. The specimen is removed from the jig, dried, and the fracture surfaces coated with collodion to prevent rusting.

While testing, an autographic record of the load-deformation curve is obtained by use of a wedge extensometer connected to a rotating drum, over which a pen moves to record loads. This record is not considered necessary to the interpretation of the test and is not recommended for future testing.

Discussion and Interpretation of Results:

There are several very definite indications of whether or not the test specimen is brittle.

One indication of the mode of fracture is the energy absorption as computed from the area under the load-deformation diagram. Typical load-deformation diagrams are shown in Figure A-9 for brittle and ductile failures.

As mentioned in the section on testing procedure, the specimens, if brittle, are bent to the point of fracture, and if ductile, are bent to slightly over 0.4 inch deflection at the midpoint.

The energy computations for ductile behavior are made on this basis, that is, allowing 0.4 inch deflection for which the absorbed energy is computed by measuring the area under the load-deformation diagram. For specimens failing in a brittle manner, the area is computed to the point of fracture.

After the energy-absorption values are obtained for a series of specimens at various temperatures, a plot is made of energy absorbed versus temperature of testing, which defines the transition region in a definite fashion. As indicated in the main body of the report, curves of this type for the project steels are plotted in Figures 3a to 5v.

The energy absorption value is not the only criterion for determining whether or not the specimen is brittle. For instance, in brittle fracture there is a sharp drop in load accompanied by a sharp report as the specimen breaks. This sharp drop in load does not occur for the specimens which fail in shear. Actually for this case the load remains constant at the maximum or even rises slightly as the angle of bend increases. This is probably due to a jamming action at the anvils and might be considered a disadvantage if it were not for the fact that it makes separation of brittle and ductile fractures very simple.

The nature of the fracture is also a positive criterion for the determination of the transition from ductile to brittle behavior. As the temperature of testing is successively lowered, the deformation preceding fracture becomes less and the extent of the cleavage fracture becomes greater. This is illustrated by the typical set of fractured bars shown in Figure A-10.

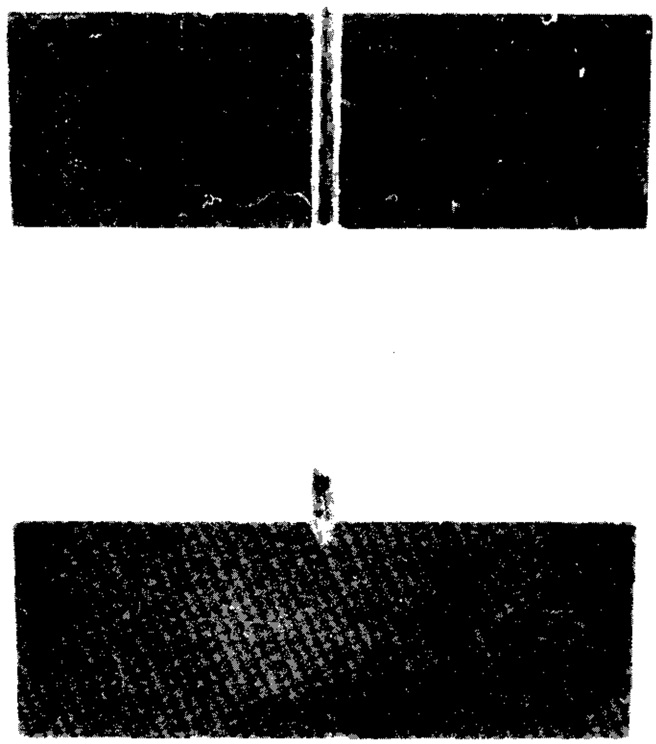


Fig. A-1 Photograph of Notched-Bend Test Specimen

SLOW BEND SPECIMEN

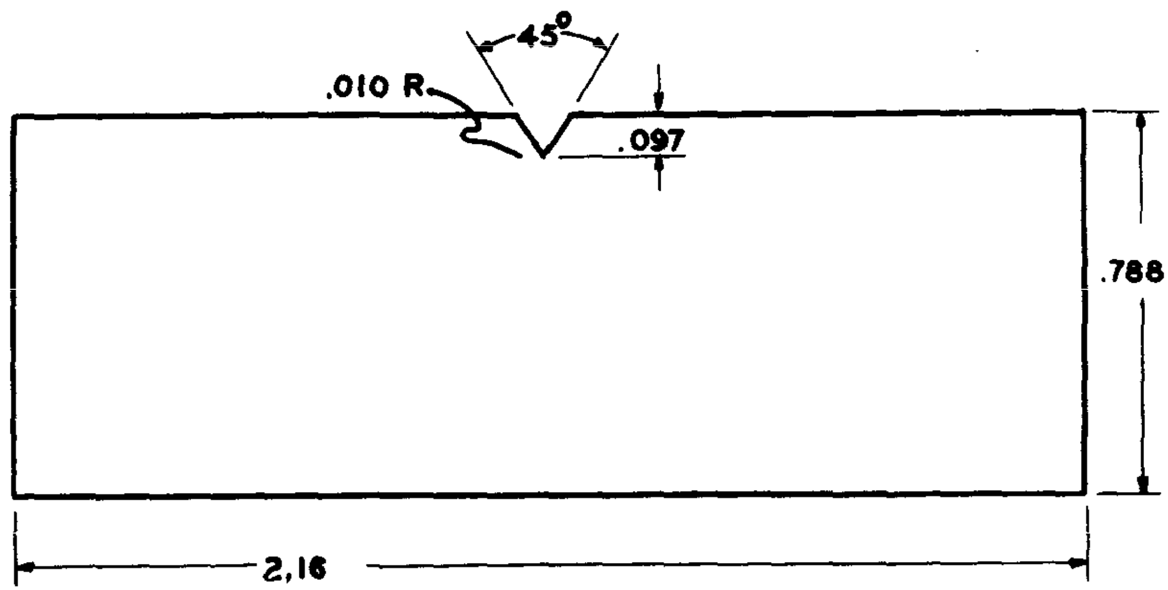


FIG. A-2

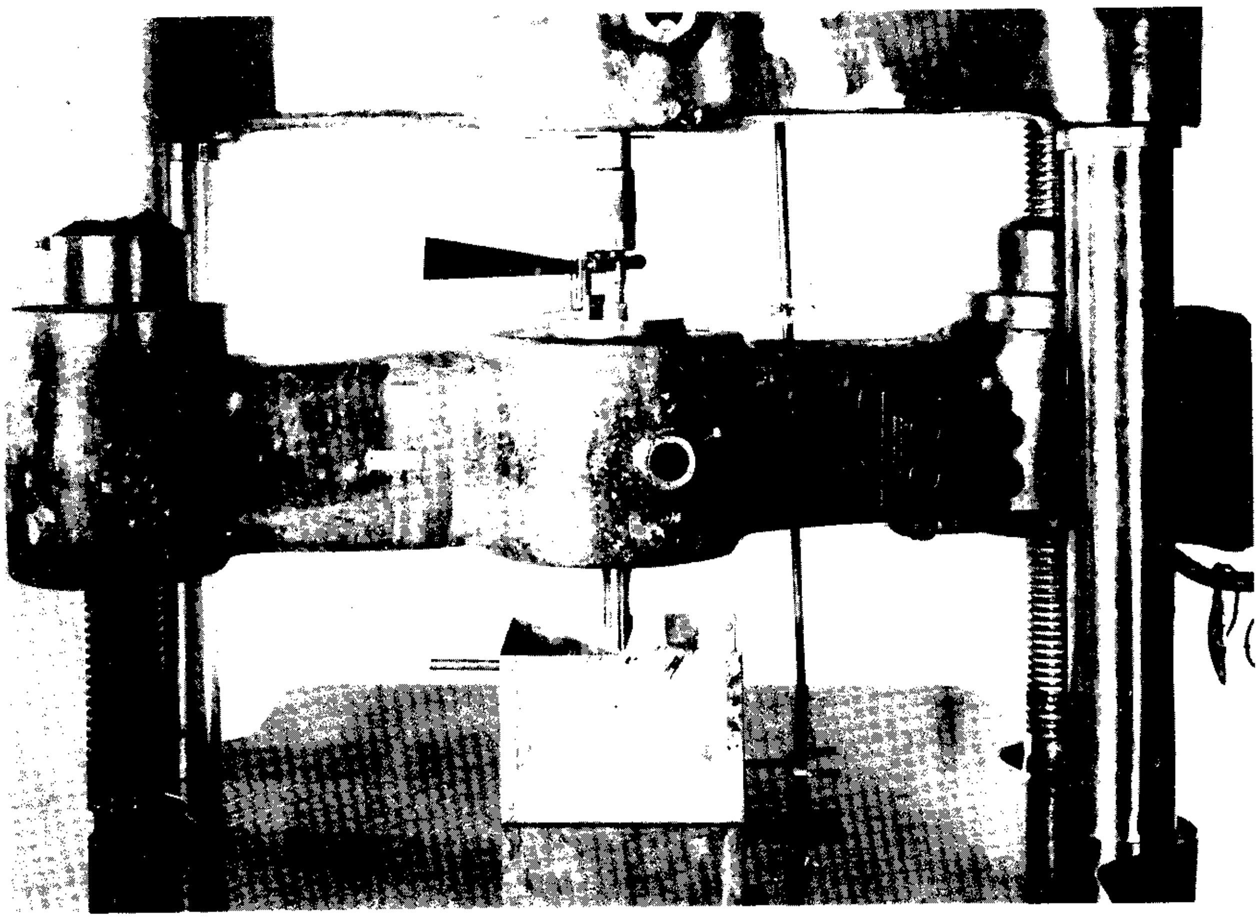


Fig. A-3 Photograph of Equipment
General Assembly

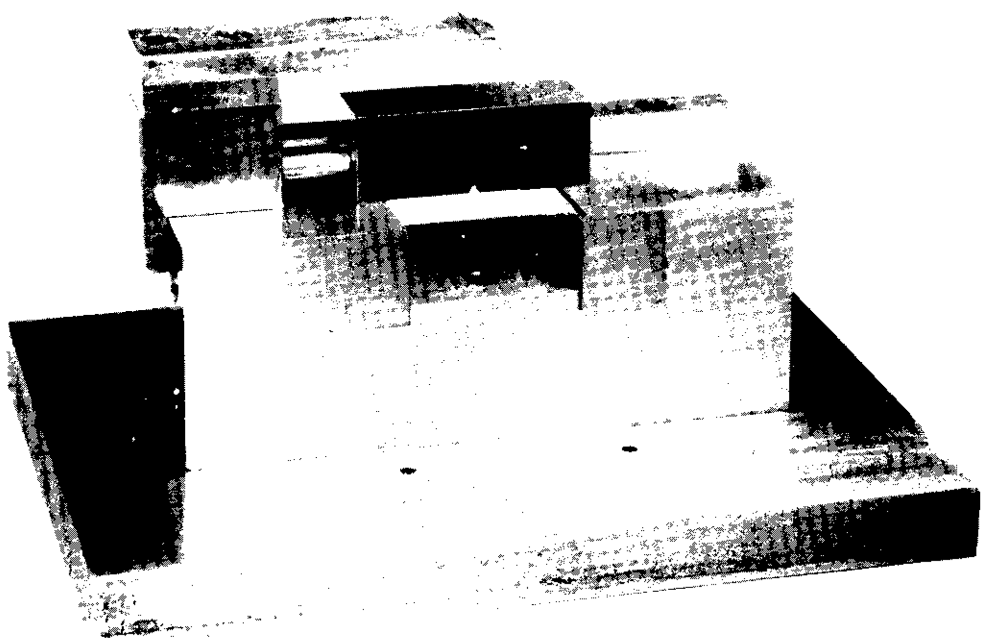


Fig. A-4 Photograph of Jig, Cantering Fixture and Specimen

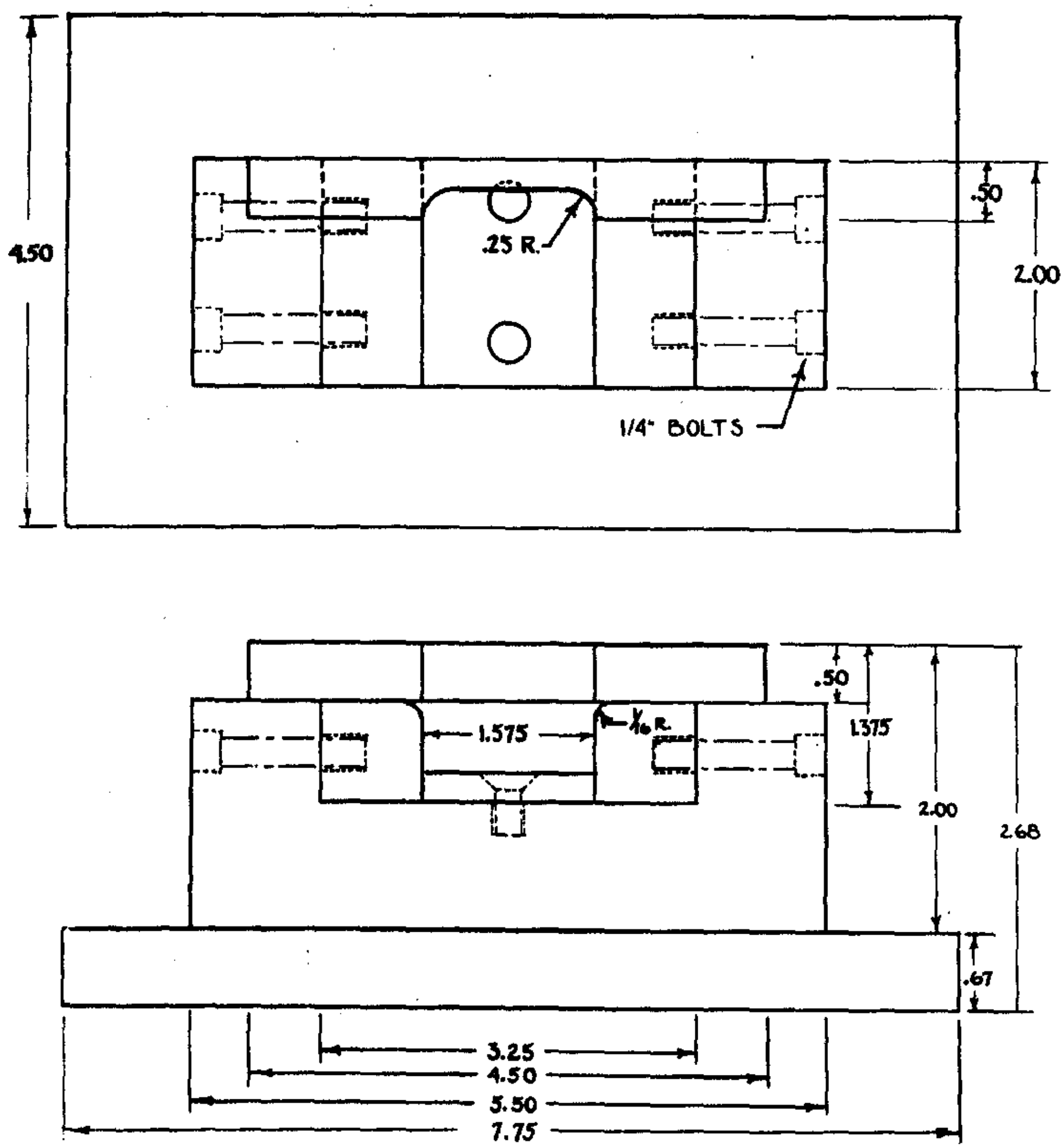


Fig. A-5 Drawing of Jig

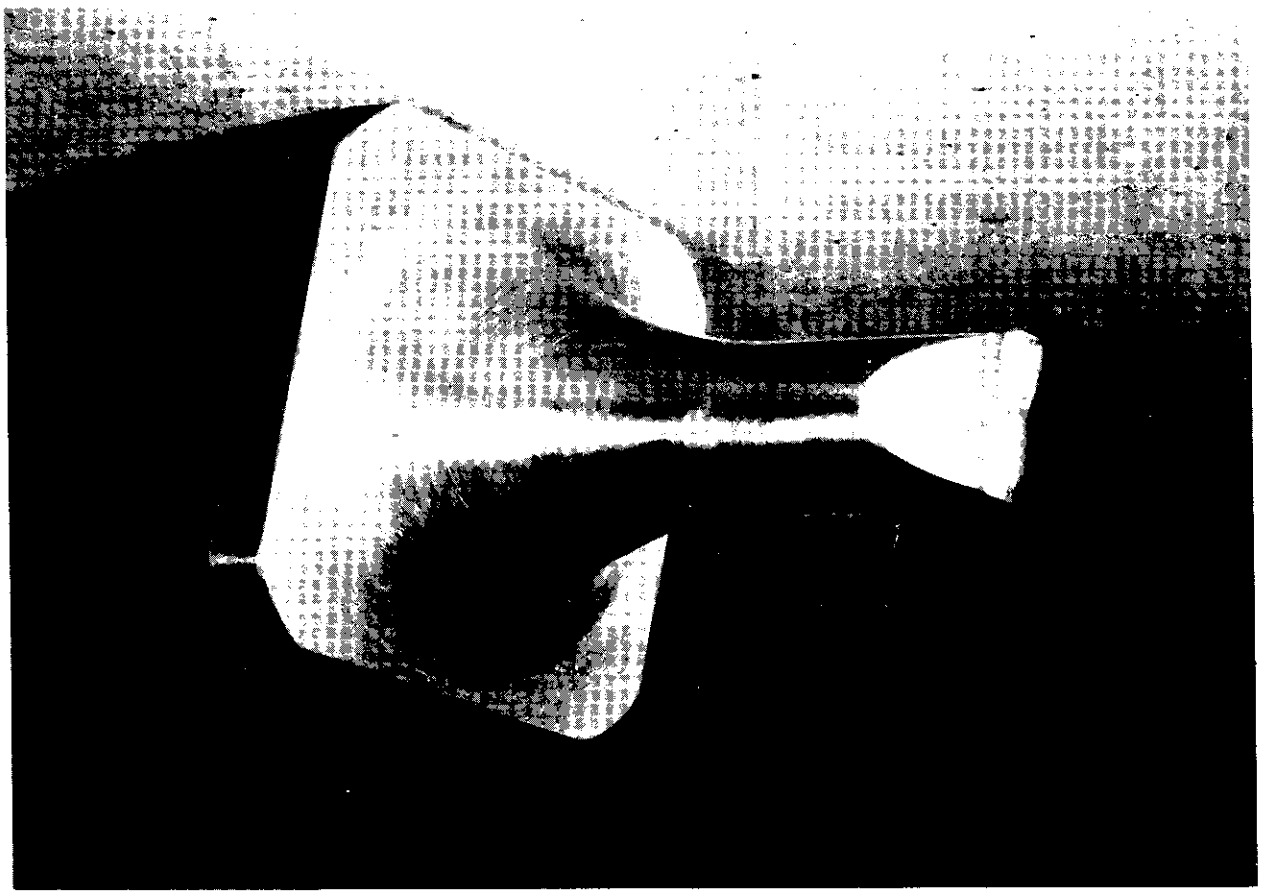


Fig. A-6 Photograph of Punch

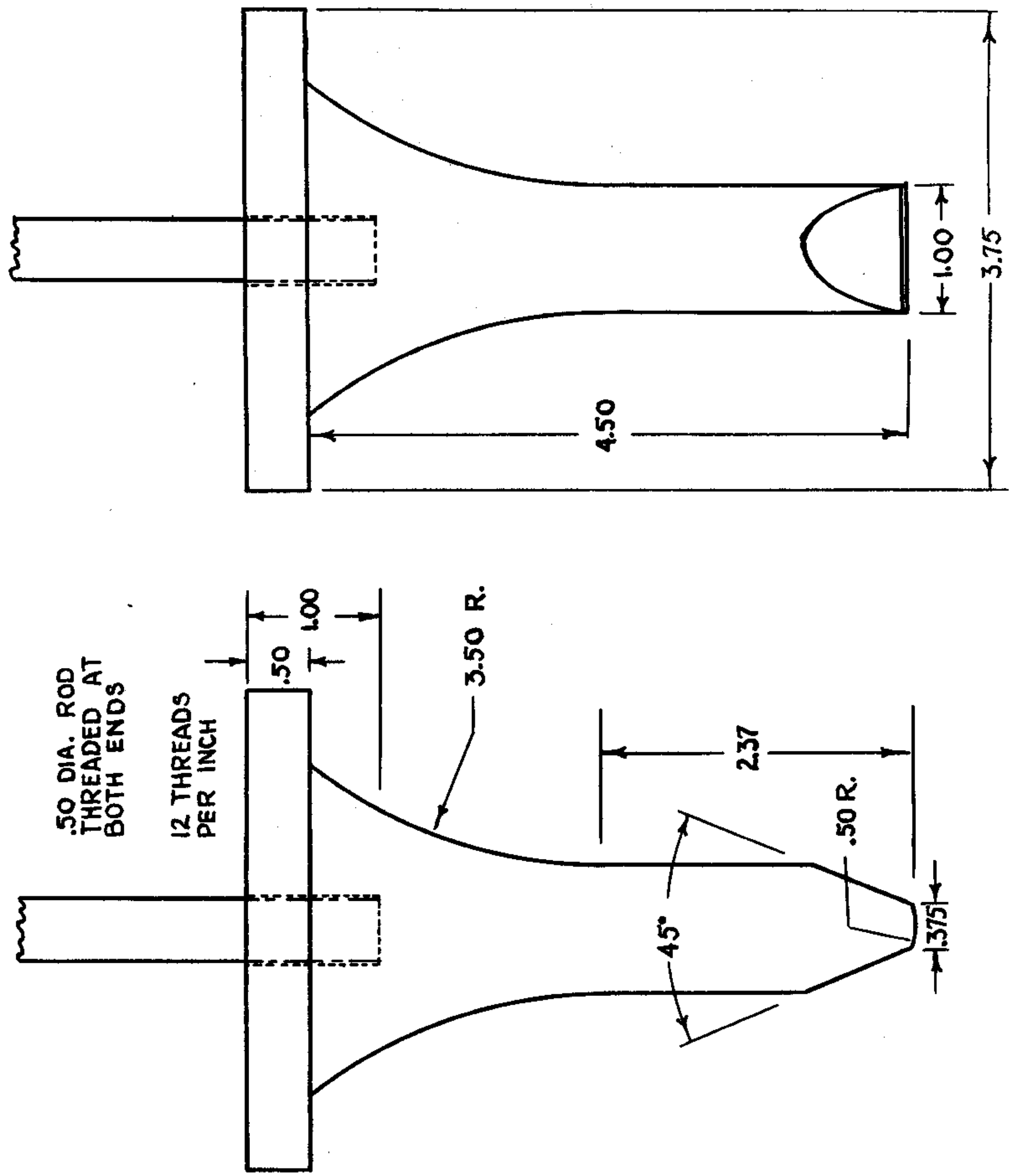


Fig. A-7 Drawing of Punch

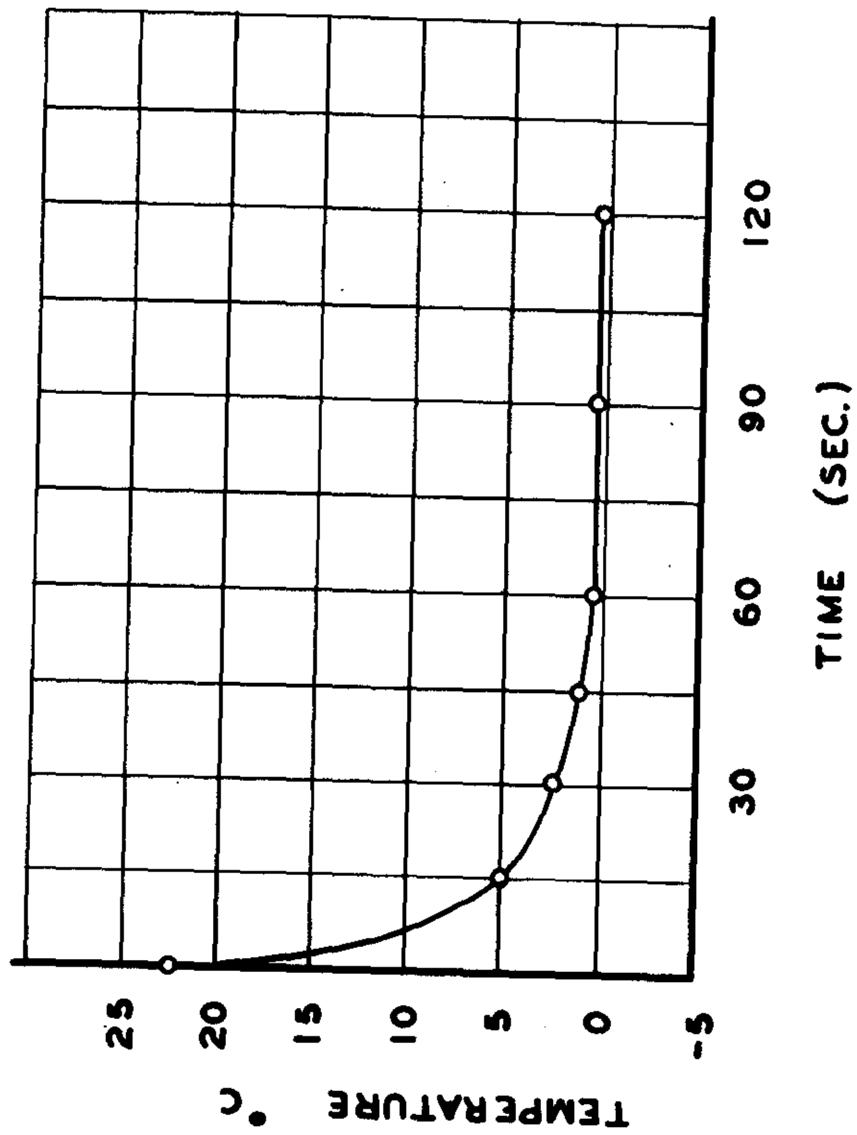


FIG. A-8

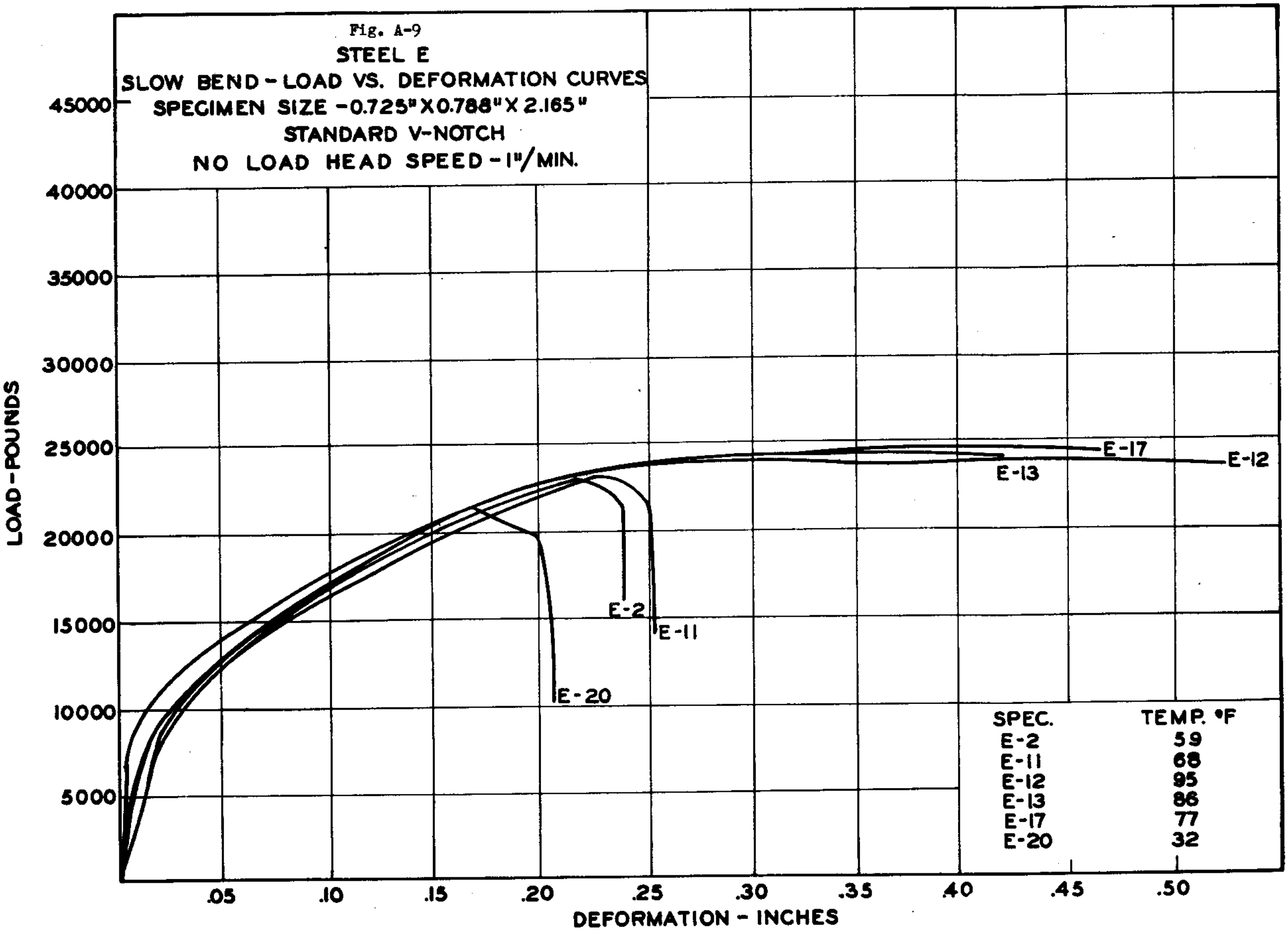


Fig. A-9
STEEL E
SLOW BEND - LOAD VS. DEFORMATION CURVES
SPECIMEN SIZE -0.725" X 0.788" X 2.165"
STANDARD V-NOTCH
NO LOAD HEAD SPEED - 1"/MIN.
LOAD - POUNDS
45000
40000
35000
30000
25000
20000
15000
10000
5000
DEFORMATION - INCHES
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
E-17
E-12
E-13
E-2
E-11
E-20
SPEC. TEMP. °F
E-2 59
E-11 68
E-12 95
E-13 86
E-17 77
E-20 32

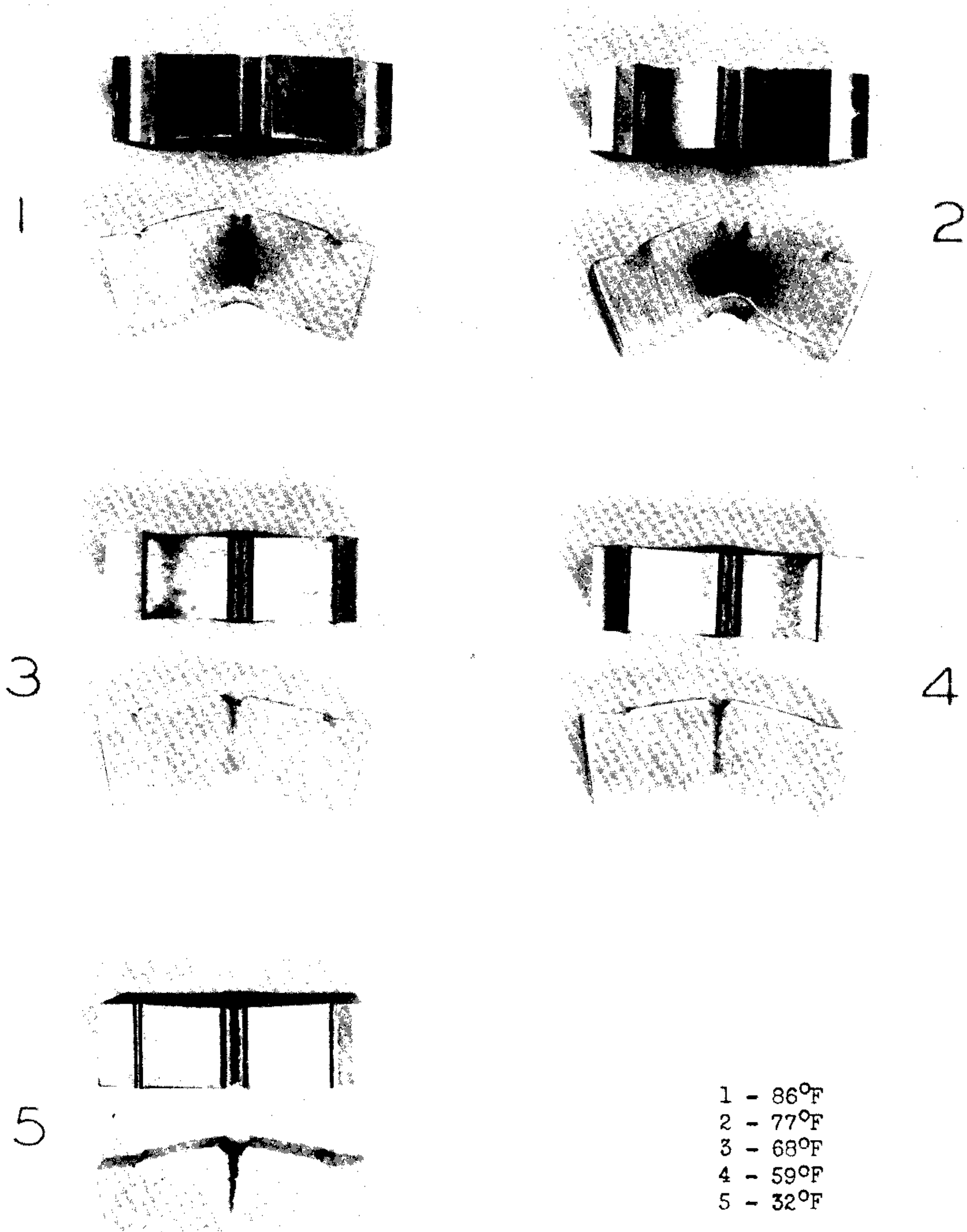


Fig. A-10 Photograph of Typical Set of Fractured Test Bars (E Steel)