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SERIAL NO. **SSC-51**

FIRST

Progress Report

(PROJECT SR-118)

on

CRACKING OF SIMPLE STRUCTURAL GEOMETRIES:

The Effects of Edge Notch Geometry on Flat Steel Plates

by

S. T. CARPENTER AND R. F. LINSENMEYER

Swarthmore College

Under Bureau of Ships Contract NObs-50250

(Index No. NS-731-034)

for

SHIP STRUCTURE COMMITTEE

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The Secretary of the Treasury

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MAY 12, 1952

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May 12, 1952

Dear Sir:

Herewith is a copy of the first Progress Report from Project SR-118 at Swarthmore College entitled, "Cracking of Simple Structural Geometries: The Effects of Edge Notch Geometry on Flat Steel Plates" by S. T. Carpenter and Roy F. Linsenmeyer. This investigation is being conducted for the Ship Structure Committee and covers work completed between January 1950 and November 1951.

This report is being distributed to those individuals and agencies associated with and interested in the work of the Ship Structure Committee.

Any questions, comments, criticism or other matters pertaining to the report should be addressed to the Secretary, Ship Structure Committee.

Yours sincerely,

K. K. Cowart

K. K. COWART
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

FIRST PROGRESS REPORT

NAVY BUSHIPS CONTRACT NObs-50250
PROJECT SR-118

"CRACKING OF SIMPLE STRUCTURAL GEOMETRIES"

THE EFFECTS OF EDGE NOTCH GEOMETRY ON FLAT STEEL PLATES

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ABSTRACT

This report covers the first portion of an investigation to determine the relative cracking tendency of simple geometries common to ship structures and presents the results of tensile tests on edge notched specimens. The edge notched specimens were 15" wide by 40" long and prepared from 3/4" thick Dn steel. Flame cutting was generally utilized in preparing the edges and notches of the specimens. However, for one type of specimen, the edge notches were prepared with a jeweler's hack saw. The edge notching consisted of notches at the mid-length of the specimen and notches separated by a reduced width portion.

The results of the tests are classified on the basis of strength, energy absorption and transition temperatures. The results indicate that there is no marked difference in transition temperature for the various types of edge notches, which included a jeweler's hack saw cut at 90° to the plate edge, a similar flame cut notch, flame cut notches with various included angles, flame cut semi-circles, and notches similar to the foregoing but having an elongated reduced width section. There is, however, a considerable difference in the action of the specimens with regard to strength and energy absorption.

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APPENDIX C

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INTRODUCTION

The program herein described was established to secure facts relating to the tensile strength, energy absorption, and transition temperature of flat steel plates of various design geometries, and is the initial part of a broad program planned to study the relative cracking tendencies of simple structural geometries common to ship design. The geometries investigated in this report include specimens with symmetrical edge notch variations using 15" wide plates of 3/4" thick Dn steel, and faired unnotched specimens $13\frac{1}{2}$" wide and 3/4" thick. The plate edges and edge notching, except in cases to be noted, were all prepared by flame cutting. The flame cutting employed was intended to represent average shipyard workmanship.

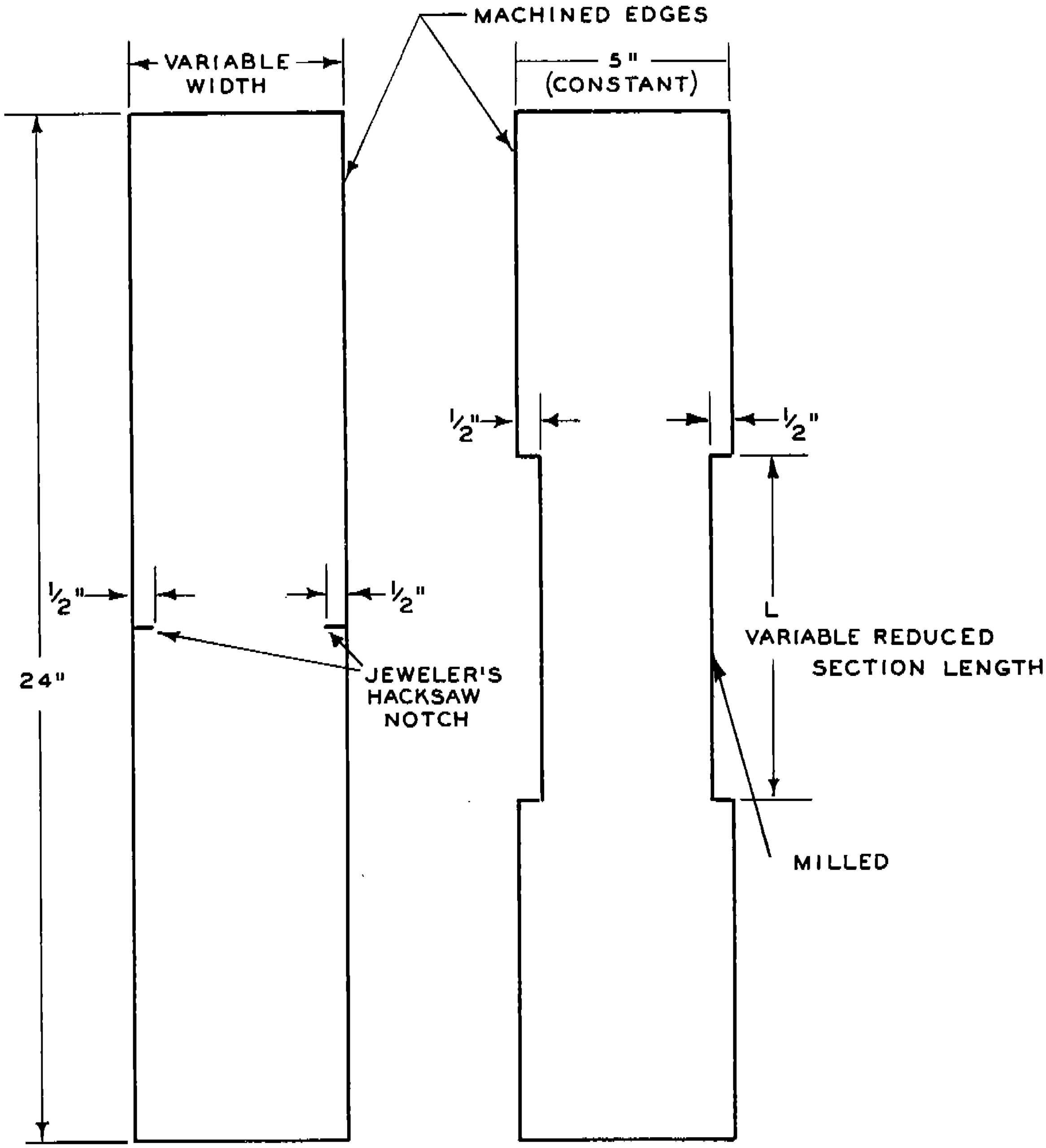
The edge notch variations included notches prepared by a jeweler's hack saw cut, flame cut square notches, flame cut notches with included angles of 90° and 135°, and semi-circular notches. Notched specimens were tested with two variations in plate layout. One variation placed the edge notches at the mid-length of the plate, the other placed the notches at the ends of a centrally located reduced width. (See Fig. 9)

An exploratory program to determine the optimum width of the test specimens preceded the testing of the 3/4" thick plates. The exploratory test specimens were made from 1/4" hot-rolled steel plates.

EXPLORATORY TESTS

Since the overall objective of the project involves a comparison of notch geometries to be directly useful in the design and inspection of ships' hulls, the test specimens should yield results which approach the full scale and bear the same interrelationships as they would in the full scale. It was therefore deemed desirable to select a minimum width for 3/4" thick specimens which would approach the behavior of an infinitely wide plate. This was accomplished by examining the action of smaller and thinner specimens. All exploratory tensile tests were made using 24" long specimens cut from 1/4" thick hot-rolled plates. The specimens fell into two categories as shown in Fig. 1. The type shown in Fig. 1 a had variable widths, with saw cut edge notches, while the type shown in Fig. 1 b had constant widths of 5" with the reduced width section variable in length. All tests were made at a room temperature of about $75^{\circ}F$.

Specimens of varying widths (See Fig. 1 a) were used to determine an optimum width which was considered to be greater



(a) VARIABLE WIDTH

(b) CONSTANT WIDTH VARIABLE REDUCED SECTION

NOTE:
ALL SPECIMENS ARE OF HOT-ROLLED PLATE, AVERAGE THICKNESS BEING .275"

FIG. 1 EXPLORATORY SPECIMENS

than the minimum width which would still permit plastic deformation to occur in the plate above and below the notched cross-section before fracture, and at which the average unit tensile resistance of the notched cross-section did not reflect localized notch restraint. Table 1 lists the test results for specimens of varying widths. The first specimen listed, X-1.5.U, is an unnotched specimen 1½" wide. All others are notched, with widths varying from 1.5" to 17". The unit stress on the net-section for the yield and maximum loads are plotted in Fig. 2. As the widths of the specimens increased, the average unit stress at maximum load decreased. When the net width was about 8" the stress at maximum load was nearly equal to the yield stress of the unnotched specimen. The strength impairment of notched bars is thus clearly shown. The yield point stresses shown in Fig. 2 were based on loads giving a 0.2% elongation over the 24" gage length. These yield stresses are comparable, with some variations, to the yield stresses based on general yielding throughout the notched cross-section. Restraining effects of the notch are clearly shown by the high unit yield stress for the narrow specimens. It is also important to note that the unit yield stress was only slightly lower than the unit maximum stress as widths were increased.

The volumes of the exploratory specimens undergoing plastic strain is clearly shown in the photographs of Fig. 3. These scaling patterns are those at the fracture load. The 1.5" and 2" wide specimens have a perfect circle pattern, whereas with increased

TABLE 1

Exploratory Tests 1/4" Thick Hot-Rolled Plates
Variable Specimen Widths

Specimen No.	Width, inches Total	Net	Net Area sq.in.	Yield and Maximum Loads: Yield* lbs.	psi.	Yield** lbs.	psi.	Maximum lbs.	psi.	Energy, in. lbs. to Max.load	to Fracture	Remarks
X 1.5	1.5	unnotched bar	.392	17,500	44,500	17,250	44,200	23,300	59,500	35,400	43,800	unnotched bar. All others notched.
X 1.5	1.5	0.5	.137	7,400	54,000	6,500	47,500	8,900	65,000	385	500	
X 2	2	1	.275	13,500	49,200	15,000	54,600	16,350	59,500	925	1,400	
X 3	3	2	.550	28,000	51,000	27,800	52,200	28,700	52,200	2,700	4,950	
X 4	4	3	.835	43,000	51,500	43,350	52,000	44,400	53,300	5,200	11,000	
X 5_1	5	4	1.1	51,500	46,750	51,000	46,500	52,500	47,700	10,200	18,200	
X 5_2	5	4	1.1	55,000	50,000	55,500	50,500	56,500	51,400	9,650	19,070	
X 6	6	5	1.37	65,500	47,800	65,000	47,500	68,000	49,600	14,250	29,680	
X 9	9	8	2.2	95,000	43,000	87,500	39,800	99,000	45,300	36,250	73,000	
X 17	17	16	4.4	175,000	39,800	176,000	40,000	189,000	43,000	54,000	188,000	

* Based on unit strain 0.2%
** Based on gen. yield across notch zone

Specimens
All specimens 24" long
Edge notches 1/2" deep made by jeweler's Hack Saw
Energy reported over 24" length.
Plates averaged 0.275 in. in thickness

TABLE 1

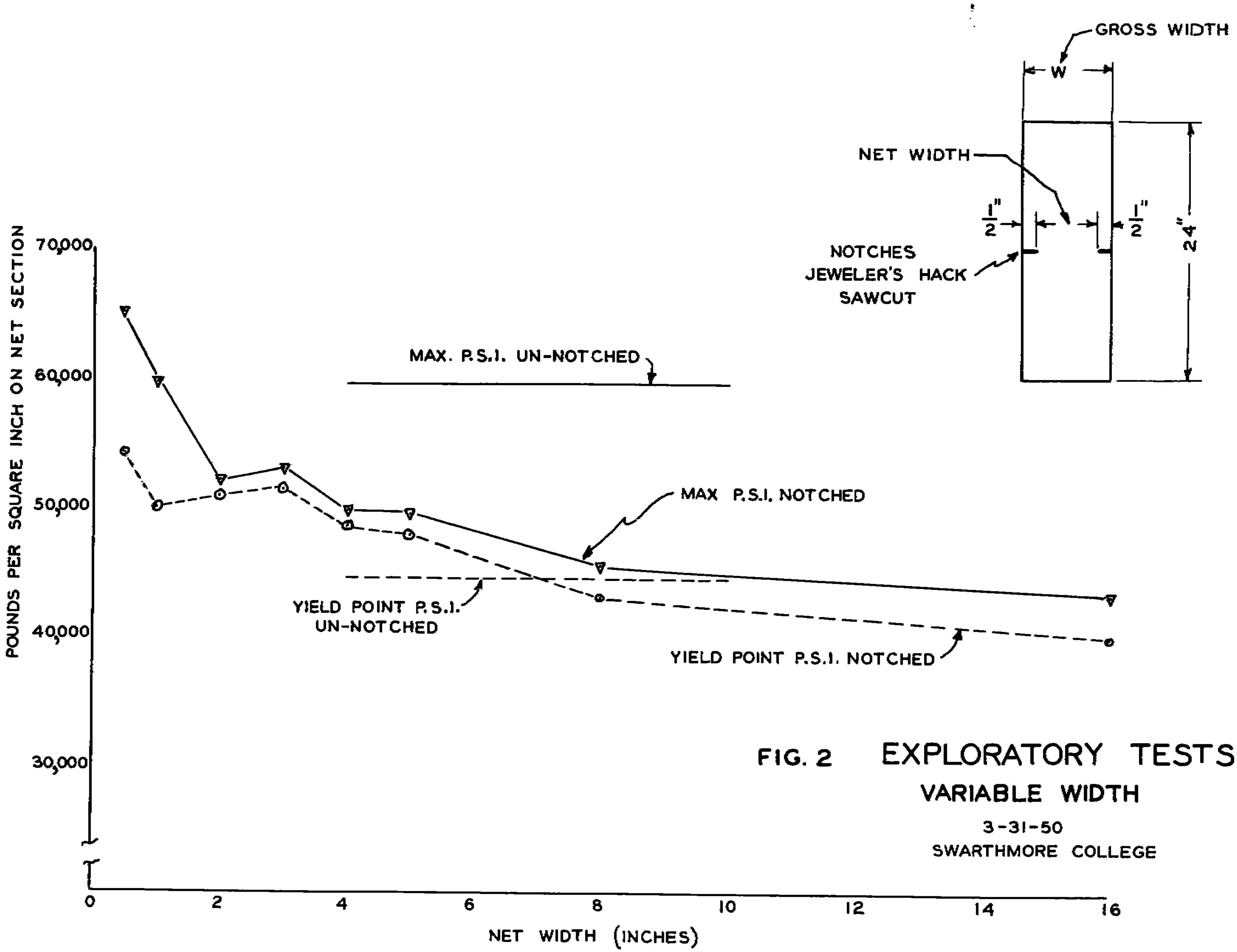


FIG. 2 EXPLORATORY TESTS

VARIABLE WIDTH

3-31-50

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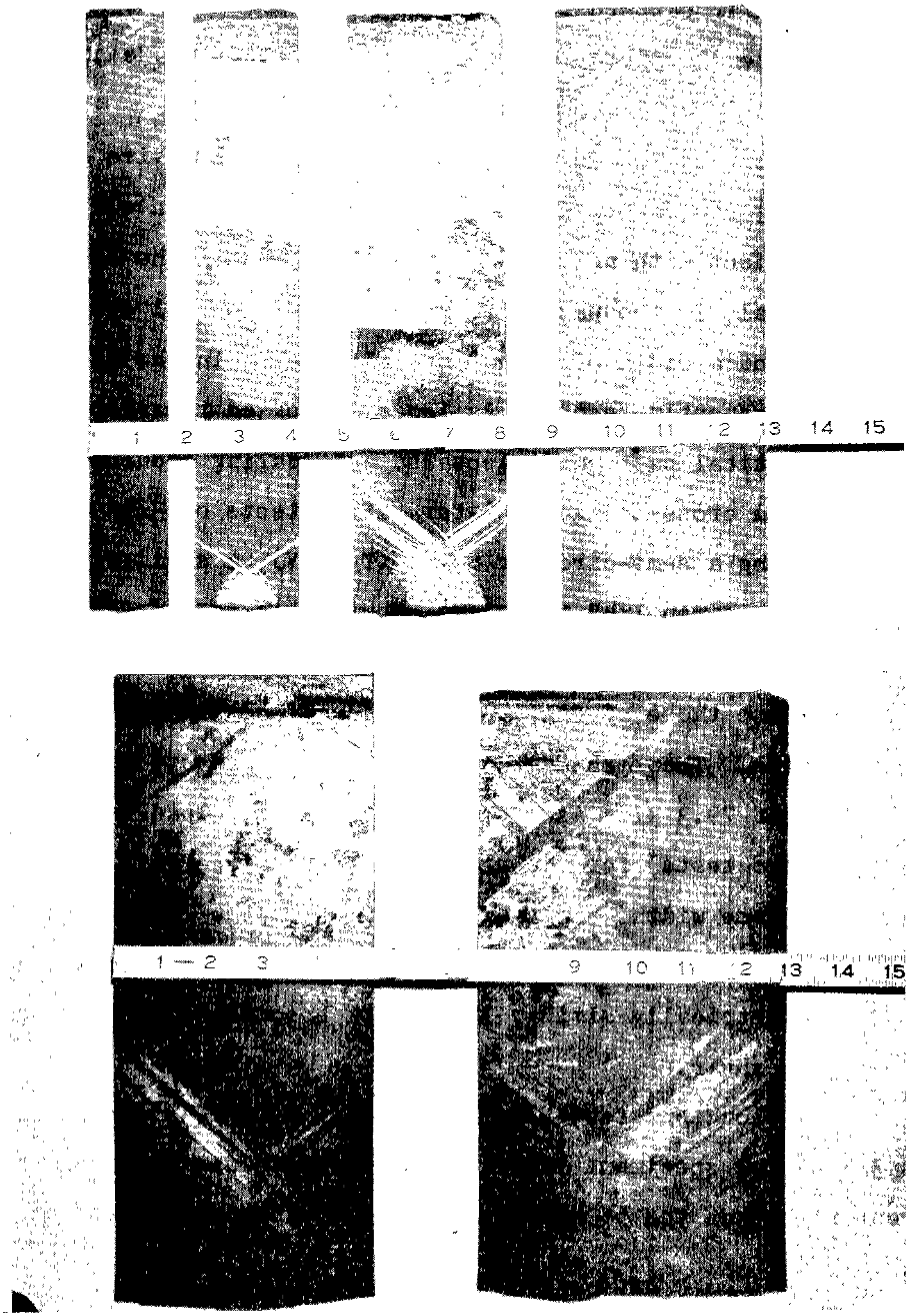
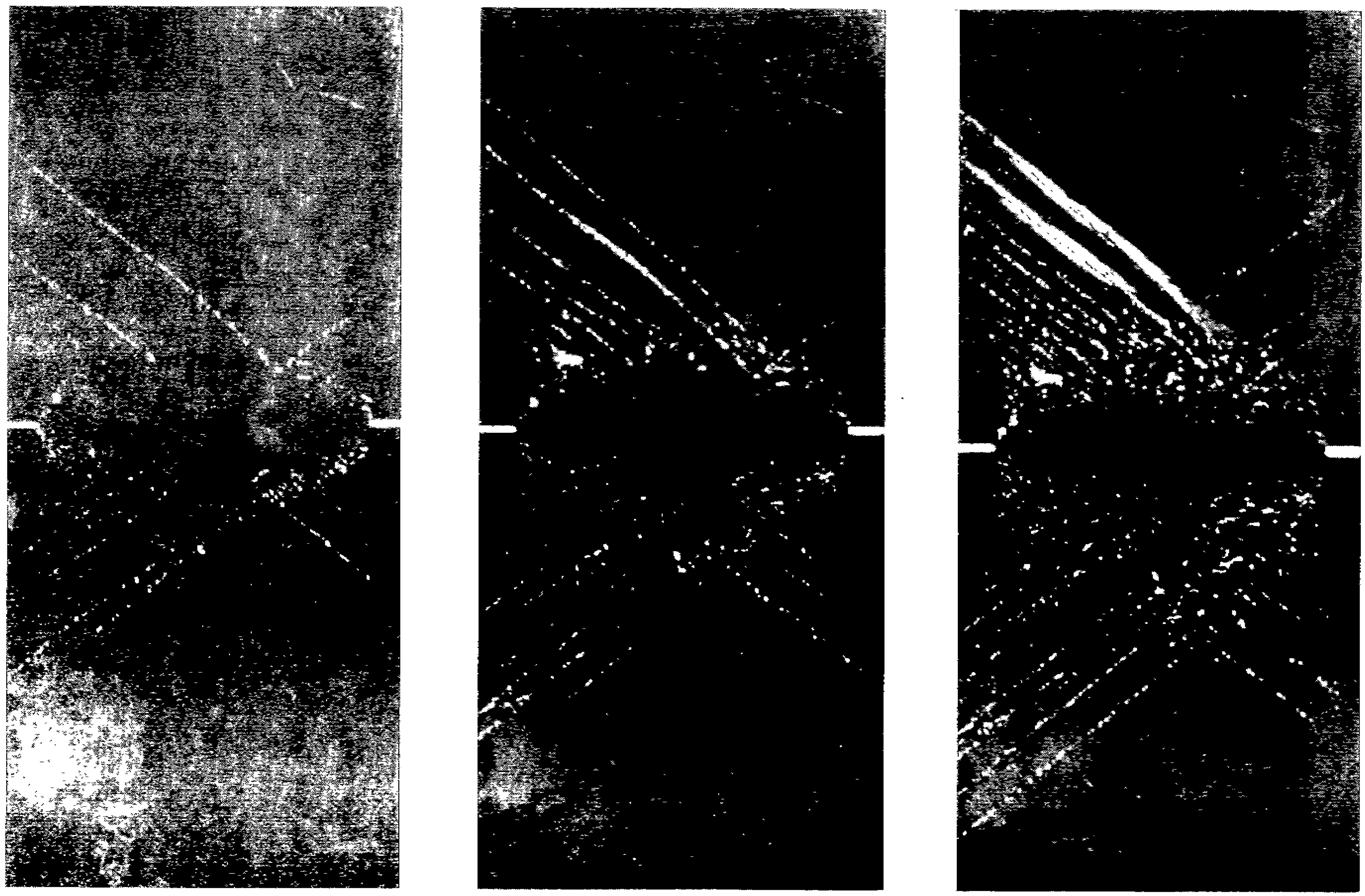


FIG. 3 Scaling Patterns after Fracture of Exploratory Specimens

width the circular pattern is replaced by a diamond pattern with Luder lines extending into the general areas of the plate above and below the notch.

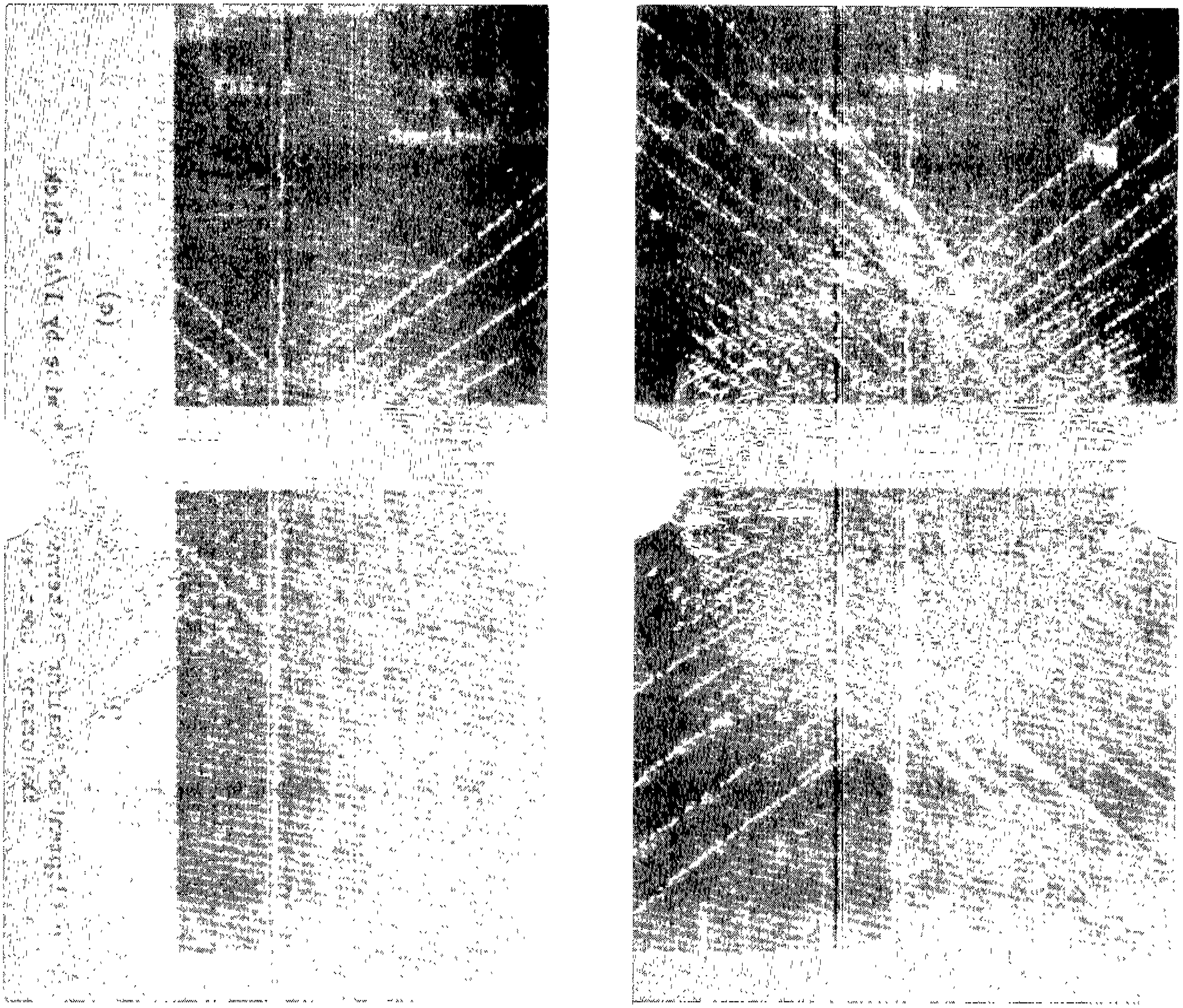
The photographs of Fig. 4 represent the progressive development of scaling for a 5" wide exploratory specimen. An elliptical pattern is evident with an absence of scaling within the ellipse. This, in general, is the pattern of development for all exploratory specimens beyond a width of 3" and was also noted in the 3/4" thick specimens subsequently tested. As loads increased toward the maximum load the elliptical pattern disappeared and scaling occurred throughout the notched cross-section. Later, after tests on 3/4" thick specimens having a semi-circular notch (Type V), a similar exploratory type of specimen 1/4" thick and 5" wide was tested. Photographs of progressive scaling are shown in Fig. 5. Similarity of patterns with those of Fig. 4 may be noted, although they occurred at higher loads. The specimen having semi-circular notches had a maximum load of 79.3 kips as compared to a maximum load of 54.4 kips (average of two tests) for the saw cut square notched exploratory tests of the same width. The maximum loads for the 1/4" thick specimens are in approximately the same ratio as the maximum loads found for geometrically similar 3/4" thick specimens, Types I and V, failing by shear.

The exploratory tests led to a decision to make the subsequent 3/4" thick specimens 15" wide. This width was based on the apparent fact that the 5" width would permit the development of



(a) (b) (c)

FIG. 4 Progressive Development of Scaling Patterns for a 5" wide by 1/4" thick Exploratory Specimen



(a) Load 55^k

(b) Load 59^k

Maximum Load = 75.3^k

FIG. 5 Progressive Development of Scaling Pattern for a 5" wide by 1/4" thick specimen Specimen similar to Type V specimens general yielding in, above, and below the notched cross-section. The 5" width also appears to be a threshold width where specimens wider than 5" would show only slight losses in strength, and where narrower specimens had increased strength and also restricted deformation. The 15" wide by 3/4" thick specimens are accordingly geometrically similar specimens based on the 5" width of the 1/4" thick specimens.

Longitudinal separation of the notches was another variable investigated. An exploratory series of tests were made using 1/4" thick specimens of the type shown in Fig. 1 b. The specimens all had a gross width of 5", the optimum width selected by the previously described exploratory tests. The results are recorded in Table 2. The first notable fact is that the maximum loads exceeded the maximum loads of the saw cut notched specimens of equal width and remained approximately equal as the edge opening, or reduced section increased in length. Visual examinations of scaling indicated the formation of two scaling zones, one at each end of the reduced section, which, with increasing reduced section length, developed into patterns similar to those noted for a series notched at mid-length. For a reduced section length of 4" and greater, two square shaped (horizontal diagonals at notch) scaling patterns, one at each end of the reduced width section developed. At a reduced section length of 5" both patterns were separately distinct and did not overlap. After the formation of these patterns, an increasing load caused general scaling throughout the reduced width.

TABLE 2

Exploratory Tests 1/4" Thick Hot-Rolled Plates
Constant width and variable reduced section length.

Specimen No.	Width, inches Total	Net	Length of reduced section inches	Net Area sq. in.	Yield and Maximum Loads: Yield* lbs.	psi	Yield** lbs.	psi	Maximum lbs.	psi	Energy, in.lbs. to Max.load	to Fracture	Energy reduced section lengths in. lbs.
X 5-1/4	5	4	1/4"	1.1	52,500	47,700	51,000	46,500	63,000	57,000	39,500	52,700	see note
X 5-1/2	5	4	1/2"	1.1	52,000	47,250	55,000	50,000	65,000	59,200	47,000	58,000	
X 5-1	5	4	1	1.1	51,500	46,800	50,500	46,000	65,500	59,500	51,600	61,000	12,200
X 5-2	5	4	2	1.1	51,000	46,500	51,000	46,500	64,500	58,500	48,000	62,000	14,400
X 5-4	5	4	4	1.1	49,500	45,000	51,000	46,500	63,000	57,000	39,500	52,700	21,500
X 5-6	5	4	6	1.1	47,000	42,800	48,500	44,000	62,500	57,000	42,600	------	26,900

* Based on unit strain of 0.2%
** Based on general yielding in reduced section length

Note
Energy in reduced section zone to maximum load.
Value not obtained for 1/4" and 1/2" reduced section lengths.

Specimens
All specimens 24" long

Average specimen thickness 0.275"

The energy to maximum load per cu. in. of volume absorbed within the reduced section lengths is shown on Fig. 6. This energy trend is towards an asymptotic value as the reduced section length is increased. This is largely due to the elimination of notching restraint at the ends of the reduced section. Accordingly, it was reasoned that a reduced section length of 5", i.e., 15" for the 3/4" thick specimen, would reduce notch effects on energy absorption to practically a constant value, and as previously indicated, not affect maximum load capacity.

Figure 7 is a plot of the unit tensile stresses at yield and maximum loads for the specimens having various lengths of reduced section. (Values for a so-called zero length of reduced section were taken from the exploratory tests first discussed.) As the length of reduced section increased, only a small difference was noted between the yield and maximum stresses of the specimens having a section of reduced width and the yield and maximum stresses for an un-notched plate. This indicates that the impairment of load capacity noted for the previous series can be partially eliminated by increasing the distance between notches.

Hence, the exploratory tests led to the adoption of 15" wide specimens of 3/4" thick steel with 15" as the reduced section length for the types involving a separation of the notches.

GEOMETRIC VARIATION PROGRAM WITH 3/4" THICK PLATES

Specimens and Materials

With only one exception the specimens had flame cut edges and

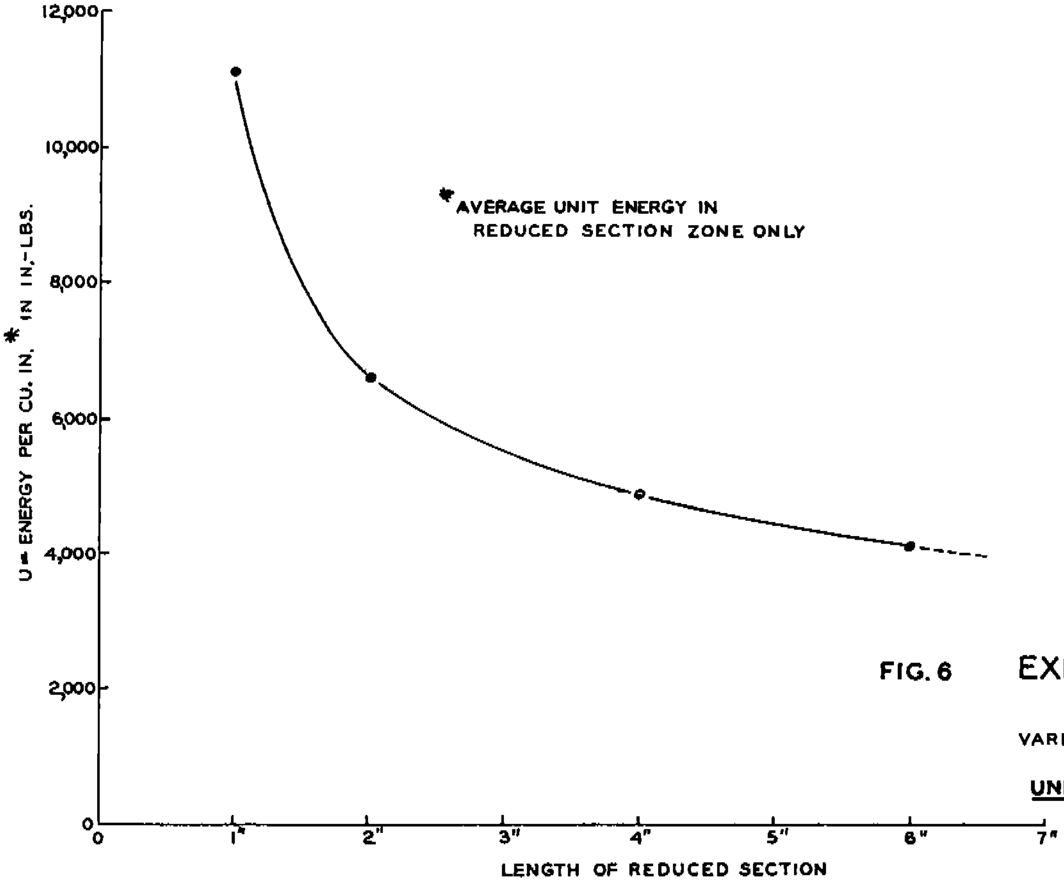


FIG. 6 EXPLORATORY TESTS

CONSTANT WIDTH 5"

VARIABLE REDUCED SECTION LENGTH

UNIT ENERGY TO MAX. LOAD

4-1-50

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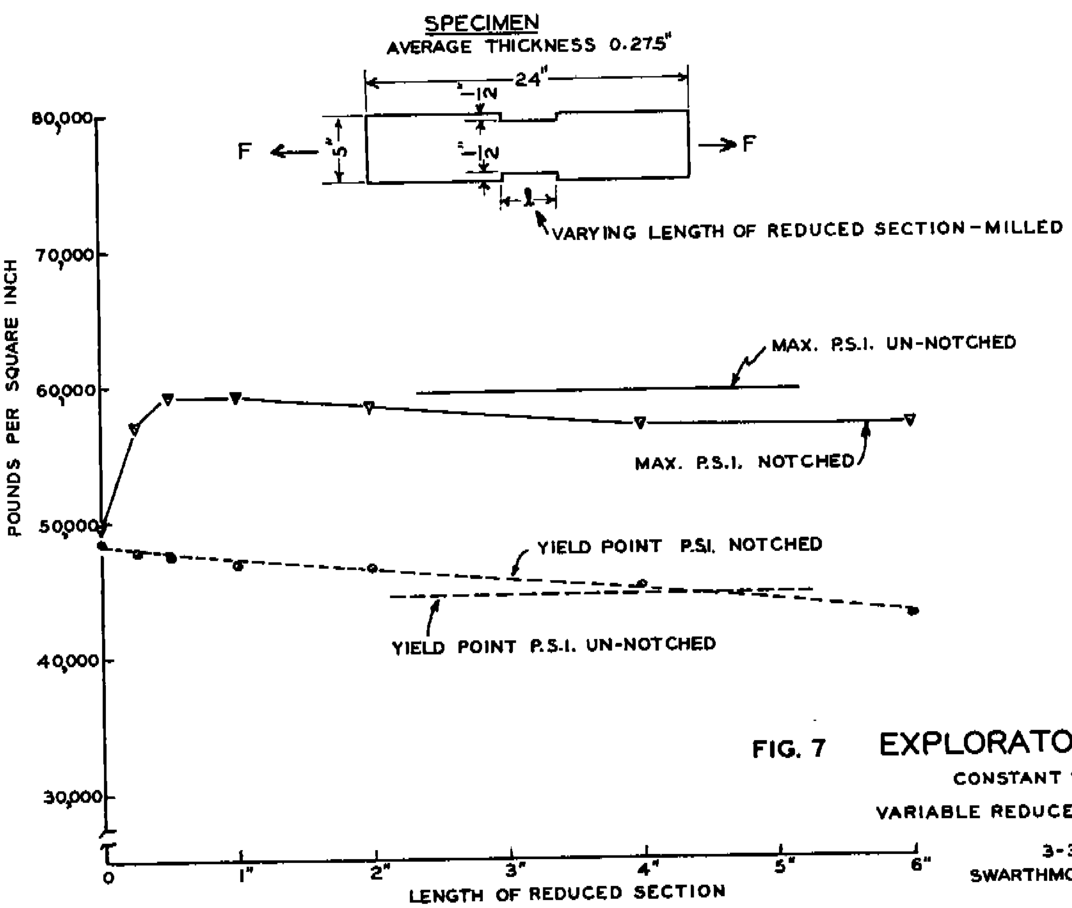


FIG. 7 EXPLORATORY TESTS

CONSTANT WIDTH

VARIABLE REDUCED SECTION LENGTH

3-31-50

SWARTHMORE COLLEGE

flame cut edge notches. The edges and notches all showed the usual burning variations and grooving. Figure 8 is a photograph representing typical edge conditions after burning.

The steel used for all specimens used in the program was a fully killed steel normalized, designated as Dn. Dn steel is fairly uniform in character and has been used in earlier investigations.[1*] The chemical analysis of this steel is, C-0.19, Mn-0.54, Si-0.19, Al-0.019, Ni-0.15.

The geometries of the test specimens are shown in Fig. 9. The types of specimen fall into three categories; (a) Types I, II, III, IV and V with edge notches at the mid-length of the 40" long specimens, (b) Types X-1, X-2, X-3 were edge notched at the extrementies of the 15" long reduced width mid-section of the 40" long specimen, and (c) Type Y, a faired unnotched specimen. All notches were flame cut, except for Type I which had jeweler's hack saw notches.

The specimens were cut from 6' X 10 plates of 3/4" thick Dn steel, with the 40" length in the rolling direction. The plate layouts are shown in Figs. 10 to 16 inclusive, indicating the location of the specimens. Seven plates of steel were used and were given the laboratory notation of plates A,B,C,D,E,F, and G. A test specimen is designated by giving its Type, a letter identifying the 6' X 10' plate from which it was cut, and a number giving its location within the plate. For example, (IIA4) indicates

* Numbers shown as superscripts refer to references listed in the bibliography.

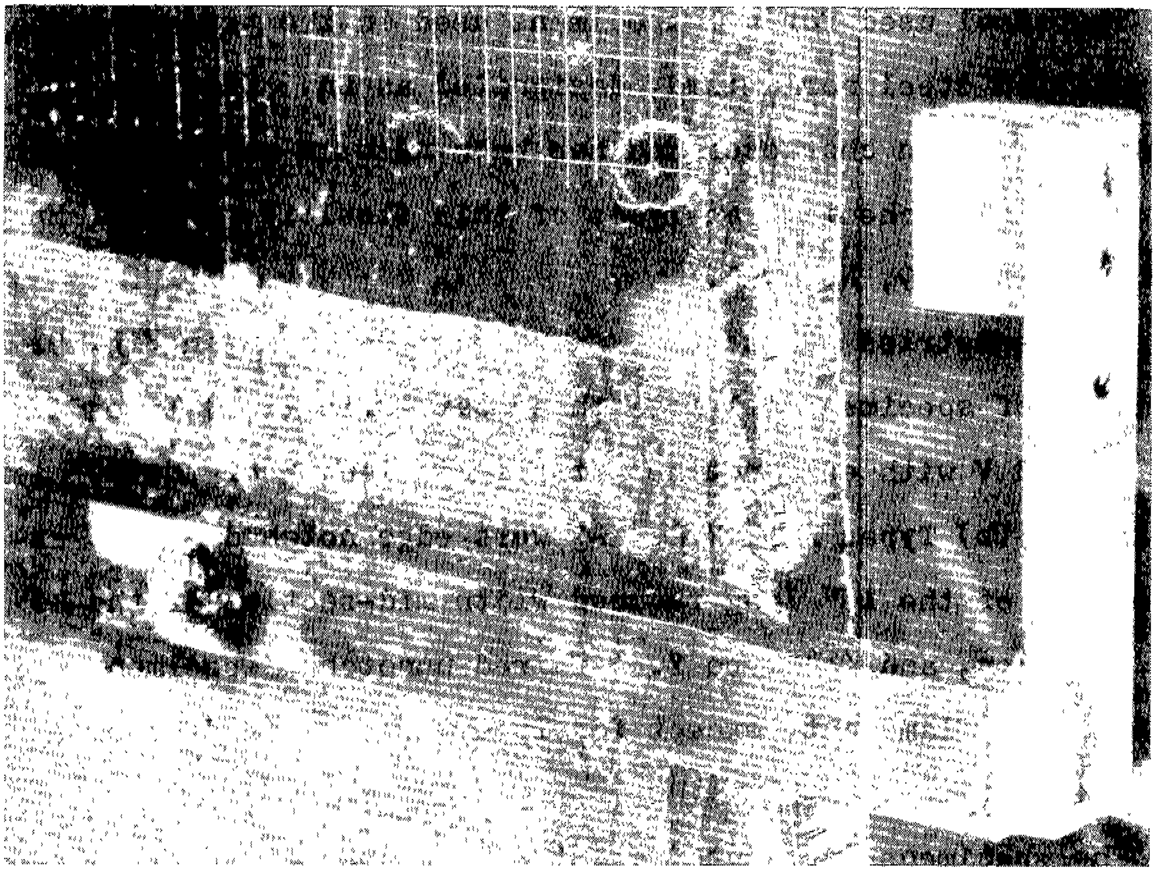
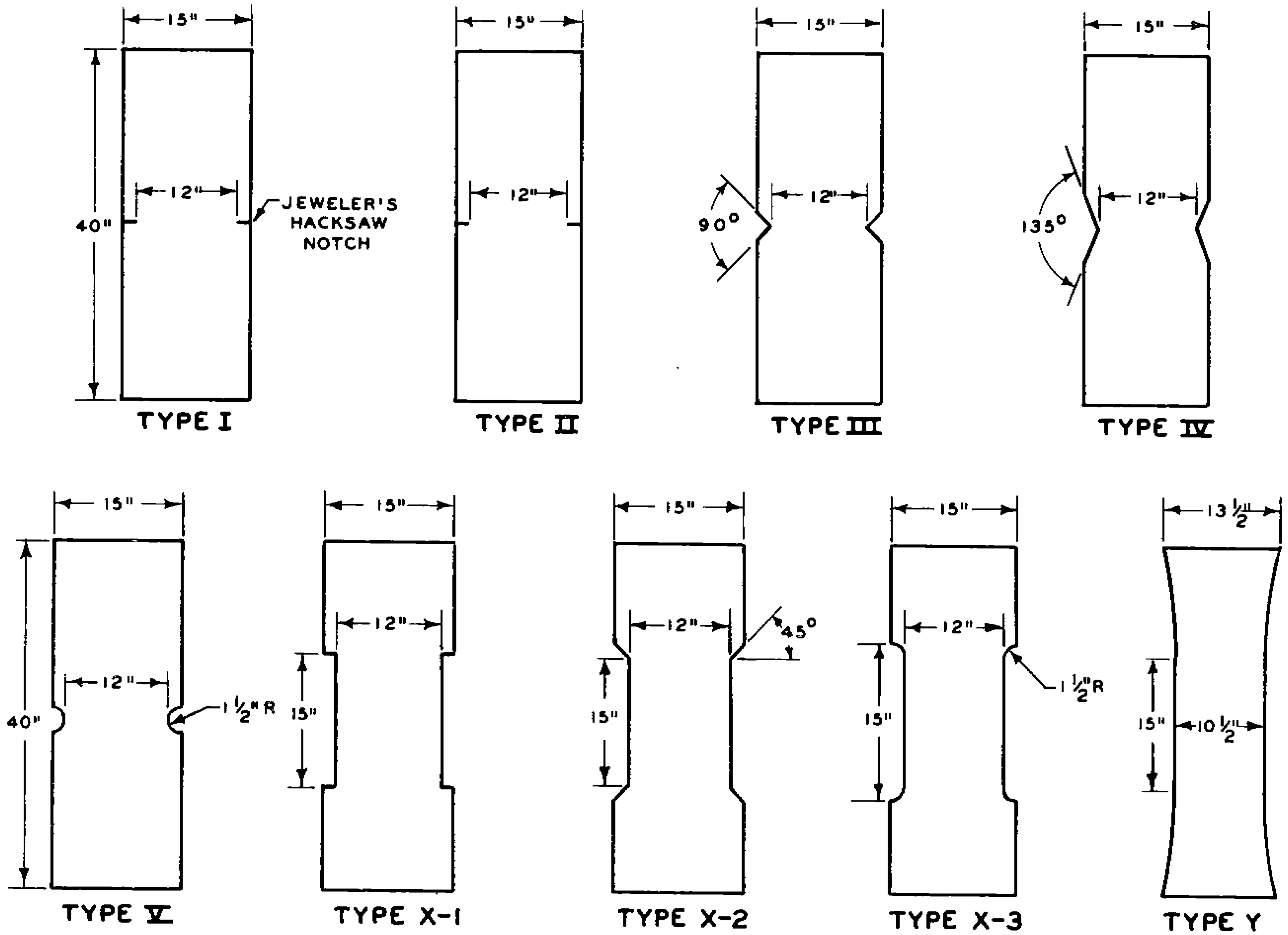


FIG. 8 General Edge Conditions



NOTE:

1. ALL SPECIMENS HAVE FLAME CUT EDGES AND NOTCHES EXCEPT TYPE I.
2. SPECIMENS WERE CUT FROM 3/4" DN STEEL PLATE WITH THE 40" DIMENSION IN THE DIRECTION OF ROLLING.

TYPES OF SPECIMENS

FIG. 9

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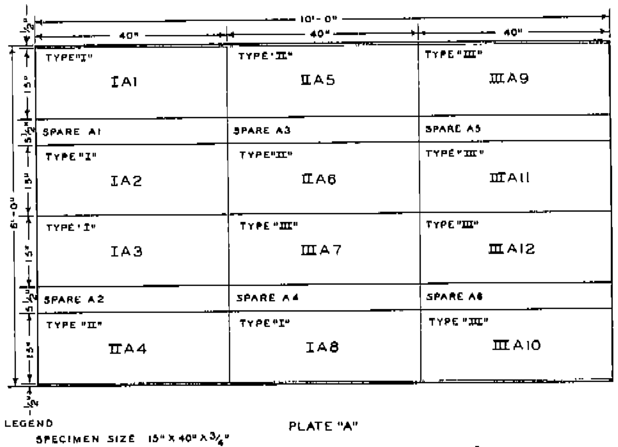

FIG. 10 3/4" DN PLATE LAYOUT

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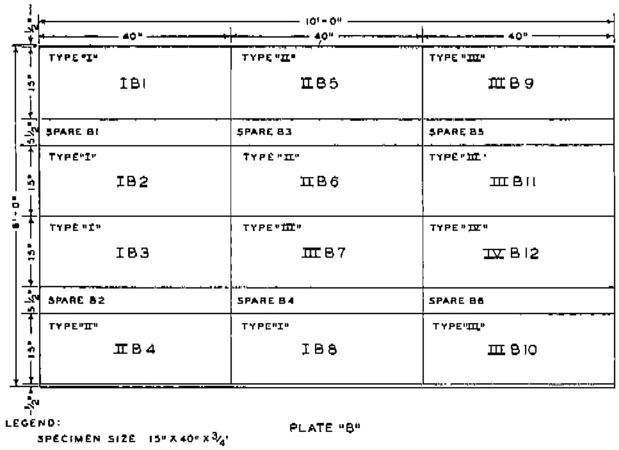

FIG. 11 3/4" DN PLATE LAYOUT

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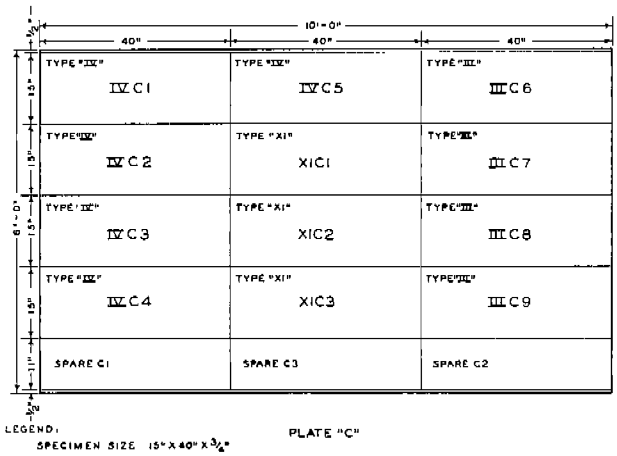

FIG. 12 3/4" DN PLATE LAYOUT

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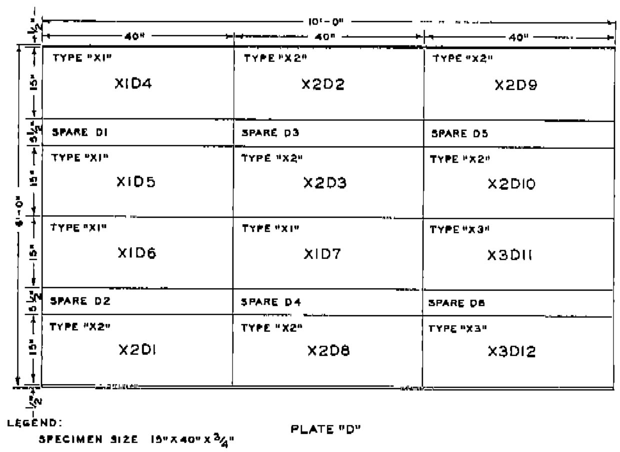

FIG. 13 3/4" DN PLATE LAYOUT

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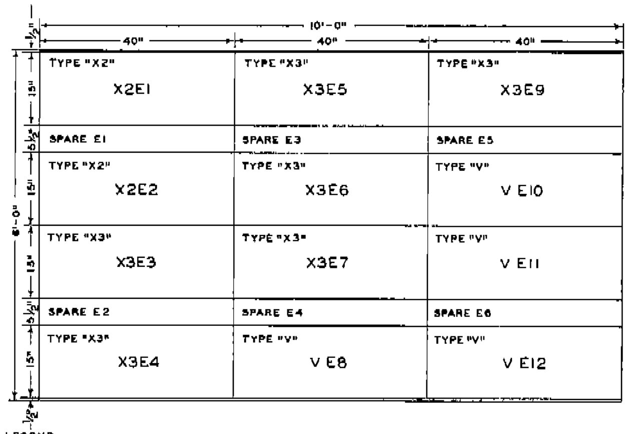
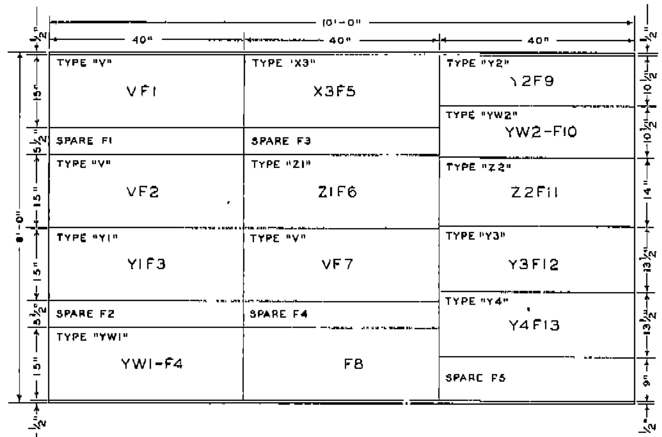


LEGEND
SPECIMEN SIZE 15" X 40" X 3/4"

PLATE "E"

FIG. 14 3/4" DN PLATE LAYOUT



LEGEND
SPECIMEN SIZE AS INDICATED

PLATE "F"

FIG. 15 3/4" DN PLATE LAYOUT

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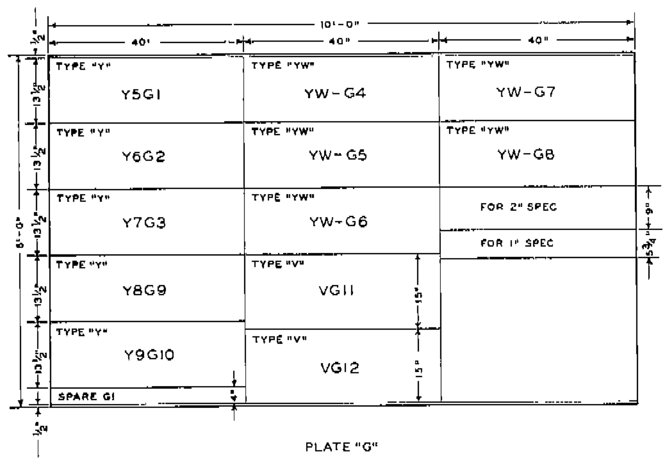

PLATE "G"

FIG. 16 3/4" DN PLATE LAYOUT

a Type II specimen cut from plate "A", location 4.

Figure 17 is a typical arrangement for the specimens. The figure shows a Type I specimen welded to the pulling heads.

To determine the effects of burning on edge and notch hardness, a hardness survey was made using a Rockwell Hardness Tester.

Two samples were saw cut from a fractured Type III specimen. Sample #1 was 1" wide and parallel to a flame cut notch surface, and Sample #2 was 3" long and normal to a flame cut notch surface.

On Sample #1, the average of the hardness readings on the flame cut surface was B-92. On the saw cut surface parallel and 1" from the flame cut surface, the average of the hardness reading was B-70.

On Sample #2, on a saw cut surface normal to a flame cut surface, the hardness reading was B-80 at a distance of 0.1" from the burned surface; at 0.2", the reading was B-76; and from 0.75" to 3" the increased hardness due to flame cutting seemed to vanish.

Since the hardness measurements were made on specimens cut from a strained plate, additional hardness readings were taken on a cut surface of an unstrained Dn steel specimen. The average of these readings was also B-70. The positions from which the hardness survey specimens were cut from the fractured plate were regions of very low unit strain.

Control Tests

The uniformity of the various 6' X 10' plates with regard to

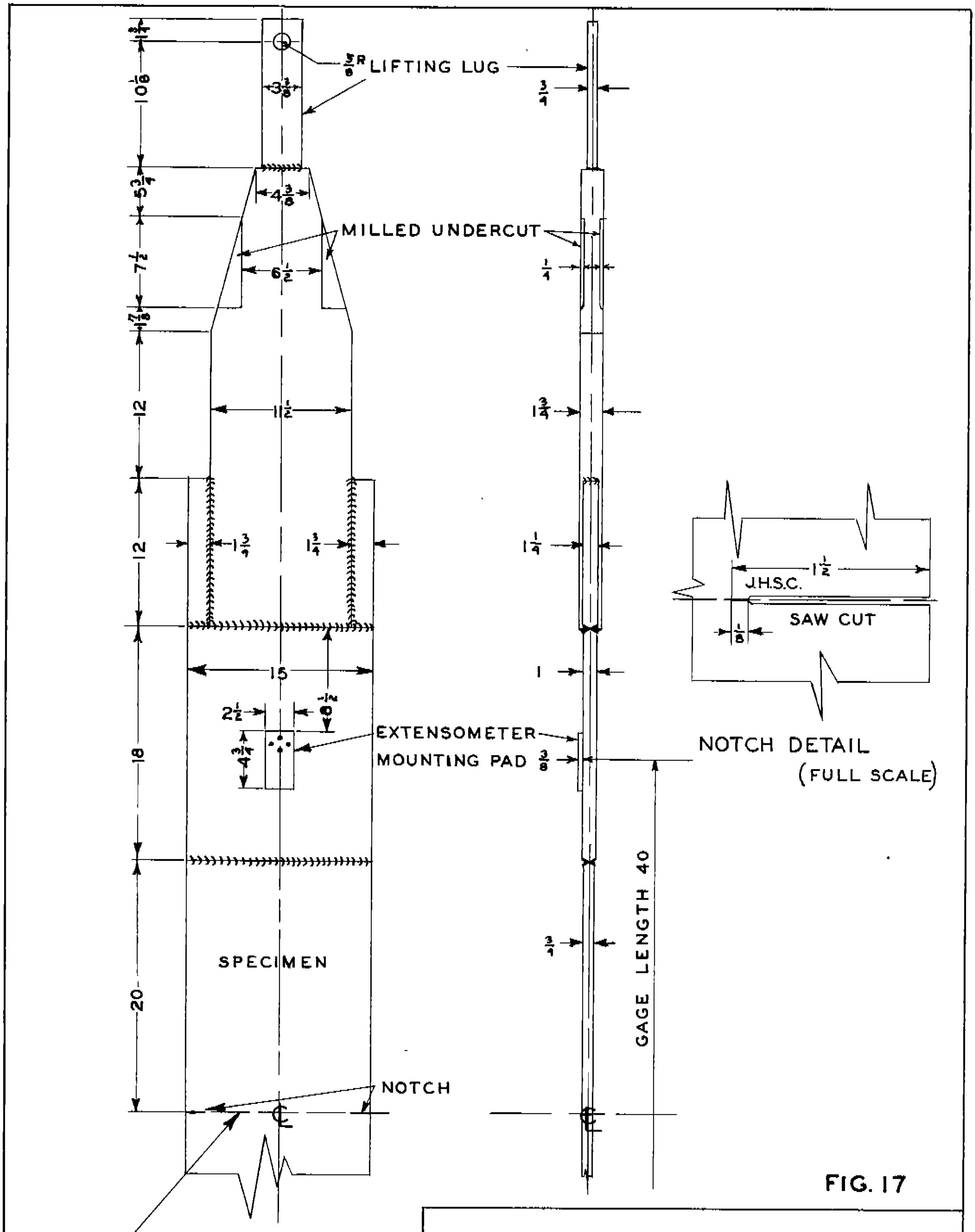

FIG. 17

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$\frac{3}{4}''$ X $15''$ X $40''$ SPECIMEN ARRANGEMENT

SCALE: $\frac{3}{32}'' = 1''$ ALL DIMENSIONS IN INCHES

DRAWN BY: *John Calvin* 16 MAY 1950

temperature sensitivity was checked by the use of the small edge notched tensile specimens shown in Fig. 18. The test specimens were loaded to 15,000 lbs. in one minute, and the temperature read at that load. The reduction in thickness at the notch after fracture was obtained and the plot of these reductions against temperature is also shown in Fig. 18. Although scattering of the results is apparent, the separate plates were deemed to be essentially uniform in notch sensitivity. It is to be noted that control specimens were also tested from a remnant of plate No. 33. This plate was of Dn steel and was used in Contract NObs-45521, which dealt with 12" wide internally notched specimens. The control tests indicate that this plate was quite similar to the plates used in the present program.

Elongation Measurements

The elongations of the test specimens with an increasing tensile loading were measured on two gage lengths, $16\frac{1}{2}$" and 40".

A modified clip gage utilizing two SR-4 bonded bakelite gages measured the elongations on the $16\frac{1}{2}$" gage length. The gage length was symmetrically located with respect to the mid-length of the specimen. Four such gages were used on one face of the specimen. The $16\frac{1}{2}$" gage length was adopted so that all or nearly all of the localized elongation of the specimen at the notch might be included.

The measurement of elongations on the 40" gage length was accomplished by using a spool extensometer. Although the terminal points of the extensometer mountings were placed on the pulling heads,

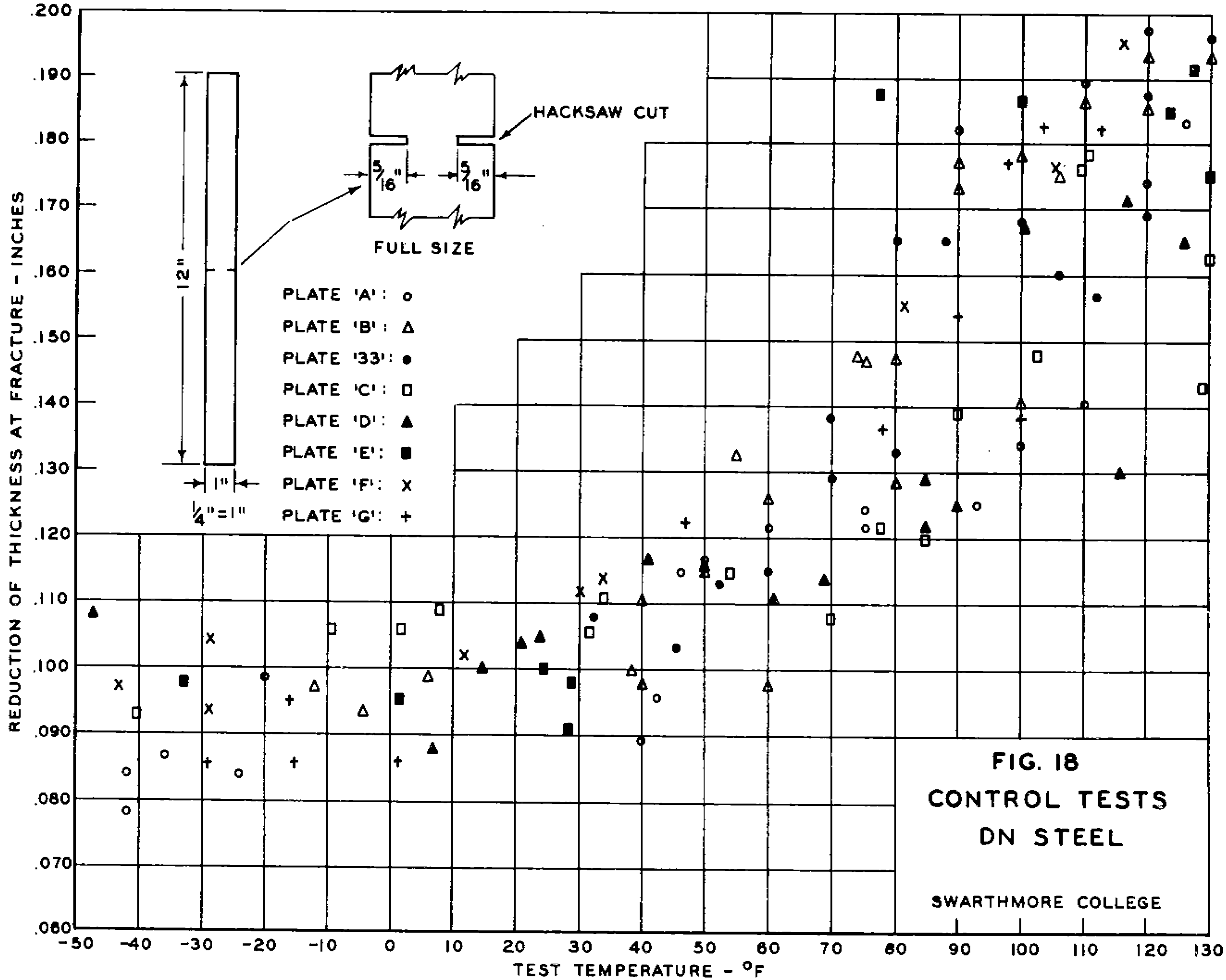

FIG. 18
CONTROL TESTS
DN STEEL

SWARTHMORE COLLEGE

see Fig. 17, making a length between attachments greater than 40", the measured elongations were attributed, in view of the thick head plates, to the test specimen alone. These elongations were read to the nearest 0.005". Figure 19 is a photograph of a type III specimen with slip gages and spool extensometer attached.

Temperature Control

The entire specimen was surrounded with an insulated temperature control chamber with Plexiglass windows. Below room temperatures were obtained by blowing air over dry ice placed in a separate box and circulating the cooled air into and through the chamber. Above room temperatures were obtained by placing electric strip heaters inside the chamber. Two thermocouples were placed on each specimen near the notch to measure the temperature of the steel.

Test Data

The detailed load elongation diagrams for each specimen are given in Appendix "C". The data, including temperature, loads, energy, character of the fracture and elongations, are summarized in Tables 1-A to 9-A, inclusive of Appendix "A". The loads are tabulated for three points on the loading curve: (a) the load at which a visible crack was noted at the notch or edge of specimen; (b) the maximum load observed; (c) the load at complete fracture. The energies absorbed (areas under load-elongation curves) are given for the three loads for both the $16\frac{1}{2}$" and 40" gage lengths.

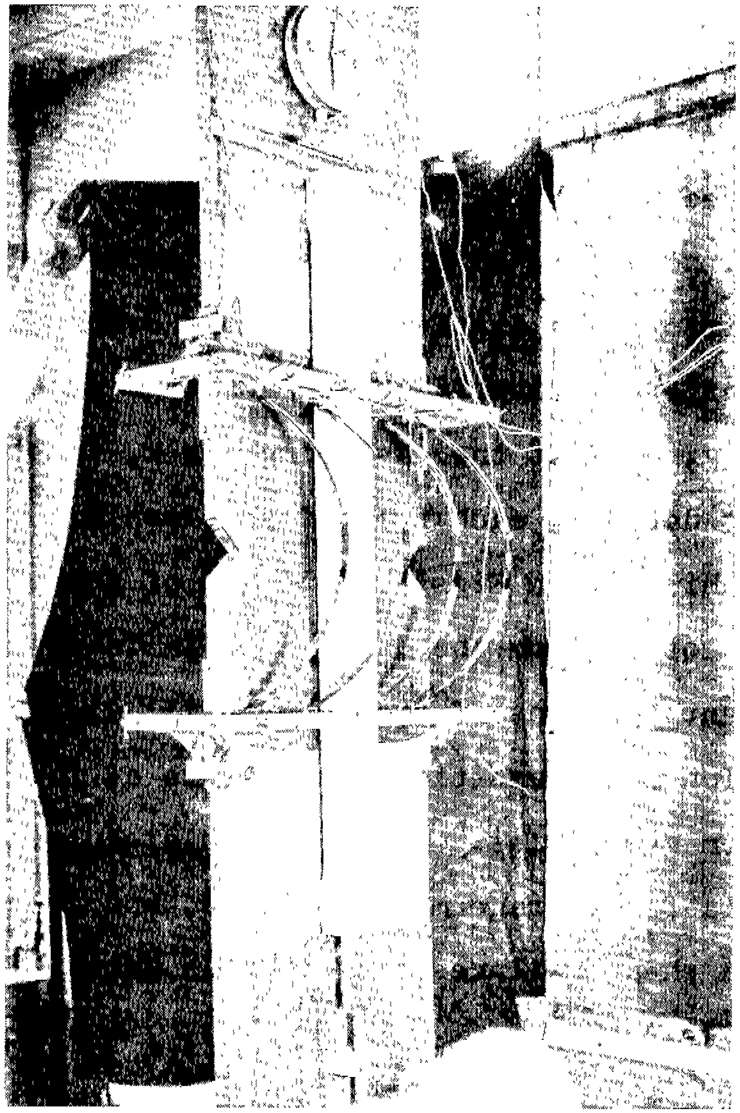

FIG. 19 Type III Specimen with Clip Gages and Spool Extensometer Attached

Elongations of the specimens for both gage lengths are recorded for the maximum and fracture loads. The character of the fracture is stated as a percentage of the fracture surface exhibiting a shear failure. A specimen failing completely in the cleavage mode is designated by 0% shear. All fractures occurred at the notched cross-sections.

The load necessary to establish a visible crack was considered to be important, as after a visible crack has been established the effect of initial notch acuity is probably minimized and a new acuity, that of the advancing crack, substituted.

The test data for each type of specimen has also been summarized graphically in Figs. 1-B to 9-B of Appendix "B". These summaries are plotted from the data given in Tables 1-A to 9-A.

Subsequent sections of the report will discuss strength, energy absorption and transition temperature as found for the various specimen geometries. As an aid in discussing overall effects the data for average maximum loads, and average energy for 100% and 0% shear failures are given in Table 3 and graphically summarized in Fig. 20.

DISCUSSION OF TEST RESULTS

Stresses at Visible Crack

With all notched specimens, the first visible evidence of fracture showed as a small crack in the root of the notch at the mid-thickness of the plate. As the load was increased, the crack opened slightly, deepened, and extended towards the edges of the plate. The crack reached the edge and "rounded" the corners

TABLE 3

SUMMARY OF RESULTS OF WIDE PLATE Dn STEEL SERIES WITH NO WELDMENT

Type	Transition Temp, °F Based on Fracture Appearance	Ave. Load to Visible Crack		Ave. Max Load-kips		Ave. Energy to Max. Load - inch kips $16\frac{1}{2}$" gage length		Ave. Energy to Max. Load - inch kips 40" gage length		Remarks
		100% Shear Failures	0% Shear Failures	100% Shear Failures	0% Shear Failures	100% Shear Failures	0% Shear Failures	100% Shear Failures	0% Shear Failures	
I	42	377(4)	374(3)	443(4)*	387(3)	242(4)	92(3)	420(4)	112(3)	Edges Burned; Notches Jeweler's Hack Saw Cut
II	39	373(3)	381(2)	448(3)	397(3)	230(3)	92(3)	410(3)	92(3)	Edges & Notches Burned
III	53	371(2)	374(5)	455(2)	425(5)	255(2)	118(5)	432(2)	215(5)	" " " "
IV	48	381(3)	383(3)	508(2)	438(3)	295(2)	135(3)	558(2)	262(3)	" " " "
V	25	416(4)	426(4)	590(4)	586(3)	658(3)	591(3)	1145(4)	1109(3)	" " " "
X-1	42	368(4)	411(1)	502(4)	445(3)	510(4)	255(3)	791(4)	390(3)	" " " "
X-2	52	371(5)	369(4)	508(5)	488(3)	425(5)	378(3)	742(5)	677(3)	" " " "
X-3	42	415(3)	387(3)	563(3)	553(3)	951(3)	851(3)	1505(3)	1264(3)	" " " "
Y	25			580(2)	600(6)	2190(2)	1790(6)	3190(2)	2930(6)	Net Width $10\frac{1}{2}$"; Values Inflated to Correspond to 12" Net Width.

* Numbers in parentheses indicate the number of tests included in the average.

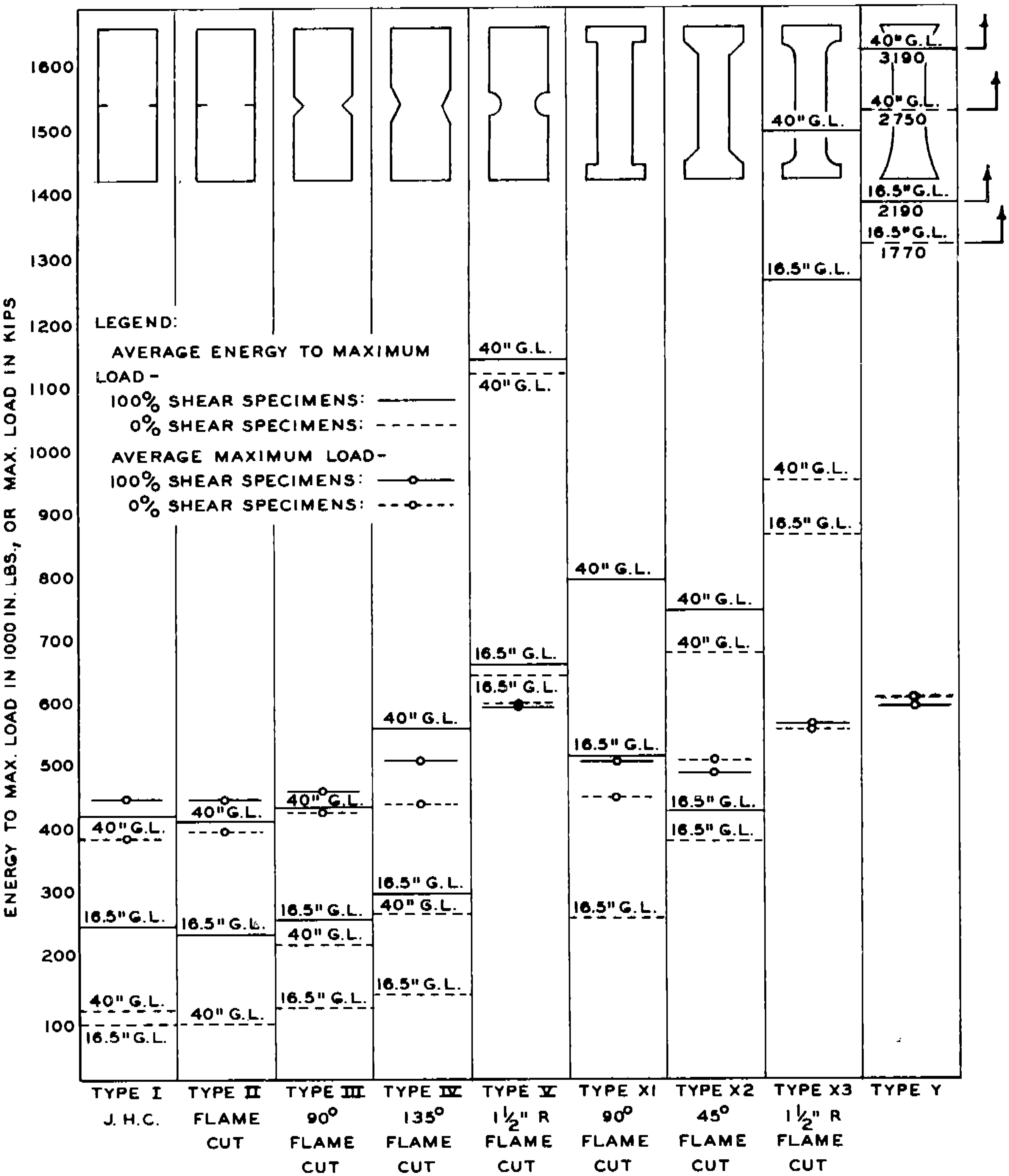

FIG. 20 SUMMARY OF AVERAGE ENERGY AND LOAD VALUES

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to the faces immediately prior to maximum load.

The loads at which the first crack became visible were recorded and are tabulated in Tables 1-A through 9-A. The unit tensile stress at the first visible crack on the 15" wide sections above and below the notches for all types of specimens, except types V, X-3, and Y, was approximately 33.5 k.s.i. On the 12" wide reduced section, at the notch, the unit tensile stress was about 41.0 k.s.i. For specimens exhibiting 0% shear failures, the unit stresses at visible crack are in substantial agreement with those for specimens exhibiting 100% shear failures.

Types V and X-3 are not in close agreement with the types just considered. For both of these types, the unit tensile stress at visible crack was about 37.8 k.s.i. on the 15" wide sections, and 46.1 k.s.i. on the 12" wide sections.

It appears from these data that the stresses at the visible crack are relatively independent of the test temperature, and independent of the mode of subsequent fracture. Some scattering of these data is evident, but since the determination of the crack was by visual inspection, it is expected that a certain amount of scatter would be present.

Maximum Tensile Strength

The results for Types I, II, III, IV and V, specimens having edge notches at their mid-lengths, indicate that Type V with semi-circular notches is superior in load carrying capacity. The load capacity of Types I and II are about the same although I had a jeweler's hack saw notch and II a burned notch. Type V shows a load improvement of 32% over Types I and II for 100% shear failures and 52% for 0% shear failures. Types III and IV with vee-type notches also show a slight improvement in load capacity as compared with Type I.

The results for Types X-1 and X-2 with the 15" long reduced width sections terminating in end notches indicate a general imprvement in load capacity over their edge notched counterparts represented by Types II and III. However, a comparison of Types X-3 and V indicates V as slightly better.

Increasing the angle of the notches improved the strength of specimens notched at mid-section. The less acute the notch the greater the load improvement for specimens failing in 0% shear. (See Table 3). In fact, for Types V and X-3, each having a notch burned to a radius, the average maximum loads for either shear or cleavage failures are essentially the same.

The average unit stress at maximum load for the individual specimens of various types with varying temperature are compared in Figs. 21 and 22. Also, on Figs. 21 and 22 the maximum unit stresses have been plotted for 3/4" square un-notched tensile bars of Dn steel. These data agree with those on .505" diameter tensile bars presented in the Final Report[2] of the University of Illinois. Figure 21 also shows the results obtained by the University of California[3] for 3" wide, 3/4" thick edge notched specimens of Dn steel.

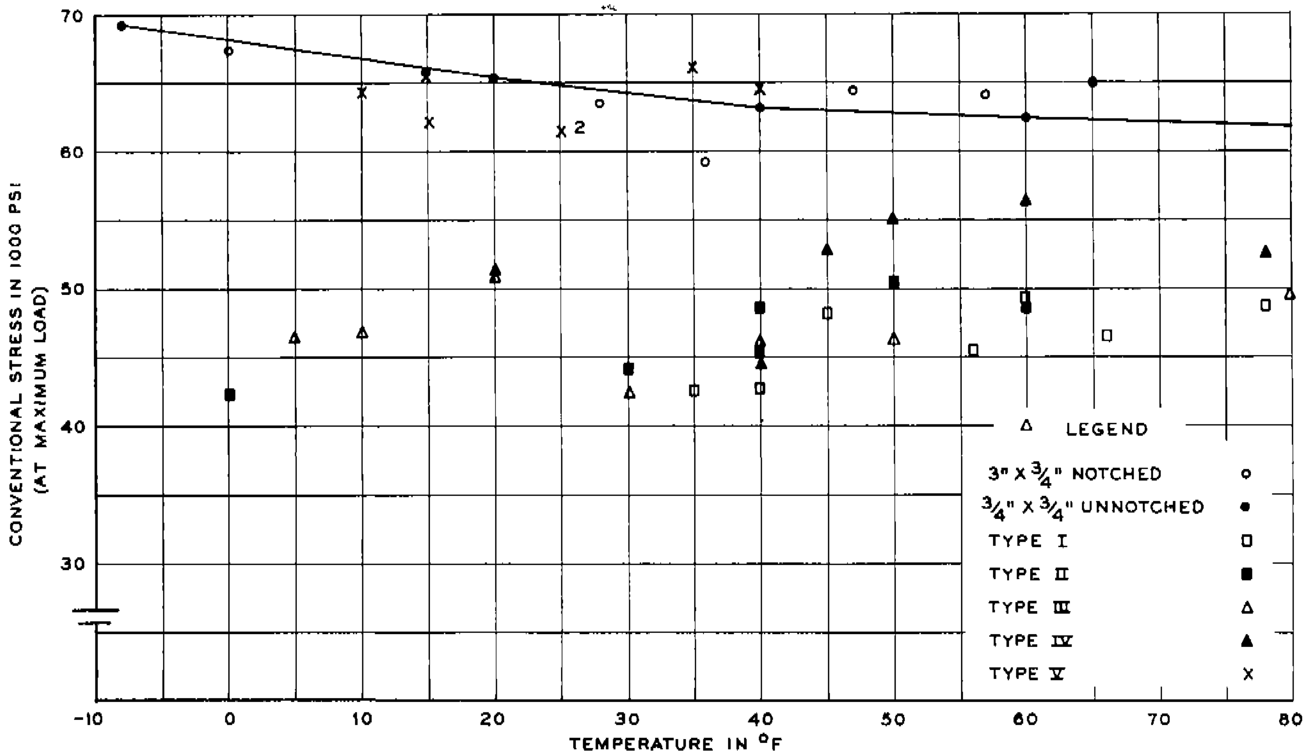

FIG. 21 RELATIONSHIPS BETWEEN ULTIMATE TENSILE STRENGTH AND TEMPERATURE

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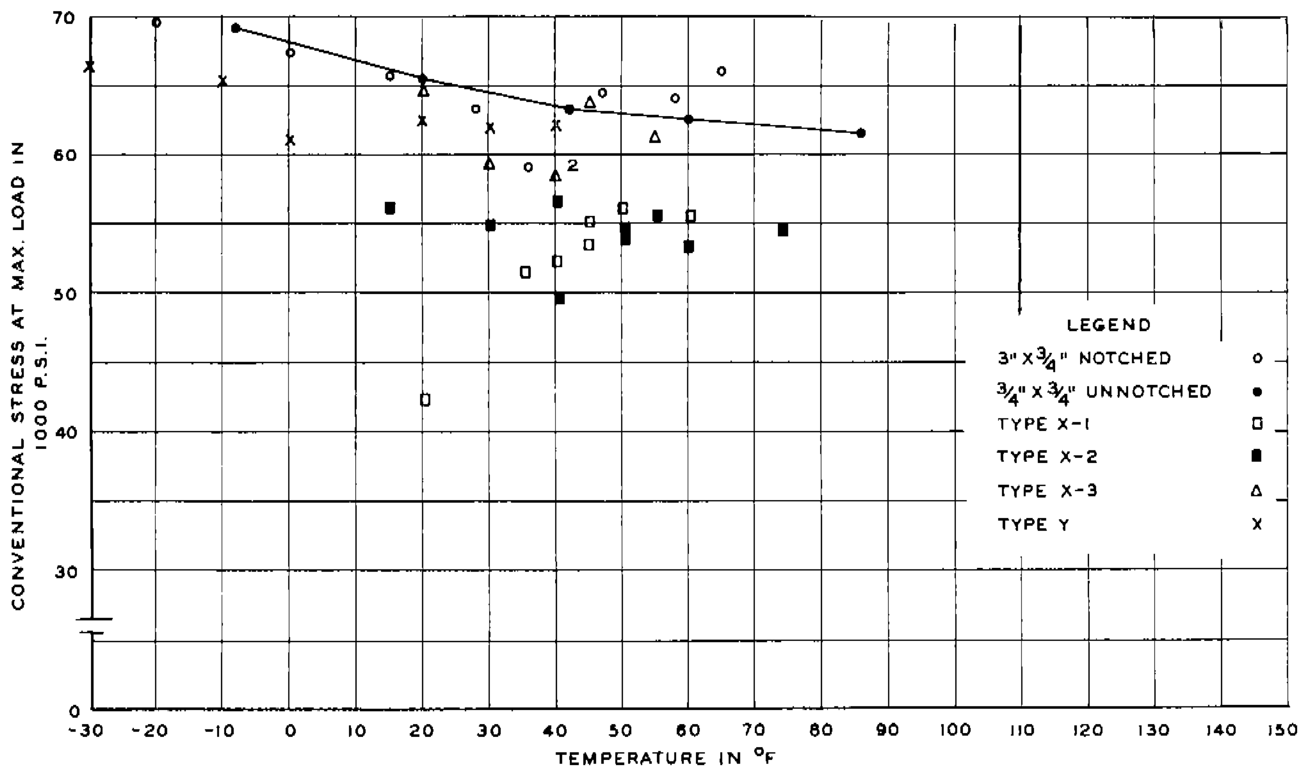

FIG. 22 RELATIONSHIPS BETWEEN ULTIMATE TENSILE STRENGTH AND TEMPERATURE

Standard tensile bars show an increase in the ultimate stress as temperature decreases. The 3" wide tests follow this trend, with a discernable drop in value in the region where the transition from shear to cleavage fracture occurs. Notch effects prevent the ultimate strength of the various 15" wide Types tested from rising to the "par level" for the unnotched specimens.

The Type Y specimens also show an increase in maximum tensile stress when test temperatures are lowered, except for a drop in value in the transition temperature range. However, the maximum tensile strength values are from 3 to 5 k.s.i. lower than those for the 3/4" square unnotched specimens. Since previous investigators[3] have shown that maximum tensile strength of unnotched specimens is little affected by specimen size, these lower values for the unnotched Type Y series may be the result of edge hardness and edge grooving due to burning. It should be noted too, that the 3/4" unnotched square specimens did not show a transition from shear to cleavage modes of failure in the range of test temperatures.

Specimens of the Type V series failing in the shear mode exceeded the "par level" of maximum tensile stress established by the 3/4" square unnotched specimens by 1 to 2 k.s.i. For specimens of the Type V series which failed in the cleavage mode, the maximum tensile strengths were 3 to 4 k.s.i. lower than the "par level". There was a tendency for the specimens of the Type V series to show increasing values of maximum tensile strength as test temperatures were lowered.

To determine the effect of the edge and notch grooving due to burning, one specimen of Type V was prepared with the notch surfaces ground smooth. This specimen was tested at $0^{\circ}F$, $25^{\circ}F$ lower than the transition temperature for the Type V series. The specimen did not fail at 616 kips, the capacity of the testing machine. This was 8 kips higher than the maximum load on any previous Type V specimen. The 616 Kip load produced an average unit stress equal to the unit stress on the "par level" at $0^{\circ}F$.

A comparison of Type I and the California 3" wide specimens is possible since each had square saw cut notches. Previous investigations[2,3] have shown that for internally notched wide plates maximum unit stress is reduced by increasing width while maintaining a constant thickness. These findings probably account for the difference in maximum tensile stresses between the 3" wide specimens and Type I.

Energy to Visible Crack

The energy absorbed by the test specimens to visible crack was calculated for all types except type Y. These energies are tabulated in Tables 1-A through 9-A for energies absorbed in the $16\frac{1}{2}$ and 40 in. gage lengths.

For all specimens of types X-1, X-2, X-3, the elongations to visible crack and the energies to visible crack are greater than for their centrally notched counter-parts on both the $16\frac{1}{2}$" and 40" gage lengths. It was shown in a preceding section that for all types of specimens except types X-3 and V that the average unit stress on the 15" width of specimens was 33.8 k.s.i. and on the 12" width, 41.2 k.s.i. Since a greater proportion of the lengths of the X-1, X-2 and X-3 Type of specimen are subjected to the higher stress, it is to be expected that the elongations would be greater. These increased elongations are reflected in higher energies to the visible crack load. The average energies to the visible crack load are tabulated for all specimens in the Tables of Appendix A.

Energy to Maximum Load

Energy absorption to maximum load, averaged separately for 100% or 0% shear fractures is given for all Types in Table 3. Specimen Types I to IV inclusive absorbed less energy than Types V, X-1, X-2, and X-3. This is true for either the shear or cleavage modes of failure. The above general statements are equally true for the average energy determinations for both the $16\frac{1}{2}$" and 40" gage lengths.

The average energies to maximum load as given in Table 3 may be misleading. Whereas, it has been generally expected that energy would decrease for cleavage fracture and generally be lower than the energy found in the shear mode, such has not always been the case. Two factors, load and elongation, enter the determination of energy. The maximum loads for certain of the Types were greater in the cleavage than in the shear mode, and it was not unusual for elongations to be greater also. Broadly, a trend toward a decrease in energy for the cleavage mode was significant only for Types I to IV inclusive, and X-I. For the other types, values for single test specimens generally show that energy in the cleavage mode can be as great or greater than in the shear mode. (See Figs. 1-B to 9-B.)

There is little question but that the separation of the edge notches by the 15" slot length improves energy absorption. Increased loads and increased elongations are each contributing to this improvement. This can also be physically explained by the formation of two regions of high plastic strain, one at each end of the slotted length, rather than the single plastic region developed when notches are at the mid-length only.

Energy to Fracture

Values for energy to complete fracture were calculated and are tabulated in Tables 1-A through 9-A, and are shown graphically in Figs. 23 through 25.

Energies to fracture for specimens failing in the cleavage mode are equal to the energy to maximum load. The values of energy to fracture for specimens failing partly or totally in the shear mode were greater than the energies to maximum load. The values for the shear mode depended upon the readable elongations after maximum load.

There was a general trend for the loads at fracture, for specimens exhibiting 100% shear fracture surfaces, to increase as temperatures were lowered. In a few instances (Y-F12, X1-C3,) specimens tested near the transition temperature failed suddenly at the maximum load but still exhibited 100% shear fracture surfaces. The test temperature at which single specimens absorbed the greatest energy to fracture was 5° to $10^{\circ}F$ above the transition temperature for all types. (See Figs. 23 through 25). At higher temperatures there was marked tendency for the energies to be somewhat less than this value. At lower temperatures, within the transition zone from shear to cleavage modes of failure, there was a considerable drop in

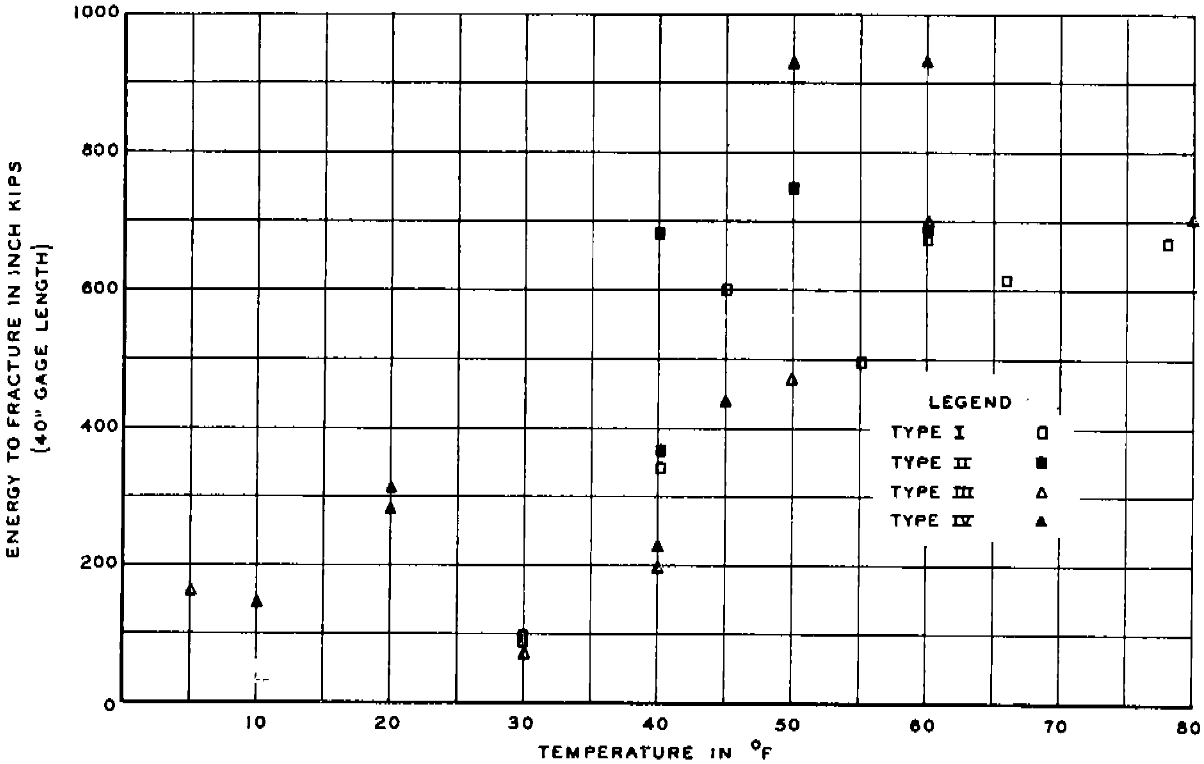

FIG. 23 RELATIONSHIP BETWEEN ENERGY TO FRACTURE AND TEST TEMPERATURE OF NOTCHED EDGE SPECIMENS

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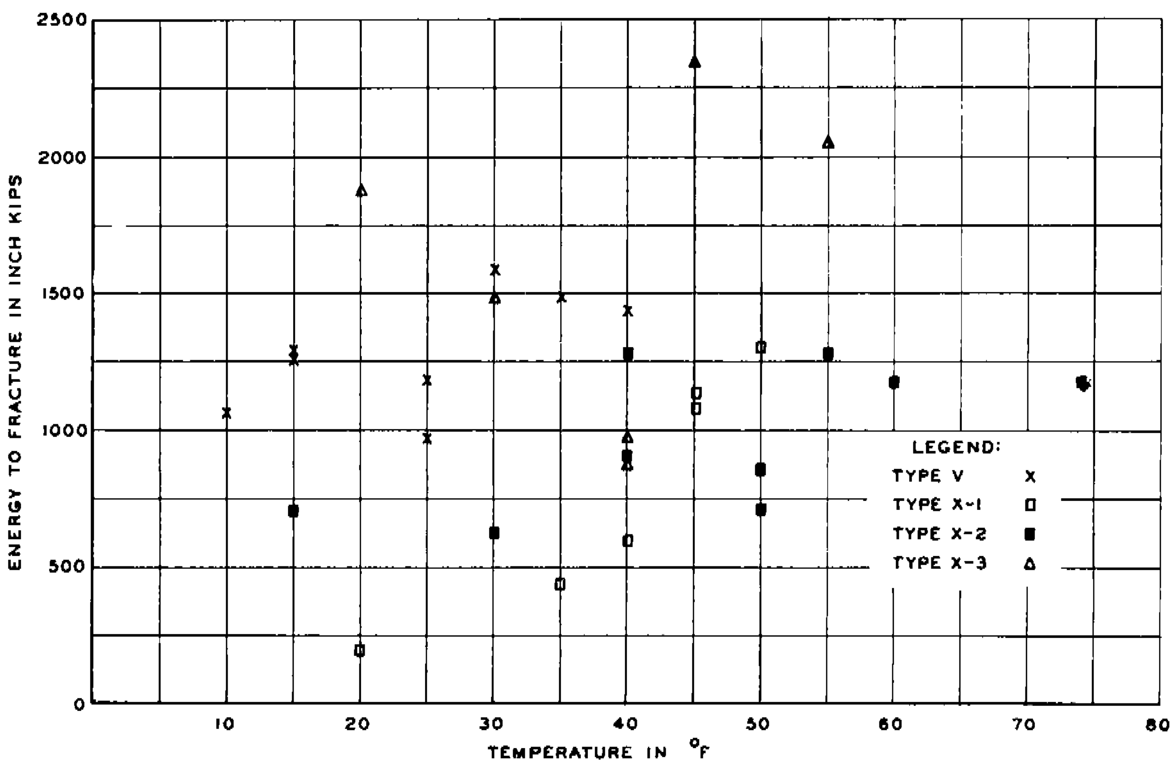

FIG. 24 RELATIONSHIP BETWEEN ENERGY TO FRACTURE AND TEST TEMPERATURE OF NOTCHED EDGE SPECIMENS

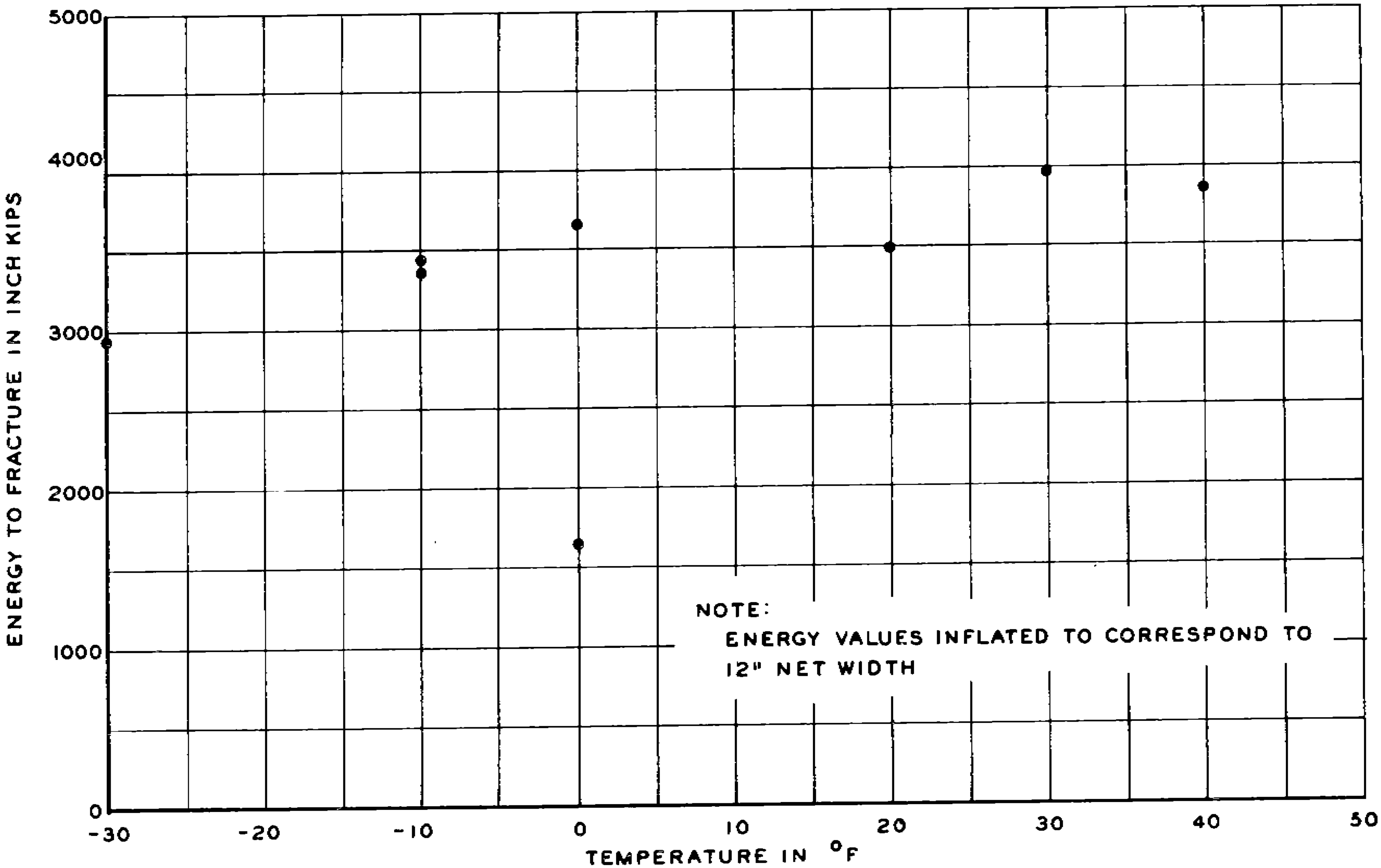

FIG. 25 RELATIONSHIP BETWEEN ENERGY TO FRACTURE AND TEST TEMPERATURE FOR UNNOTCHED TYPE "Y" SPECIMENS

the energy values. The energies remained low on further lowering of test temperatures, except for Types III, X-2, X-3, and V. The results for these types indicated a tendency for the energies to rise again to some higher level. However, it cannot be established from the limited data available whether this represents scatter or a natural phenomenon.

None of the notched specimens were capable of absorbing as much energy as the unnotched Type Y, when the values for that specimen were expanded to correspond to 12" width, the net width of the other specimens. The closest approach to Type Y were the specimens of the X-3 series. The average energy to fracture for these specimens was about 55% of the average of Type Y. The specimens of the Type I series absorbed an average energy to fracture which was about 15% of the average value for Type Y. All centrally notched types exhibited average energies to fracture which were less than 20% of the average value for Type Y, with the single exception of Type V which was about 40% of the average Type Y value.

As in the case of the average unit stress and energy to visible crack, the energies to fracture for the X-1, X-2, X-3 types were higher than the energies for their centrally notched counterparts.

Transition Temperatures

Transition temperatures for all types are summarized in Table 4. They have been determined as single values of temperature and as temperature ranges.

The basis for selecting single values of transition temperature is as follows: The mid-value between maximum and minimum values of percent of shear, or energy to maximum load, or energy to fracture, where the latter quantities were separately plotted against temperature, was first located. An intersection of the mid-value line with the curve in question determined the single value of temperature defined as transition temperature. Transition temperature ranges were determined as the temperature zone within which there was a likelihood of an abrupt change in energy level or a change in fracture from a shear to a cleavage mode.

In general, the transition temperatures and ranges fora given Type of specimen were about the same, regardless of whether they were based on fracture appearance, energy to maximum load, or energy to fracture. Minor variations of this occur particularly for Type Y, when the transition temperature was 10 to 12°F lower based on energy than when based on fracture appearance.

All types except V and Y might be said, with small error, to have a transition temperature of about 45°F. The effect of the less severe notching of Type V is to lower the transition temperature to approximately that of the unnotched Type Y, 20 to 25°F.

TABLE 4

TRANSITION TEMPERATURES

°F

Type of Specimen	Based on Fracture Appearance		Based on Energy to Maximum Load		Based on Energy to Fracture	
	Single Pt.	Range	Single Pt.	Range	Single Pt.	Range
I	42	45 to 60	45 or 57	45 to 60	38	30 to 45
II	39	40 to 50	35	40 to 50	39	40 to 50
III	53	50 to 60	48	50 to 60	46	50 to 60
IV	48	45 to 50	45	45 to 50	46	45 to 50
V	25	25 to 30				
X-1	42	40 to 45	40	40 to 50	42	40 to 50
X-2	52	30 to 55	52	30 to 55	52	30 to 55
X-3	42	40 to 45	42	40 to 45	42	40 to 45
Y	25	20 to 30				

Type I having notches produced by jewelers hack saw cuts, has essentially the same transition temperature as Type II with burned notches. The acuity of the notch is definitely different until the visible crack occurs at the notch. It may be postulated that the acuity of the visible crack is the controlling factor instead of the original notch. The visible crack should also establish the notch acuity for Types V and Y. This is apparently confirmed by their near equality in transition temperature. The fact that these Types show a lower transition than the others may be due to the higher local strain in the region of the initial crack, thus shifting the transition downward.

CONCLUSIONS

The following conclusions are based on an analysis of the test results of tensile specimens made from Dn steel. The specimens were 15" wide,* 40" long, and 3/4" thick, having flame cut edges and edge notches of varying geometry. The edge notching variations including square cut notches using a jeweler's hack-saw, square cut flame cut notches, flame cut Vee type notches with variations in the notch angle from 90° to 135°, and flame cut semi-circular notches. All notched specimens had a net width of 12". The specimens were either notched at mid-length or at the ends of a 15" long section having a reduced width of 12".

The basis for selecting single transition temperature values is as follows: The mid value between maximum and minimum values

* Except for unnotched specimens which were $10\frac{1}{2}$" wide and faired to a $13\frac{1}{2}$" width at the ends.

of; (a) the percentage of shear failure observed in the fracture surface, (b) energy to maximum load, or (c) energy to fracture, where the percentage of shear and energy values were separately plotted against temperature.

(1) For any of the criteria stated above, the transition temperature does not appear to change significantly with a change in the geometry of the flame cut edge notches investigated, except in the case of semi-circular notches at mid-length. The transition temperature for the latter form of notch is approximately 20 to 25°F lower than the results for the other notch forms, and is approximately the same as the transition temperature for flame cut unnotched plate.

(2) The transition temperature of specimens having flame cut notches are approximately equal to the transition temperature found for specimens having jeweler's hacksaw notches, the semi-circular notch excepted.

(3) The transition temperature of 10½" wide unnotched specimens with flame cut edges is approximately 20 to 25°F lower than the transition temperature for the notched specimens, except for the types having semi-circular notches at mid-length. In the latter instance, the transition temperature was essentially the same as for the unnotched specimens.

(4) The tensile strengths are severely impaired by edge notching but the impairment is less as the included angle of the notch is increased. None of the notched specimens except those with notches cut to a radius have strengths approaching the tensile strength of unnotched bars.

(5) The tensile strength of specimens having the shear mode of fracture exceeds that of specimens having a cleavage mode of fracture, except in the case of notches cut to a radius. For these specimens the strengths are approximately equal for the two modes of fracture.

(6) The energy absorbing capacity to maximum load and to fracture i severely impaired by edge notching. The energy to maximum load absorbed by specimens fracturing in the cleavage mode is less than the energy absorbed in the shear mode of fracture except for unnotched specimens and for those specimens with notches cut to a radius, where the energy to maximum load absorbed in the two modes of fracture may be nearly equal.

(7) Specimens with notches cut to a radius show less impairment in load and energy absorbing capacity to maximum load compared with unnotched specimens than any other form of notch investigated.

(8) Specimens notched at mid-length show less strength and energy absorbing capacity to maximum load than their counterparts having a reduced width section 15" long.

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University of California

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APPENDIX A

TABLE 1A

DN Steel - Type I Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

Two External Notches 1½" Long

Jeweler's Hack-saw Cut

Spec. No.	Temp. °F	% Shear Fracture Surfaces	Loads in Kips			Energy in Inch Kips						Elongation in Inches*			
			Visible Crack	Max.	Fract.	To Vis. Crack 16½"	To Vis. Crack 40"	To Maximum Load 16½"	To Maximum Load 40"	To Fracture 16½"	To Fracture 40"	Max. Load 16½"	Max. Load 40"	Fracture 16½"	Fracture 40"
A1	78	100	370.0	446.0	160.0	12.0	44.0	245.0	434.0	450.0	668.0	0.620	1.075	1.125	1.65
B3	66	100	374.0	426.0	180.0	66.0	66.0	208.0	360.0	410.0	616.0	0.540	0.945	1.050	1.60
B1	60	100	371.0	450.5	165.0	32.0	40.0	305.0	500.0	440.0	677.0	0.750	1.225	1.100	1.750
A2	56	75	365.5	414.2	230.0	20.0	24.0	154.0	246.0	385.0	495.0	0.400	0.655	1.070	1.315
B2	45	100	376.5	439.3	160.0	66.0	52.0	205.0	385.0	401.0	602.0	0.530	0.990	1.050	1.550
**B8	40	25	366.3	391.5	300.0	13.0	32.0	110.0	72.4	285.0	344.0	0.300	0.315	0.830	1.025
A8	35	0	390.0	390.0	322.0	114.1	—	114.1	122.4	166.0	—	0.300	0.350	0.450	—
A3	30	0	366.2	389.0	389.0	19.8	35.0	73.0	102.0	73.0	90.0	0.200	0.300	—	—

*Energy and elongation given for 16½" and 40" Gage Lengths
**Unsymmetrical Tear

TABLE 2A

DN Steel - Type II Specimen

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

Two External Notches 1½" long with 1/16" Root Radius

Flame Cut

Spec. No.	Temp. °F.	% Shear Fracture Surfaces	Loads in Kips			Energy in Inch Kips*						Elongation in Inches*			
			Visible Crack	Max.	Fract.	To Vis. Crack 16½"	To Vis. Crack 40"	To Maximum Load 16½"	To Maximum Load 40"	To Fracture 16½"	To Fracture 40"	Max. Load 16½"	Max. Load 40"	Fracture 16½"	Fracture 40"
A6	60	100	364.2	444.0	155.0	20.0	50.0	240.0	400.4	508.0	682.0	0.60	1.030	1.20	1.75
A5	50	100	386.5	463.2	141.0	20.0	40.0	215.0	425.0	540.0	750.0	0.53	1.04	1.30	1.85
B5	40	100	370.7	444.0	165.0	21.0	38.0	236.0	405.0	423.0	680.0	0.58	1.01	1.20	1.70
B6	40	5	374.8	415.0	415.0	55.0	57.0	153.0	153.0	267.0	267.0	0.40	0.70	0.40	0.70
B4	30	0	388.0	404.0	404.0	67.0	61.0	91.0	93.0	91.0	93.0	0.265	0.275	0.265	0.275
A4	0	0	—	387.0	387.0	—	—	—	85.0	85.0	85.0	—	0.250	—	0.250

*Energy and elongation given for 16½" and 40" Gage Lengths

TABLE 3A

DN Steel - Type III Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

Two External 90° V Notches

Flame Cut

Spec. No.	Temp. °F.	% Shear Fracture Surfaces	Loads in Kips: Visible Crack	Max.	Fract.	Energy in Inch Kips: To Vis. Crack 16½"	40"	To Maximum Load 16½"	40"	To Fracture 16½"	40"	Elongation in Inches*: Max. Load 16½"	40"	Fracture 16½"	40"
**B7	95	100	365.0	411.0	360.0	34.0	67.0	232.0	370.0	557.0	651.0	0.57	1.00	1.40	1.75
A10	80	100	373.0	450.8	170.0	66.0	62.0	220.0	430.0	510.0	702.0	0.56	1.075	1.30	1.75
**A7	73	90	370.0	416.8	336.5	40.0	55.0	134.0	278.0	469.0	654.0	0.36	0.745	1.21	1.70
**B9	60	90	375.0	393.0	160.0	44.0	50.0	90.0	86.0	346.0	324.0	0.25	0.285	1.21	1.15
**A11	50	90	378.5	403.0	180.0	20.0	30.0	80.0	102.0	380.0	470.0	0.22	0.295	1.10	1.30
**B10	40	25	368.0	460.0	400.0	24.0	30.0	218.0	400.0	340.0	524.0	0.53	0.99	0.81	1.25
B11	30	0	371.0	387.0	387.0	10.0	24.0	55.0	78.0	55.0	78.0	0.15	0.24	0.15	0.24
A9	20	0	371.0	470.0	470.0	13.0	23.0	150.0	314.0	150.0	314.0	0.38	0.775	0.38	0.775
A12	5	0	375.5	425.0	425.0	10.0	20.0	97.0	162.0	97.0	162.0	0.25	0.435	0.25	0.435

*Energy and elongation given for 16½" and 40" Gage Lengths
**Unsymmetrical tear

TABLE 3A (a)

DN Steel - Type III Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

Two External 90° V Notches

Flame Cut

Spec. No.	Temp. °F	% Shear Fracture Surfaces	Loads in Kips: Visible Crack	Max.	Fract.	Energy in Inch Kips: To Vis. Crack 16½"	40"	To Maximum Load 16½"	40"	To Fracture 16½"	40"	Elongation in Inches*: Max. Load 16½"	40"	Fracture 16½"	40"
C8	60	100	370.5	454.0	365.5	40.0	46.0	286.0	436.0	485.0	693.0	0.70	1.085	1.2	1.675
C7	50	30	377.0	421.2	95.0	35.0	50.0	177.0	275.0	365.0	470.0	0.45	0.725	0.45	0.725
C9	40	0	375.5	420.0	420.0	11.0	55.0	142.0	230.0	142.0	230.0	0.36	0.61	0.36	0.61
C6	20	0	380.0	465.0	465.0	12.0	23.0	148.0	285.0	148.0	285.0	0.36	0.70	0.36	0.70

*Energy and elongation given for 16½" and 40" Gage Lengths

TABLE 4A

DN Steel - Type IV Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

Two External 135° V Notches

Flame Cut

Spec. No.	Temp. °F.	% Shear Fracture Surfaces	Loads in Kips: Visible Crack	Loads in Kips: Max.	Loads in Kips: Fract.	Energy in Inch Kips: To Vis. Crack 16½"	Energy in Inch Kips: To Vis. Crack 40"	Energy in Inch Kips: To Maximum Load 16½"	Energy in Inch Kips: To Maximum Load 40"	Energy in Inch Kips: To Fracture 16½"	Energy in Inch Kips: To Fracture 40"	Elongation in Inches*: Max. Load 16½"	Elongation in Inches*: Max. Load 40	Elongation in Inches*: Fracture 16½"	Elongation in Inches*: Fracture 40"
**C4	78	100	368.0	480.0	105.0	44.0	52.0	287.0	480.0	677.0	920.0	0.70	1.215	1.70	2.30
C5	60	100	390.0	514.0	235.0	54.0	70.0	305.0	575.0	631.0	935.0	1.34	0.70	2.10	1.14
C2	50	100	386.7	501.0	165.0	92.0	100.0	288.0	540.0	646.0	932.0	0.69	1.31	1.50	2.20
B12	45	0	390.0	482.0	482.0	85.0	94.0	210.0	440.0	210.0	440.0	0.53	1.10	0.53	1.10
C3	40	0	385.0	407.0	407.0	81.0	100.0	112.0	199.0	112.0	199.0	0.30	0.55	0.30	0.55
C1	10	0	375.0	427.0	427.0	13.2	25.0	120.0	145.0	81.0	145.0	0.21	0.39	0.21	0.39

*Energy and elongation given for 16½" and 40" Gage Lengths
**Unsymmetrical Tear

TABLE 5A

DN Steel - Type V Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

1 1/2" Radius Notch

Flame Cut

Spec. No.	Temp. °F	% Shear Fracture Surfaces	Loads in Kips: Visible Crack	Loads in Kips: Max.	Loads in Kips: Fract.	Energy in Inch Kips: To Vis. Crack 16½"	Energy in Inch Kips: To Vis. Crack 40"	Energy in Inch Kips: To Maximum Load 16½"	Energy in Inch Kips: To Maximum Load 40"	Energy in Inch Kips: To Fracture 16½"	Energy in Inch Kips: To Fracture 40"	Elongation in Inches*: Max. Load 16½"	Elongation in Inches*: Max. Load 40"	Elongation in Inches*: Fracture 16½"	Elongation in Inches*: Fracture 40"
E12	40	100	425.0	590.2	210.0	--	125.0	--	1,135.0	--	1,440.0	1.115	2.25	2.00	2.91
E8	35	100	425.0	604.0	235.0	75.0	107.5	791.0	1,290.0	1,001.5	1,492.0	1.23	2.24	2.06	2.89
F2	30	100	423.5	602.5	235.0	122.5	165.0	722.5	1,290.0	1,007.5	1,590.0	1.41	2.55	2.23	3.18
E11	25	100	391.5	563.8	305.5	87.5	127.5	460.0	867.5	735.5	1,172.5	.96	1.845	1.50	2.45
G11	25	0	412.0	564.0	564.0	112.5	237.5	492.5	977.5	492.5	977.5	1.05	2.09	1.05	2.09
F1	15	10	420.0	607.0	607.0	66.5	92.5	707.5	1,286.0	707.5	1,286.0	1.34	2.47	1.34	2.47
G12	15	50	437.3	567.8	331.0	150.0	305.0	490.0	977.5	802.5	1,262.5	1.05	2.09	1.71	2.67
E10	10	0	434.0	587.5	587.5	145.5	247.5	574.0	1,065.0	574.0	1,065.0	1.10	2.16	1.10	2.16

*Energy and elongation given for 16½" and 40" Gage Lengths

TABLE 6A

DN Steel - Type X-1 Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

0 = 0°; d = 15"; b = 12"

Flame Cut

Spec. No.	Temp. °F.	% Shear Fracture Surfaces	Loads in Kips Visible Crack	Max.	Fract.	Energy in Inch Kips To Vis. Crack 16½"	40"	To Maximum Load 16½"	40"	To Fracture 16½"	40"	Elongation in Inches* Max. Load 16½"	40"	Fracture 16½"	40"
C1	60	100	375.3	507.5	--**	114.0	172.8	558.8	870.4	--**	--**	1.31	2.05	—	—
C3	50	100	385.0	510.3	510.3	159.6	199.6	566.4	848.4	--	1,302.0	1.35	2.135	3.82	3.115
D5	45	100	375.0	488.0	140.0	114.0	146.0	420.0	664.0	760.0	1,088.0	1.05	1.635	1.90	2.650
D6	45	100	340.0	503.5	244.0	31.2	51.2	492.8	782.0	832.0	1,141.0	1.16	1.87	2.05	2.775
C2	40	0	411.0	476.0	476.0	177.4	237.3	331.0	559.3	331.0	559.3	.88	1.41	.88	1.41
D7	35	0	--	471.5	--	98.4	101.8	333.0	430.0	333.0	430.0	.84	1.350	.84	1.350
D4	20	0	—	386.0	386.0	—	--	108.1	193.0	108.1	193.0	.30	.55	.30	.55

** Unsymmetrical tear
* Energy and elongation given for 16½" and 40" Gage Lengths

TABLE 7A

DN Steel - Type X2 Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

$\theta = 45^\circ$; d = 15"; b = 12"

Flame Cut

Spec. No.	Temp. °F	% Shear Fracture Surfaces	Loads in Kips Visible Crack	Max.	Fract.	Energy in Inch Kips To Vis. Crack 16½"	40"	To Maximum Load 16½"	40"	To Fracture 16½"	40"	Elongation in Inches" Max. Load 16½"	40"	Fracture 16½"	40"
D10	74	100	350.0	497.0	160.0	81.6	82.8	449.6	849.2	768.0	1,187.2	1.07	1.82	1.815	2.77
E2	60	100	365.0	486.0	363.0	102.4	154.4	410.8	725.6	838.0	1,187.6	1.00	2.00	1.795	2.85
E1	55	100	375.0	507.3	370.0	107.2	130.4	512.0	842.0	866.0	1,277.2	1.18	2.05	1.99	3.00
D11	50	0	350.0	501.0	501.0	40.0	68.0	404.8	701.6	404.8	701.6	.95	.95	1.67	1.67
D3	50	10	376.0	493.0	491.5	86.8	106.4	418.0	720.0	487.6	854.0	1.00	1.14	1.725	2.00
D9	40	100	400.0	517.0	293.5	120.0	162.0	477.6	818.8	903.2	1,274.8	1.08	2.05	1.845	2.91
D2	40	100	364.5	452.0	307.0	90.0	108.8	268.4	470.4	616.4	904.8	.69	1.55	1.225	2.30
D1	30	0	378.0	502.5	502.5	80.4	105.2	355.4	624.2	355.4	624.2	.83	1.475	.83	1.475
D8	15	0	375.0	511.0	511.0	91.2	110.8	420.0	709.6	420.0	709.6	.98	.98	1.65	1.65

*Energy and elongation given for 16½" and 40" Gage Lengths

TABLE 8A

DN Steel - Type X-3 Specimens

Flat Plate Tests - Size: 15" wide x 3/4" thick x 40" long

R = 1½"; d ½ 15"; b = 12"

Flame Cut

Spec. No.	Temp. °F.	%Shear Fracture Surfaces	Loads in Kips Visible Crack	Max.	Fract.	Energy in Inch Kips To Vis. Crack 16½"	40"	To Maximum Load 16½"	40"	To Fracture 16½"	40"	Elongation in Inches* Max. Load 16½"	40"	Fracture 16½"	40"
E9	55	100	422.0	568.1	125.0	167.0	249.0	1,096.0	1,620.5	1,483.5	2,060.5	2.20	3.33	3.09	4.285
D12	45	100	422.0	581.8	356.0	192.0	242.0	1,272.0	1,902.0	1,632.0	2,345.0	2.70	3.77	3.53	4.75
E6	40	0	361.0	535.0	535.0	100.0	111.5	611.5	995.0	611.5	995.0	1.36	2.255	1.36	2.255
E7	40	0	379.2	531.5	531.5	112.5	147.5	570.0	900.0	570.0	900.0	1.28	2.04	1.28	2.04
E3	30	100	401.0	540.0	329.0	146.0	210.0	484.0	994.0	915.0	1,496.0	1.30	2.22	2.00	3.30
E4	20	0	422.0	592.0	592.0	154.0	200.0	1,371.0	1,897.5	1,371.0	1,897.5	2.50	3.655	2.50	3.655
** E5	20	—	388.0	—	—	—	—	—	—	—	—	-	-	-	-

* Energy and elongation given for 16½" and 40" Gage Lengths
* *Failed in weld before maximum load

TABLE 9A

DN Steel - Type Y Specimens

Flat Plate Tests - Size: 13½" wide x 3/4" thick x 40" long

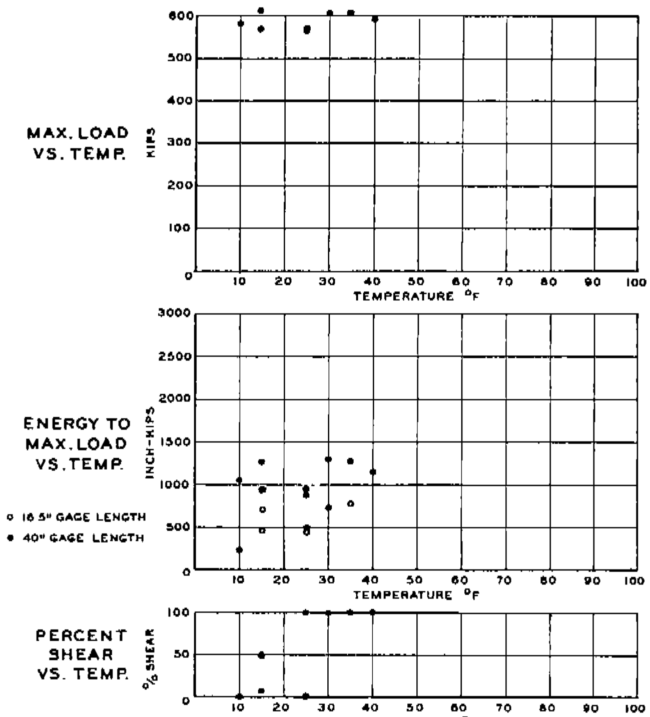
Unnotched

Flame Cut

Spec. No.	Temp. °F.	% Shear Fracture Surfaces	Loads in Kips Visible Crack	Max.	Fract.	Energy in Inch Kips To Vis. Crack 16½"	40"	To Maximum Load 16½"	40"	To Fracture 16½"	40"	Elongation in Inches* Max. Load 16½"	40"	Fracture 16½"	40"
G1	40	100	—	508.0	112.0	—	—	1,620.0	2,525.00	2,775.0	3,400	3.59	6.05	6.32	7.58
F12	30	100	—	507.5	507.5	—	—	2,220.0	3,060.0	3,210.0	3,480.0	4.85	6.775	6.80	7.575
F13	20	0	—	511.4	502.5	—	—	1,833.0	2,607.0	2,463.0	3,069.0	3.94	5.75	5.18	6.685
G3	0	0	—	500.0	500.0	—	—	717.5	1,447.5	717.5	1,447.5	1.75	3.425	1.75	3.425
G10	0	0	—	530.5	530.5	—	—	1,835.0	3,190.0	1,835.0	3,190.0	3.80	6.71	3.80	6.71
G2	-10	0	—	535.0	535.0	—	—	1,900.0	3,000.0	1,900.0	3,000.0	3.98	6.325	3.98	6.325
G9	-10	0	—	529.0	525.0	—	—	1,375.0	2,595.0	1,590.0	2,960.0	2.93	5.58	3.35	6.28
F9	-30	0	—	545.0	545.0	—	—	1,745.0	2,565.0	1,745.0	2,565.0	3.55	5.35	3.55	5.35

*Energy and elongation given for 16½" and 40" Gage Lengths

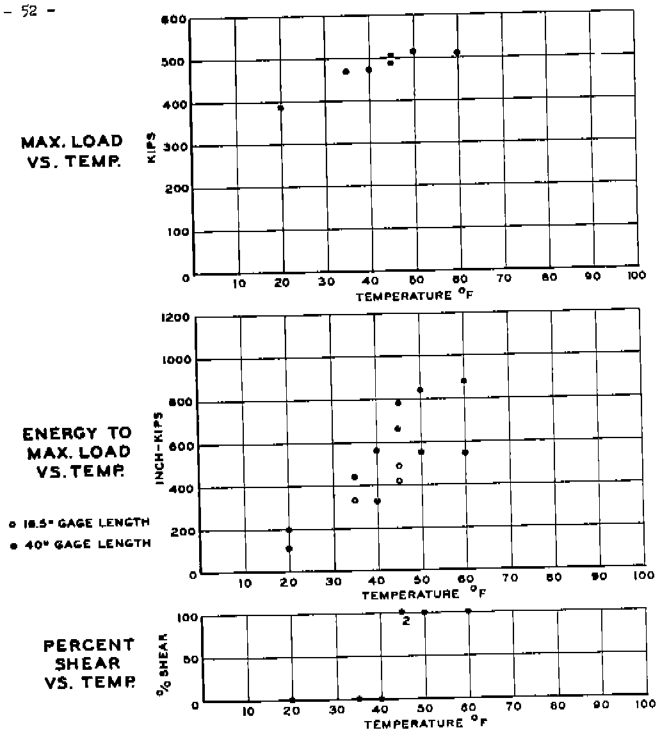
APPENDIX B



SPECIMEN SIZE:
15" X 40" X 3/4"

FIG. 5-B
SUMMARY
TYPE V SPECIMENS

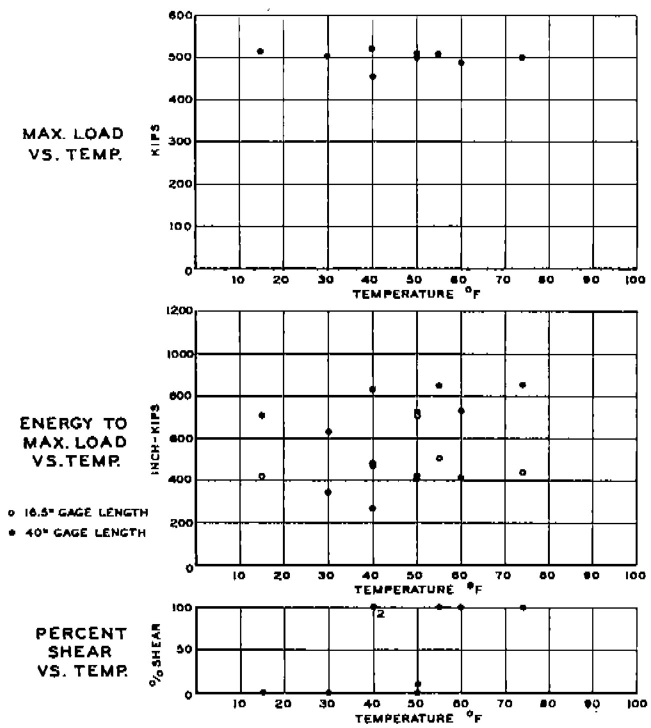
SWARTHMORE COLLEGE



SPECIMEN SIZE:
15"X40"X3/4"

FIG. 6-B
SUMMARY
TYPE X1 SPECIMENS

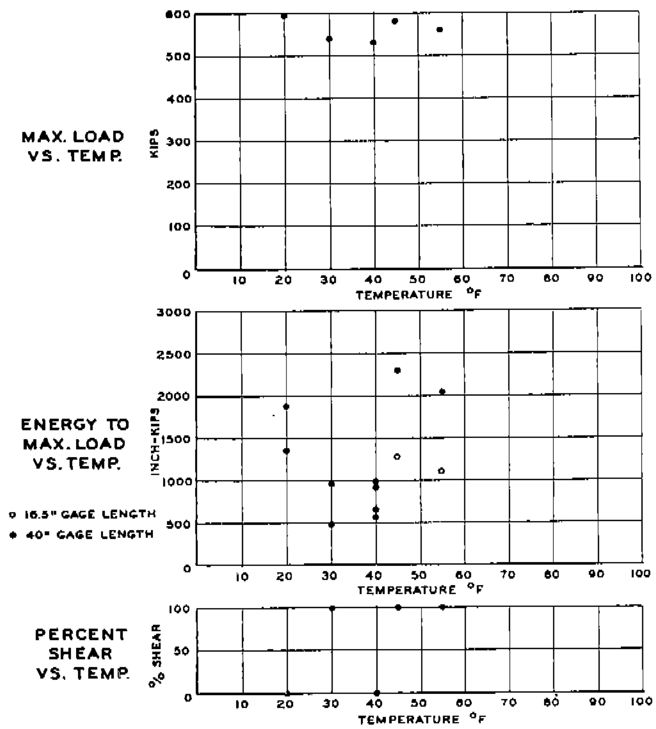
SWARTHMORE COLLEGE



SPECIMEN SIZE:
15" X 40" X 3/4"

FIG. 7-B
SUMMARY
TYPE X2 SPECIMENS

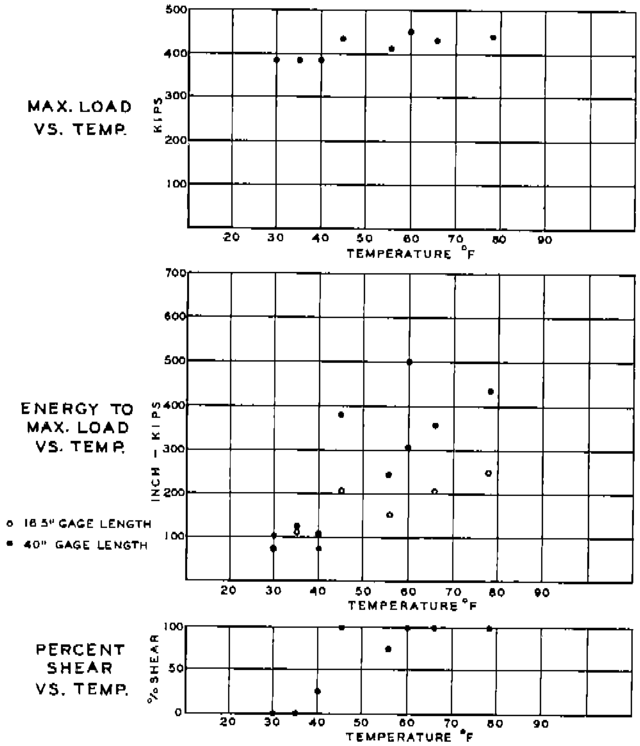
SWARTHMORE COLLEGE



SPECIMEN SIZE
15" X 40" X 3/4"

FIG. 8-B
SUMMARY
TYPE X3 SPECIMENS

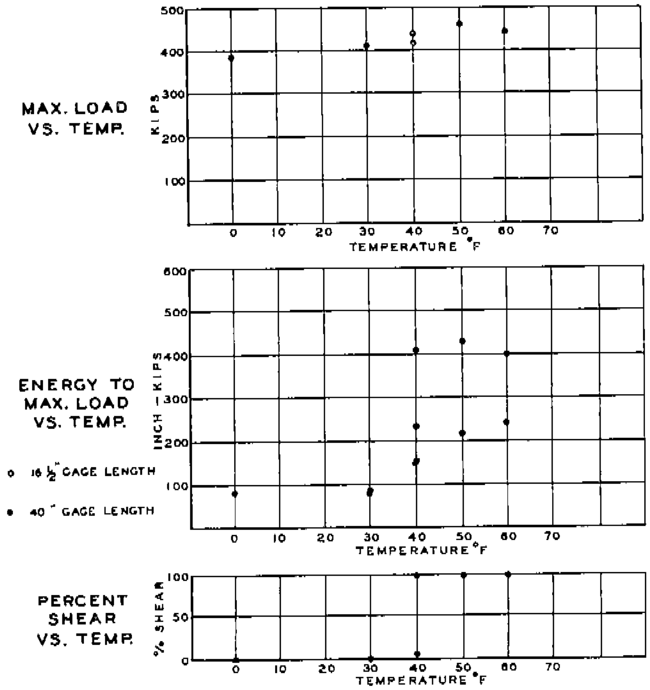
SWARTHMORE COLLEGE



SPECIMEN SIZE.
40" x 15" x 3/4"

FIG. 1-B
SUMMARY
TYPE I SPECIMENS
WITH SAW NOTCH

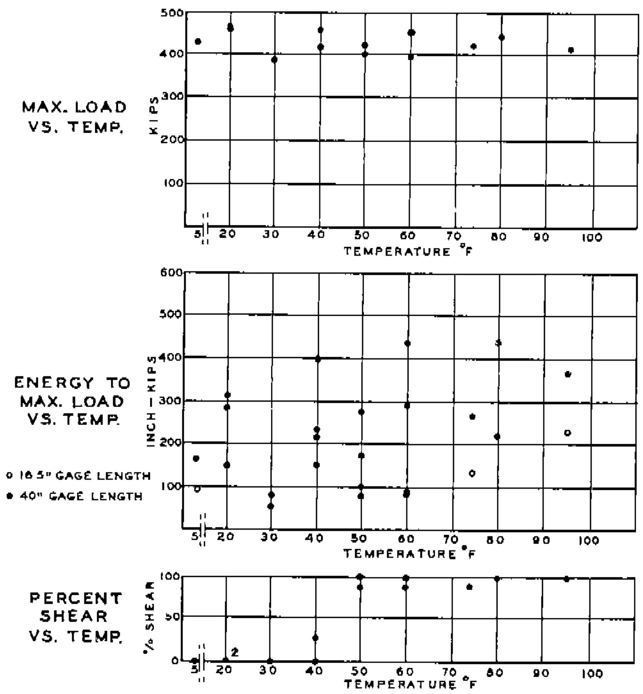
SWARTHMORE COLLEGE



SPECIMEN SIZE:
40" x 15" x 3/4"

FIG. 2-B
SUMMARY
TYPE II SPECIMENS
FLAME CUT NOTCH

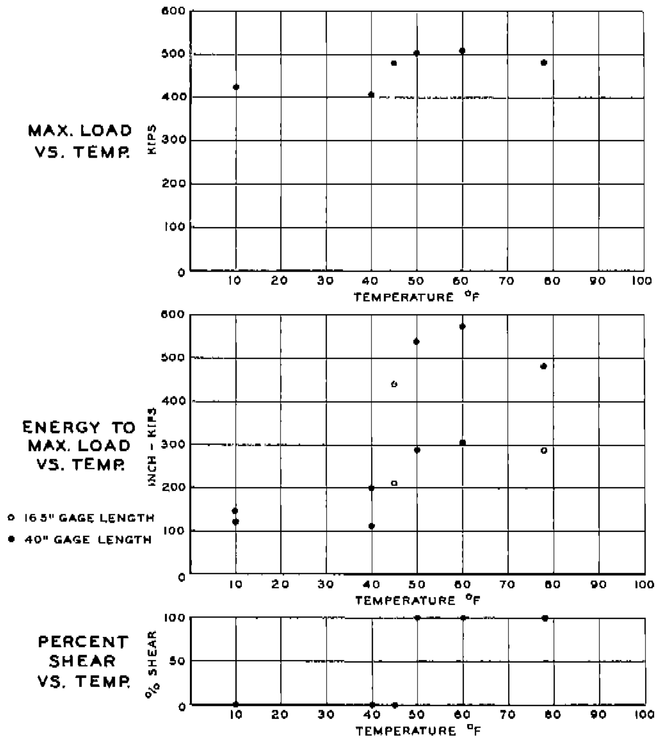
SWARTHMORE COLLEGE



SPECIMEN SIZE:
40" x 15" x 3/4"

FIG. 3-B
SUMMARY
TYPE III SPECIMENS
90° V NOTCH
FLAME CUT

SWARTHMORE COLLEGE

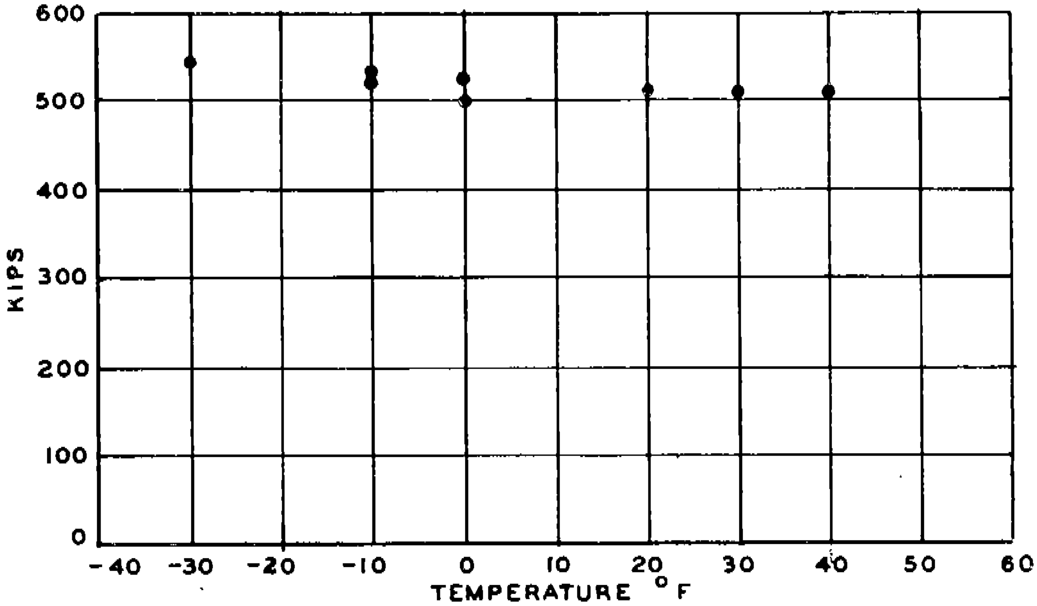


SPECIMEN SIZE:
15" x 40" x 3/4"

FIG. 4-B
SUMMARY
TYPE IV SPECIMENS

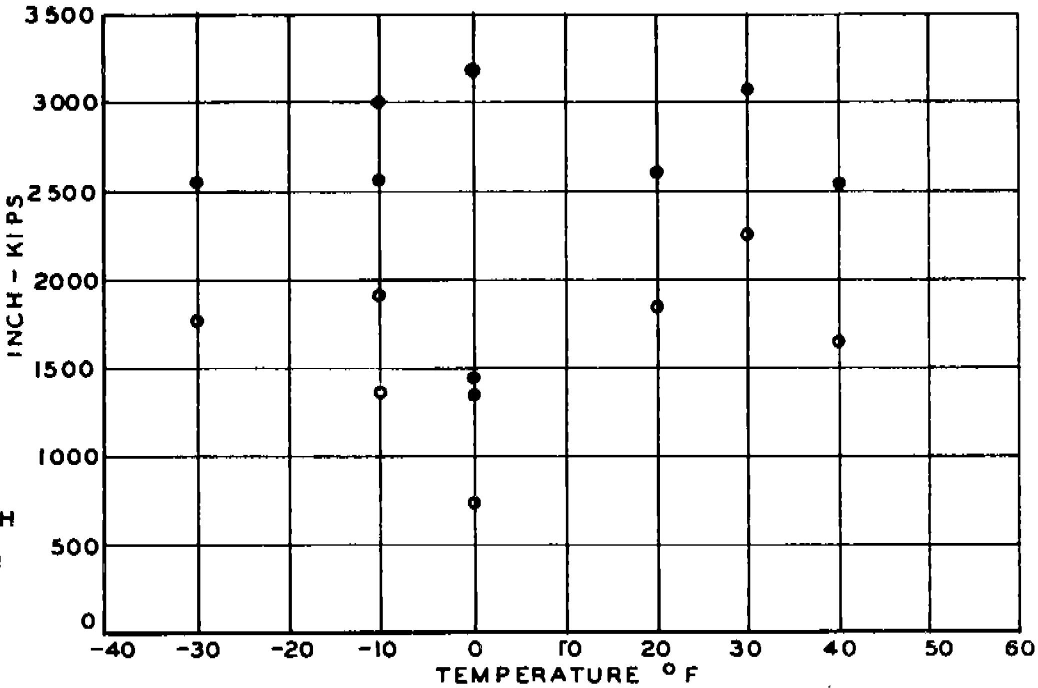
SWARTHMORE COLLEGE

MAX LOAD
VS. TEMP.

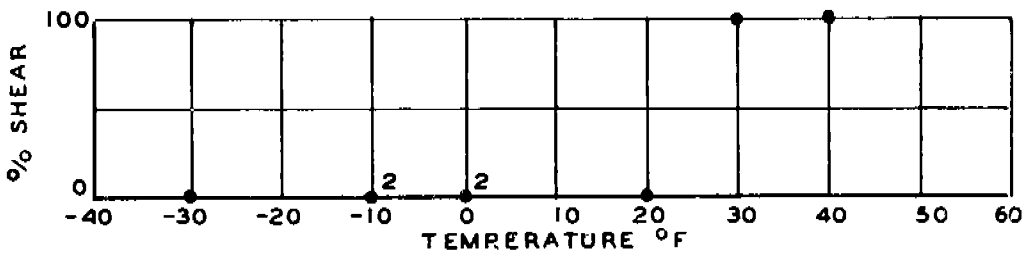


ENERGY TO
MAX. LOAD
VS. TEMP.

o 16.5" GAGE LENGTH
● 40" GAGE LENGTH



PERCENT
SHEAR
VS. TEMP.

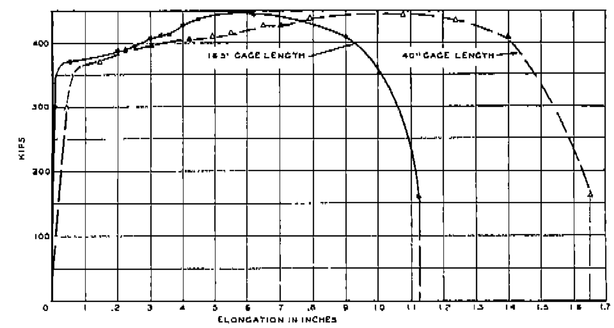


SPECIMEN SIZE:
$13\frac{1}{2}$" X 40" X $\frac{3}{4}$"

FIG. 9-B
SUMMARY
TYPE Y SPECIMENS

SWARTHMORE COLLEGE

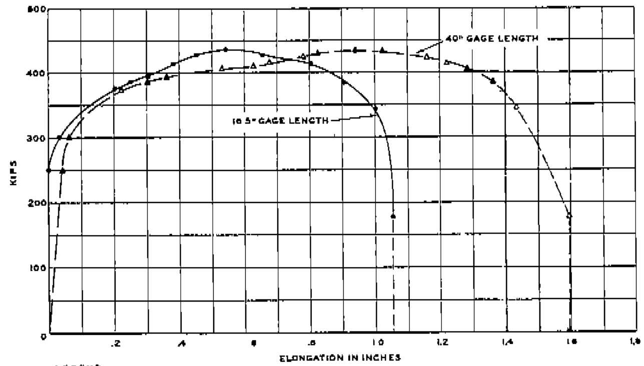
APPENDIX C



LEGEND
SPECIMEN SIZE 15" X 40" X 3/4"
WITH EXTERNAL J.H.S. NOTCH

FIG. 1-C
LOAD-ELONGATION DIAGRAM
TYPE I SPECIMEN
DN-A1 78°F

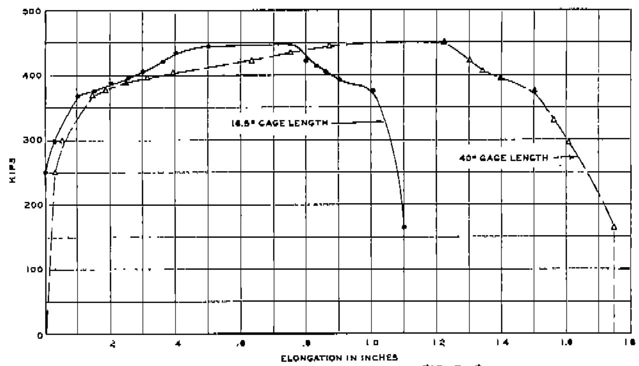
SWARTHMORE COLLEGE
8/20/51



LEGEND
SPECIMEN SIZE 15" X 40" X 3/4"
EXTERNAL J.H.S. NOTCH

FIG. 2-C
LOAD-ELONGATION DIAGRAM
TYPE I SPECIMEN
DN-B3 66°F

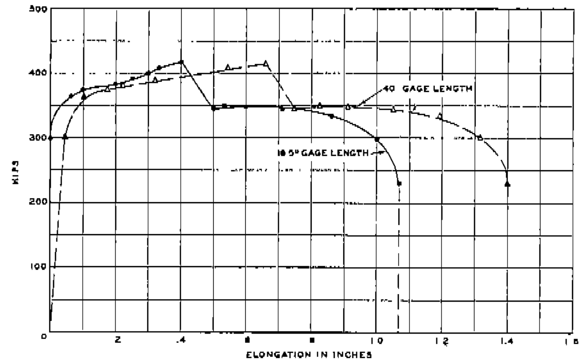
SWARTHMORE COLLEGE



LEGEND.
SPECIMEN SIZE 15" X 40" X 3/4"
EXTERNAL J H S NOTCH

FIG. 3-C
LOAD-ELONGATION DIAGRAM
TYPE I SPECIMEN
DN B-1 60°F

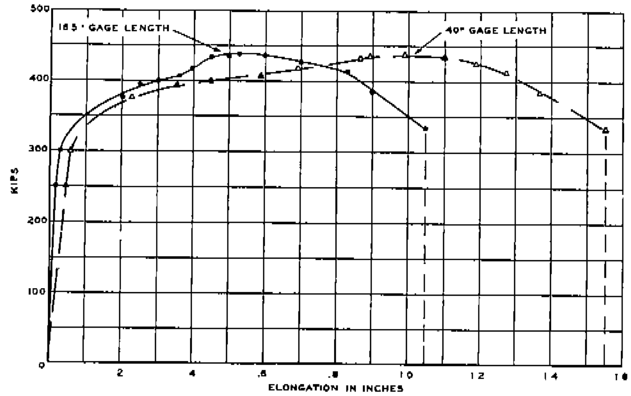
SWARTHMORE COLLEGE



LEGEND.
SPECIMEN SIZE 15 X 40" X 3/4"
EXTERNAL J.H.S NOTCH

FIG. 4-C
LOAD-ELONGATION DIAGRAM
TYPE I SPECIMEN
DN-A2 56°F

SWARTHMORE COLLEGE

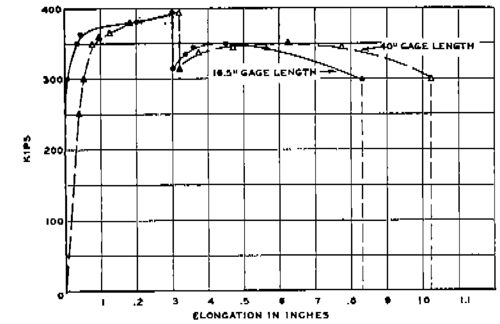


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
WITH EXTERNAL J H S NOTCH

FIG. 5-C
LOAD-ELONGATION DIAGRAM
TYPE I SPECIMEN
DN-B2 45°F

SWARTHMORE COLLEGE

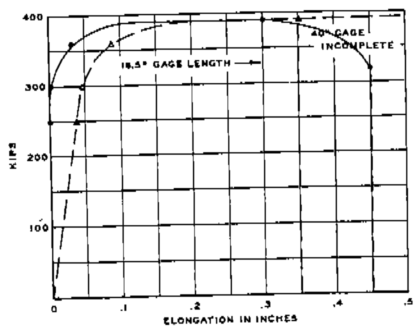


LEGEND:

SPECIMEN SIZE 15" X 40" X 3/4"
WITH EXTERNAL J H S. NOTCH

FIG. 6-C
LOAD-ELONGATION DIAGRAM
TYPE I SPECIMEN
DN-B8 40°F

SWARTHMORE COLLEGE

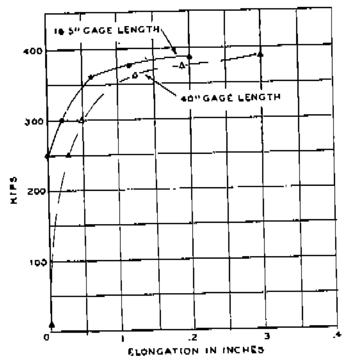


LEGEND:

SPECIMEN SIZE 15" X 40" X 3/4"
WITH EXTERNAL J.H.S. NOTCH

FIG. 7-C
LOAD-ELONGATION DIAGRAM
TYPE I SPECIMEN
DN-A8 35°F

SWARTHMORE COLLEGE

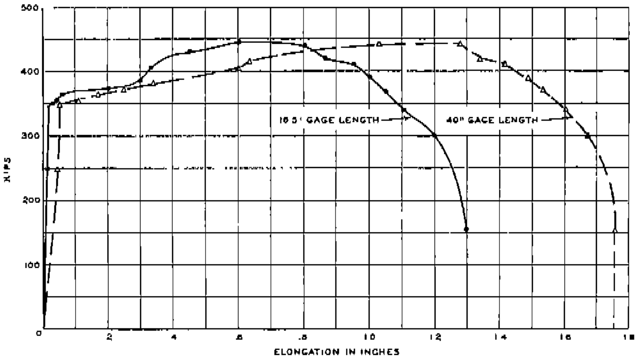


LEGEND.

SPECIMEN SIZE 15" X 40" X 3/4"
WITH EXTERNAL J H.S. NOTCH

FIG 8-C
LOAD-ELONGATION
TYPE I SPECIMEN
DN-A3 30°F

SWARTHMORE COLLEGE

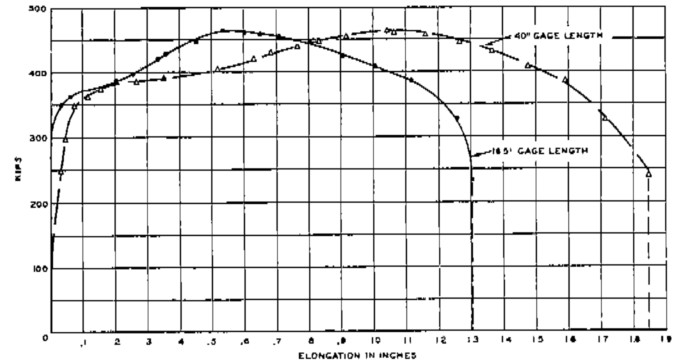


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT NOTCH

FIG. 9-C
LOAD-ELONGATION DIAGRAM
TYPE II SPECIMEN
DN-A6 60° F

SWARTHMORE COLLEGE

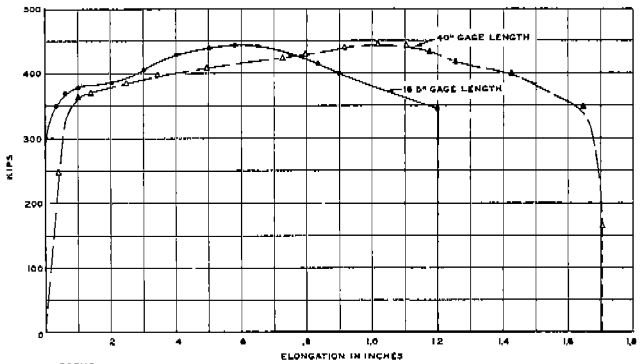


LEGEND

SPECIMEN SIZE 15 X 40" X 3/4"
FLAME CUT NOTCH

FIG. 10-C
LOAD-ELONGATION DIAGRAM
TYPE II SPECIMEN
DN-A5 50° F

SWARTHMORE COLLEGE

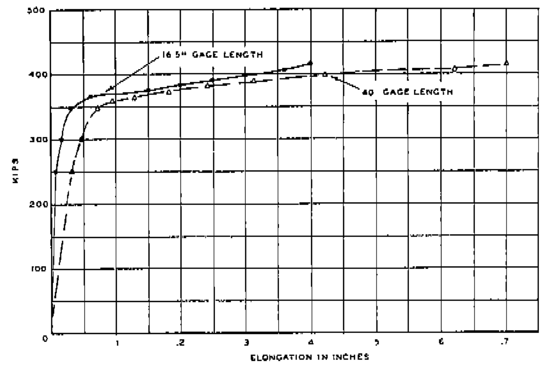


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT NOTCH

FIG. 11-C
LOAD-ELONGATION DIAGRAM
TYPE II SPECIMEN
DN-B5 50° F

SWARTHMORE COLLEGE

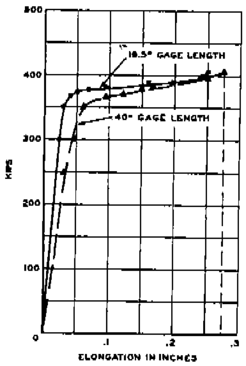


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT NOTCH

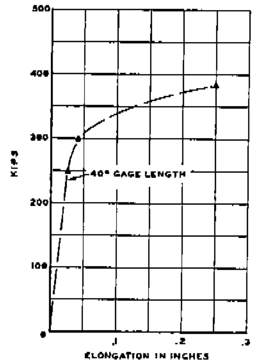
FIG. 12-C
LOAD-ELONGATION DIAGRAM
TYPE II SPECIMEN
DN-B6 40° F

SWARTHMORE COLLEGE



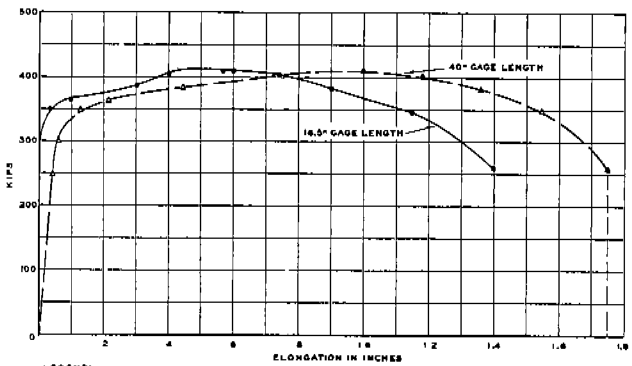
LEGEND:
SPECIMEN SIZE: 15" x 40" x 3/4"
FLAME CUT NOTCH

FIG. 13-C
LOAD-ELONGATION DIAGRAM
TYPE II SPECIMEN
DN-B4 30°F
SWARTHMORE COLLEGE



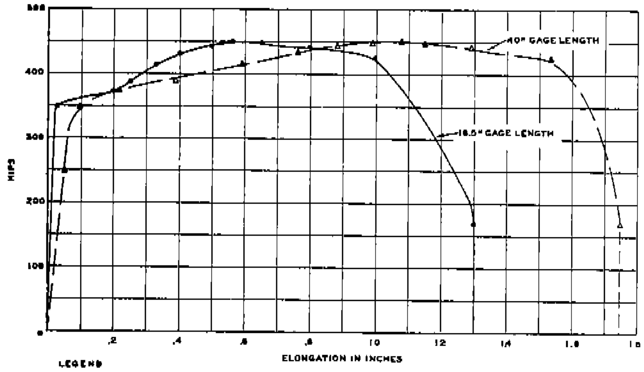
LEGEND:
SPECIMEN SIZE: 15" x 40" x 3/4"
FLAME CUT NOTCH

FIG. 14-C
LOAD-ELONGATION DIAGRAM
TYPE II SPECIMEN
DN-A4 0°F
SWARTHMORE COLLEGE



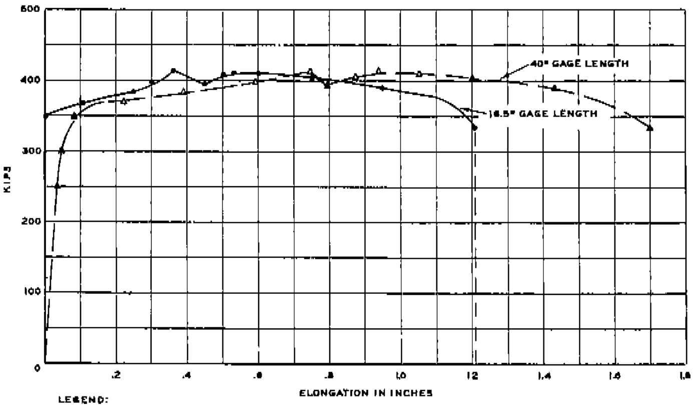
LEGEND:
SPECIMEN SIZE 15" x 40" x 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 15-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-B7 95°F
SWARTHMORE COLLEGE



LEGEND
SPECIMEN SIZE 10" x 40" x 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 16-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-A10 80°F
SWARTHMORE COLLEGE

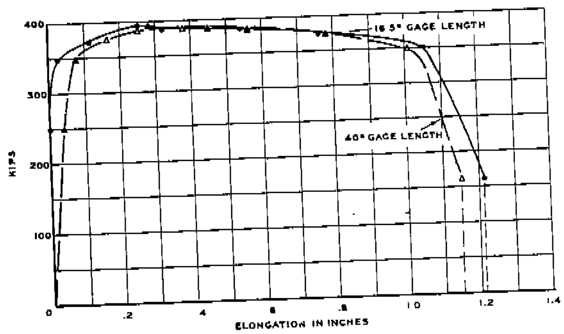


LEGEND:

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 17-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-A7 73°F

SWARTHMORE COLLEGE

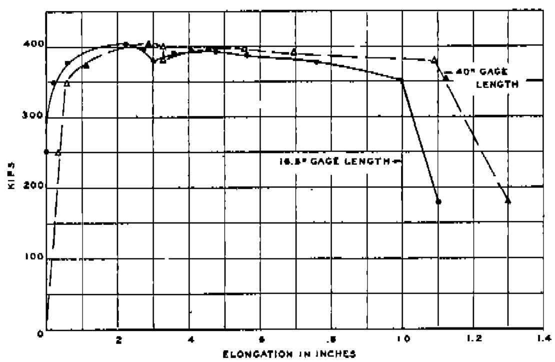


LEGEND:

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 18-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-B9 60°F

SWARTHMORE COLLEGE

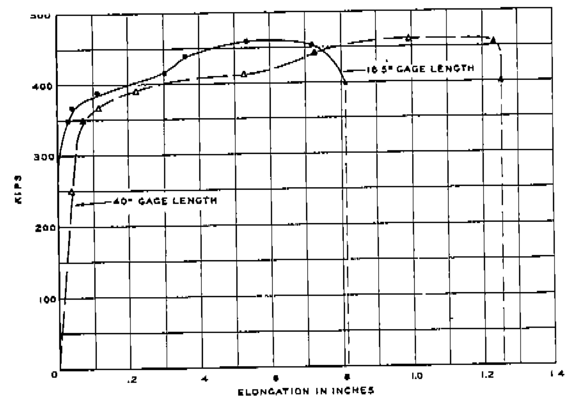


LEGEND:

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 19-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-A11 50°F

SWARTHMORE COLLEGE

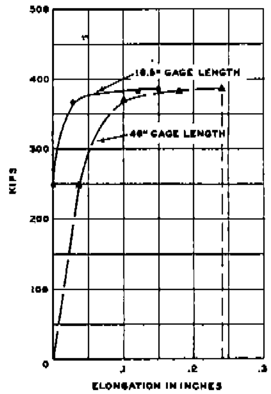


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

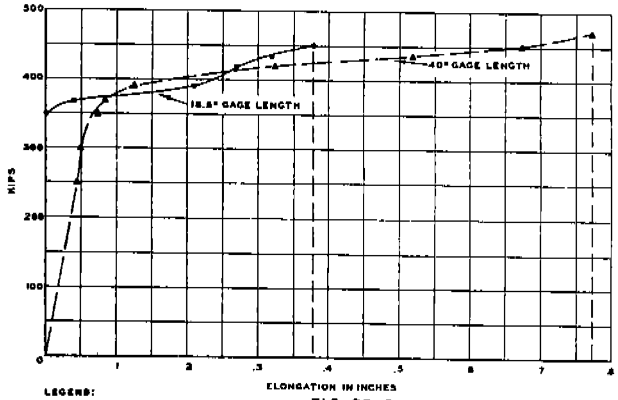
FIG. 20-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-B10 40°F

SWARTHMORE COLLEGE



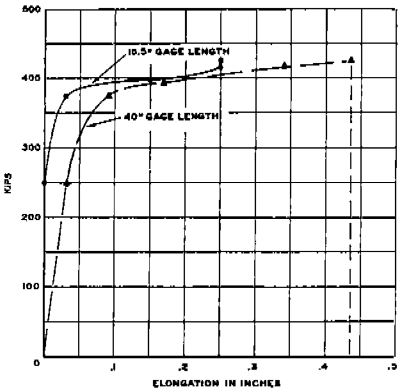
LEGEND:
SPECIMEN SIZE: 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 21-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-B11 30°F
SWARTHMORE COLLEGE



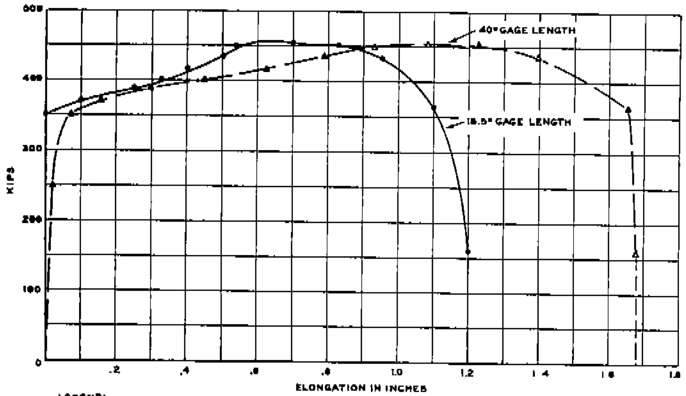
LEGEND:
SPECIMEN SIZE 15"X40"X 3/4
WITH FLAME CUT 90°"V" NOTCH

FIG. 22-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-A9 20°F
SWARTHMORE COLLEGE



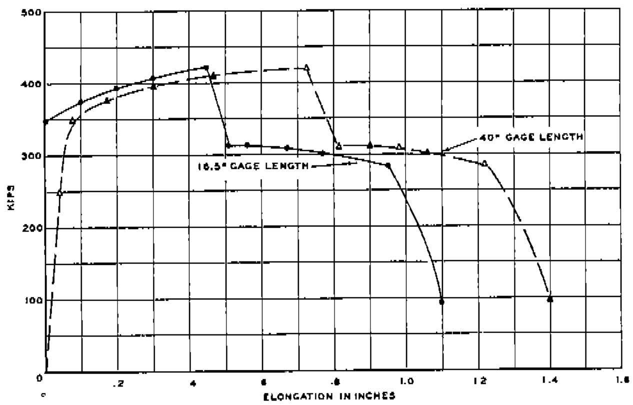
LEGEND
SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 23-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-A12 5°F
SWARTHMORE COLLEGE



LEGEND:
SPECIMEN SIZE: 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 24-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-C8 60°F
SWARTHMORE COLLEGE

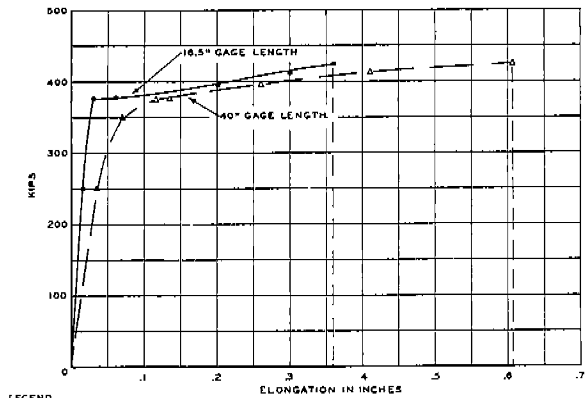


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 25-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-C7 50° F

SWARTHMORE COLLEGE

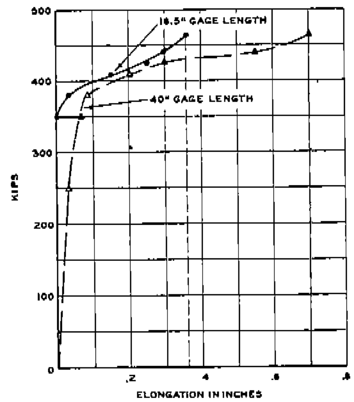


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 26-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-C9 40° F

SWARTHMORE COLLEGE

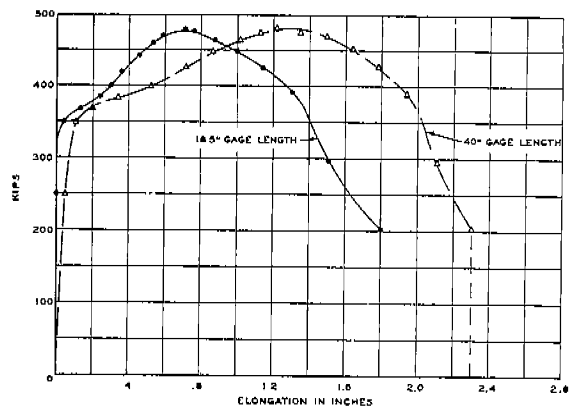


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 90° "V" NOTCH

FIG. 27-C
LOAD-ELONGATION DIAGRAM
TYPE III SPECIMEN
DN-C6 20°F

SWARTHMORE COLLEGE

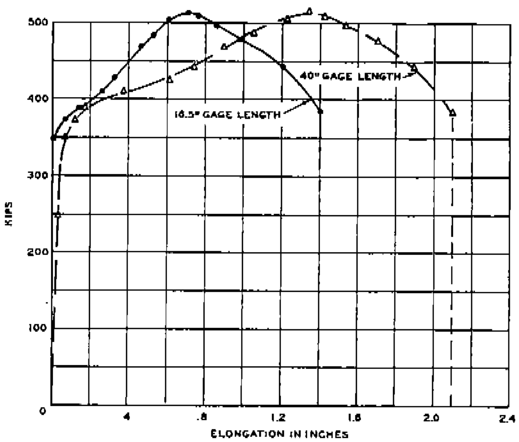


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 135° "V" NOTCH

FIG. 28-C
LOAD-ELONGATION DIAGRAM
TYPE IV SPECIMEN
DN-C4 78° F

SWARTHMORE COLLEGE

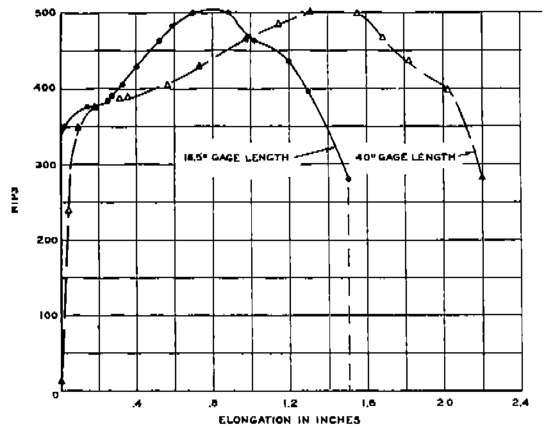


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"
FLAME CUT 135° "V" NOTCH

FIG. 29-C
LOAD-ELONGATION DIAGRAM
TYPE IV SPECIMEN
DN-C5 60°F

SWARTHMORE COLLEGE

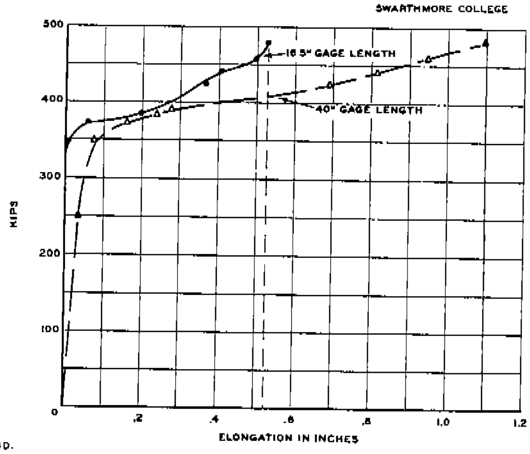


LEGEND:

SPECIMEN SIZE: 15" X 40" X 3/4"
FLAME CUT 135° "V" NOTCH

FIG. 30-C
LOAD-ELONGATION DIAGRAM
TYPE IV SPECIMEN
DN-C2 50°F

SWARTHMORE COLLEGE

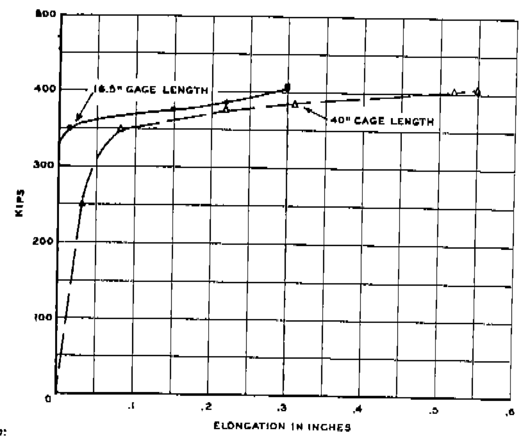


LEGEND.

SPECIMEN SIZE: 15" X 40" X 3/4"
FLAME CUT 135° "V" NOTCH

FIG. 31-C
LOAD-ELONGATION DIAGRAM
TYPE IV SPECIMEN
DN-B12 45°F

SWARTHMORE COLLEGE

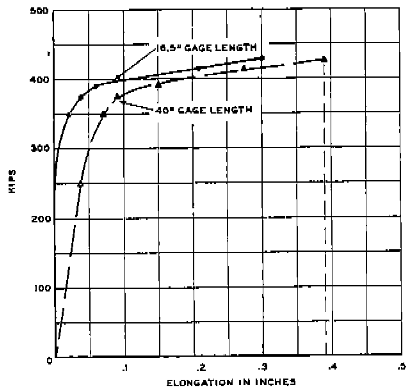


LEGEND:

SPECIMEN SIZE. 15" X 40" X 3/4"
FLAME CUT 135° "V" NOTCH

FIG. 32-C
LOAD-ELONGATION DIAGRAM
TYPE IV SPECIMEN
DN-C3 40°F

SWARTHMORE COLLEGE

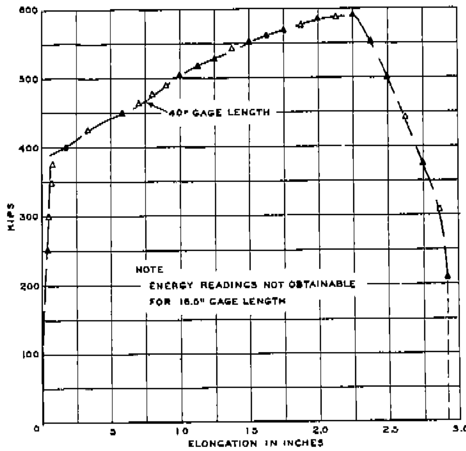


LEGEND

SPECIMEN SIZE: 15" X 40" X 3/4"
FLAME CUT 135° "V" NOTCH

FIG. 33-C
LOAD-ELONGATION DIAGRAM
TYPE IV SPECIMEN
DN-C1 10°F

SWARTHMORE COLLEGE

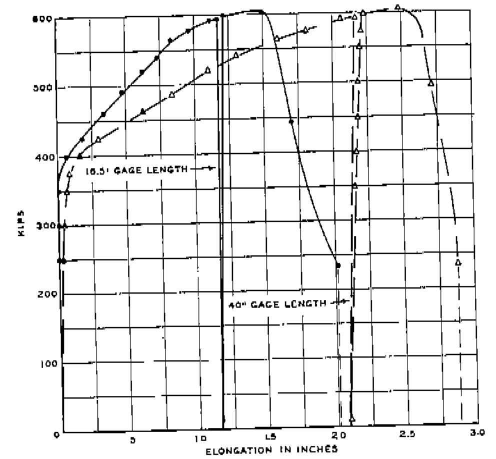


LEGEND

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 34-C
LOAD-ELONGATION DIAGRAM
TYPE V SPECIMEN
DN-VE12 40°F

SWARTHMORE COLLEGE

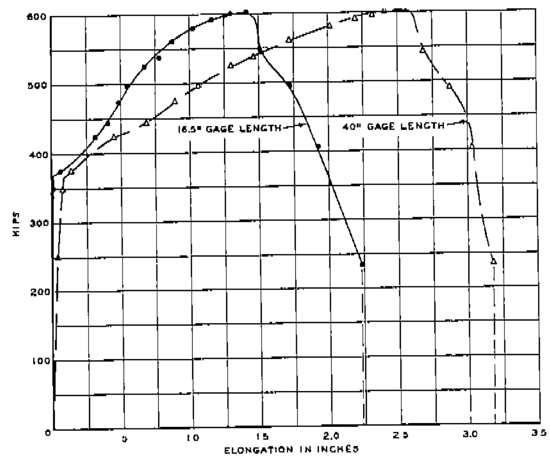


LEGEND.

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 35-C
LOAD-ELONGATION DIAGRAM
TYPE V SPECIMEN
DN-VE8 35°F

SWARTHMORE COLLEGE

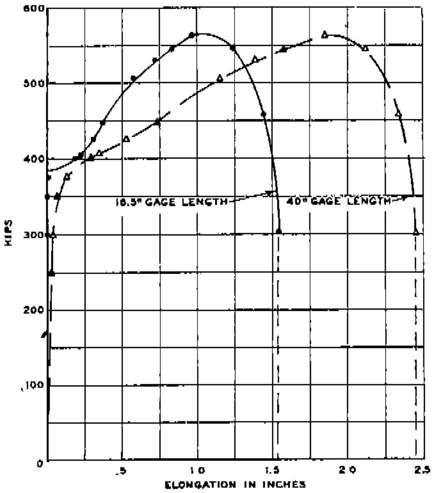


LEGEND:

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 36-C
LOAD-ELONGATION DIAGRAM
TYPE V SPECIMEN
DN-VF2 30°F

SWARTHMORE COLLEGE



LEGEND

SPECIMEN SIZE: 15" X 40" X $\frac{3}{4}$"

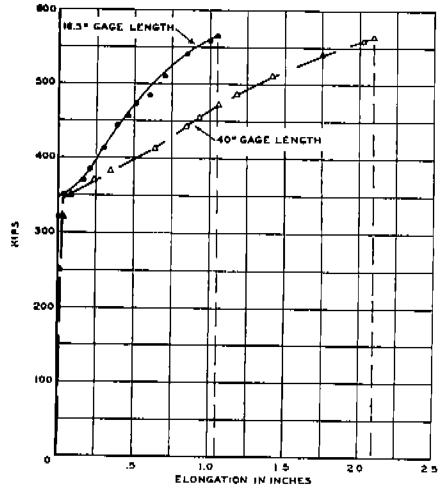
FIG. 37-C

LOAD-ELONGATION DIAGRAM

TYPE V SPECIMEN

DN-VE11 25°F

SWARTHMORE COLLEGE



LEGEND:

SPECIMEN SIZE: 15" X 40" X $\frac{3}{4}$"

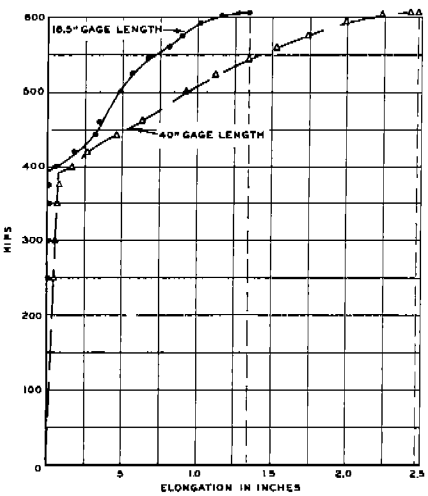
FIG. 38-C

LOAD-ELONGATION DIAGRAM

TYPE V SPECIMEN

DN-VG11 25°F

SWARTHMORE COLLEGE



LEGEND:

SPECIMEN SIZE. 15" X 40" X $\frac{3}{4}$"

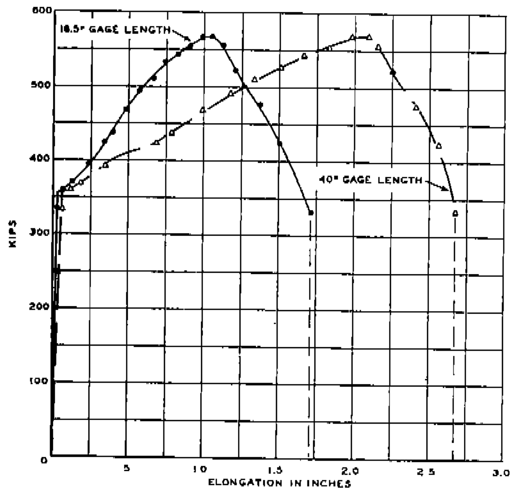
FIG. 39-C

LOAD-ELONGATION DIAGRAM

TYPE V SPECIMEN

DN-VF1 15°F

SWARTHMORE COLLEGE



LEGEND

SPECIMEN SIZE. 15" X 40" X $\frac{3}{4}$"

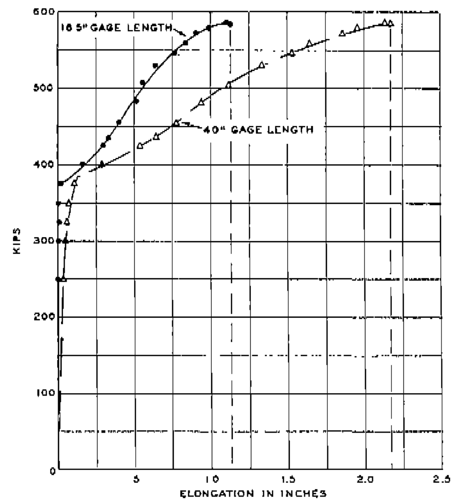
FIG. 40-C

LOAD-ELONGATION DIAGRAM

TYPE V SPECIMEN

DN-VG12 15°F

SWARTHMORE COLLEGE

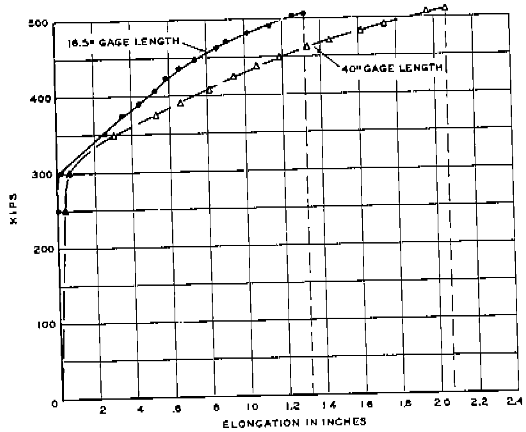


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"

FIG. 41-C
LOAD-ELONGATION DIAGRAM
TYPE V SPECIMEN
DN-VE10 10°F

SWARTHMORE COLLEGE

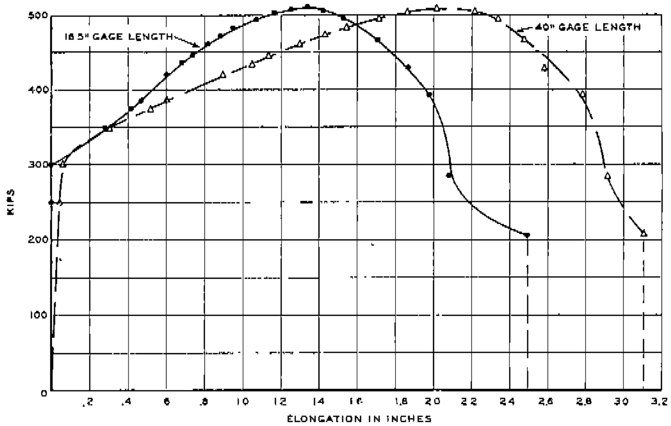


LEGEND:

SPECIMEN SIZE 15" X 40" X 3/4"

FIG. 42-C
LOAD-ELONGATION DIAGRAM
TYPE XI SPECIMEN
DN-XIC1 60°F

SWARTHMORE COLLEGE

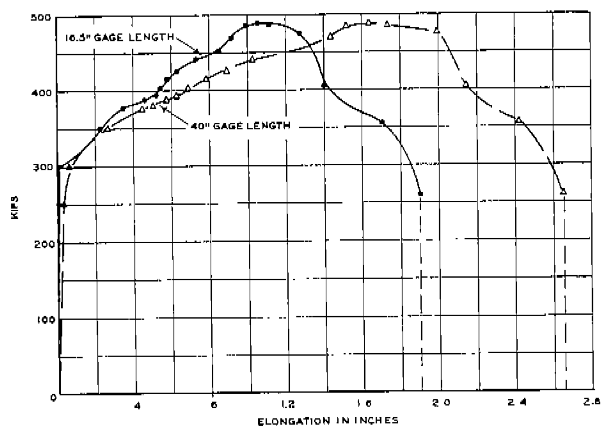


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"

FIG. 43-C
LOAD-ELONGATION DIAGRAM
TYPE XI SPECIMEN
DN-XIC3 50°F

SWARTHMORE COLLEGE

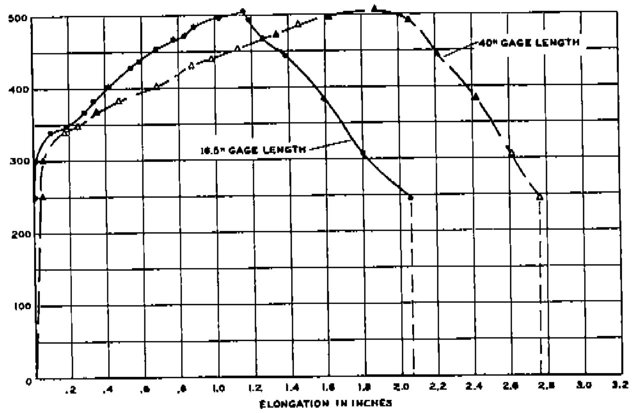


LEGEND

SPECIMEN SIZE. 15" X 40" X 3/4"

FIG. 44-C
LOAD-ELONGATION DIAGRAM
TYPE XI SPECIMEN
DN-XID5 45°F

SWARTHMORE COLLEGE

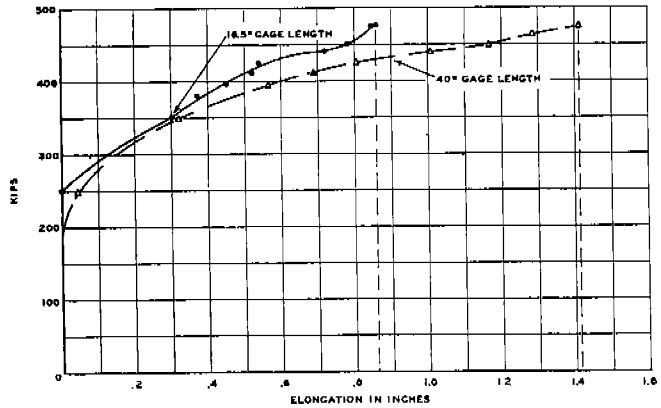


LEGEND

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 45-C
LOAD-ELONGATION DIAGRAM
TYPE XI SPECIMEN
DN-XID8 45°F

SWARTHMORE COLLEGE

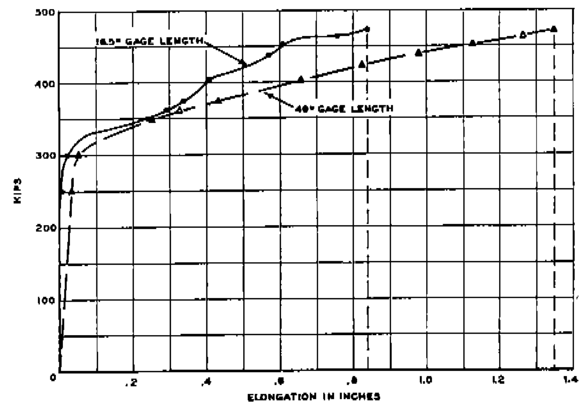


LEGEND:

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 46-C
LOAD-ELONGATION DIAGRAM
TYPE XI SPECIMEN
DN-XIC2 40°F

SWARTHMORE COLLEGE

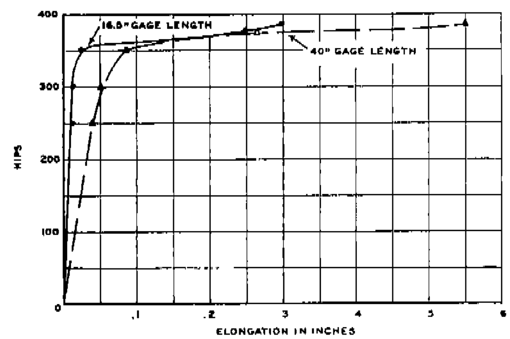


LEGEND:

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 47-C
LOAD-ELONGATION DIAGRAM
TYPE XI SPECIMEN
DN-XID7 35°F

SWARTHMORE COLLEGE

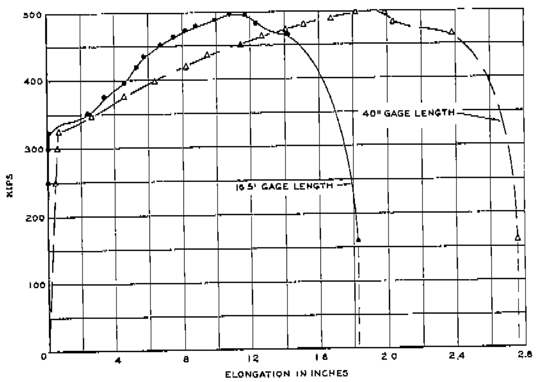


LEGEND:

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 48-C
LOAD-ELONGATION DIAGRAM
TYPE XI SPECIMEN
DN-XID4 20°F

SWARTHMORE COLLEGE

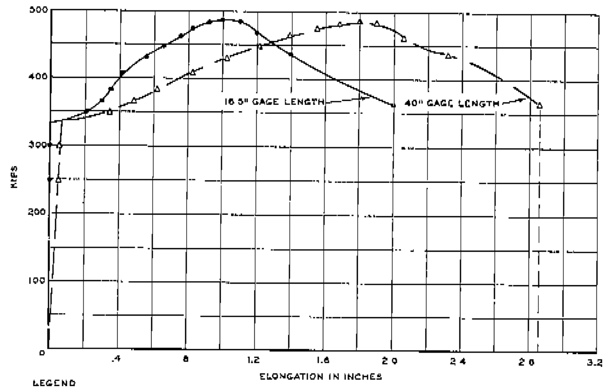


LEGEND

SPECIMEN SIZE: 15' X 40" X 3/4

FIG 49-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2D10 74°F

SWARTHMORE COLLEGE

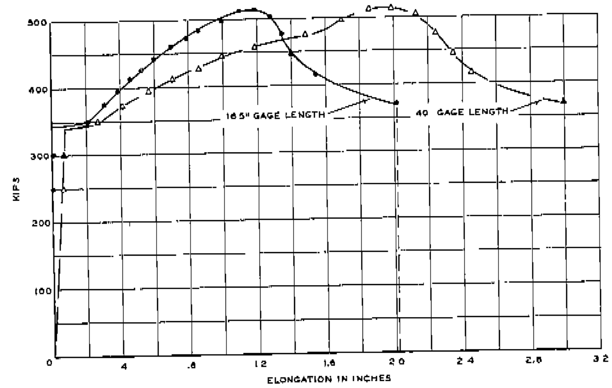


LEGEND

SPECIMEN SIZE 15' X 40" X 3/4"

FIG. 50-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2E2 60°F

SWARTHMORE COLLEGE

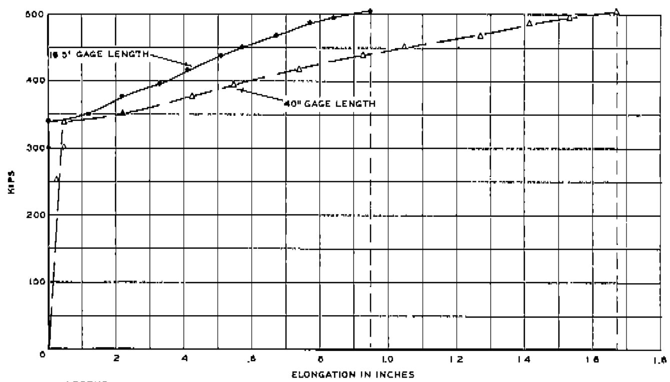


LEGEND.

SPECIMEN SIZE 15' X 40" X 3/4"

FIG. 51-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2E1 55°F

SWARTHMORE COLLEGE

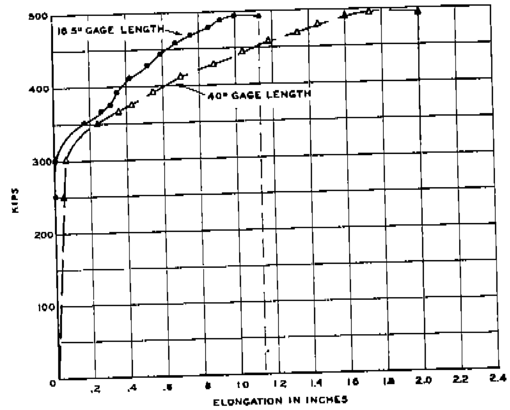


LEGEND

SPECIMEN SIZE. 15" X 40' X 3/4

FIG. 52-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2D11 50°F

SWARTHMORE COLLEGE

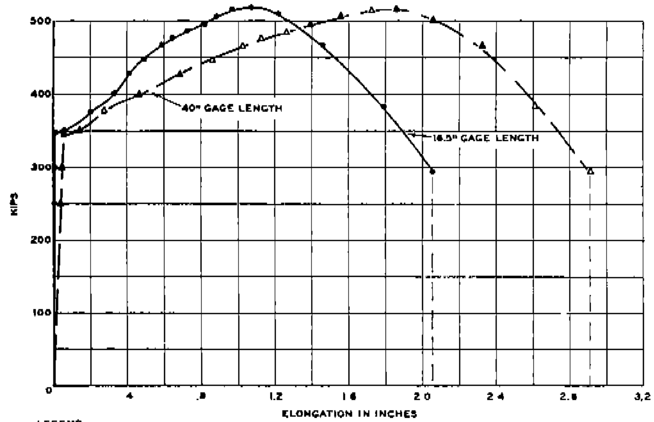


LEGEND

SPECIMEN SIZE 15" x 40" x 3/4"

FIG. 53-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2D3 50°F

SWARTHMORE COLLEGE

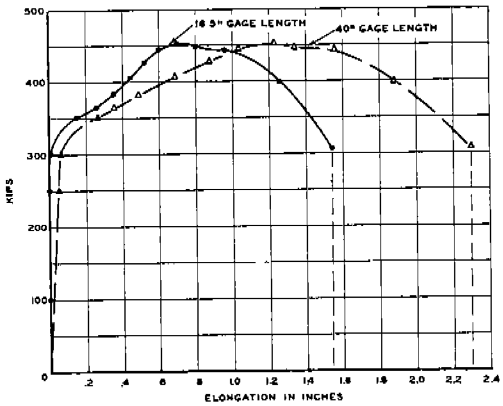


LEGEND.

SPECIMEN SIZE: 15" x 40" x 3/4"

FIG. 54-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2D9 40°F

SWARTHMORE COLLEGE

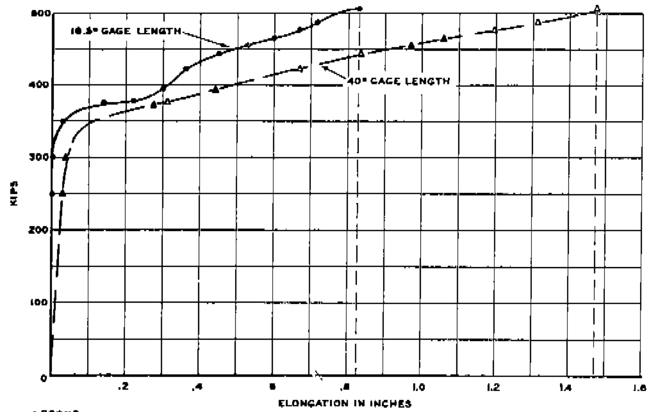


LEGEND

SPECIMEN SIZE: 15" x 40" x 3/4"

FIG. 55-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2D2 40°F

SWARTHMORE COLLEGE

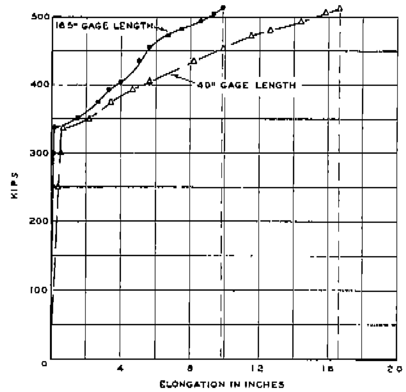


LEGEND

SPECIMEN SIZE: 15" x 40" x 3/4"

FIG. 56-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2D1 30°F

SWARTHMORE COLLEGE

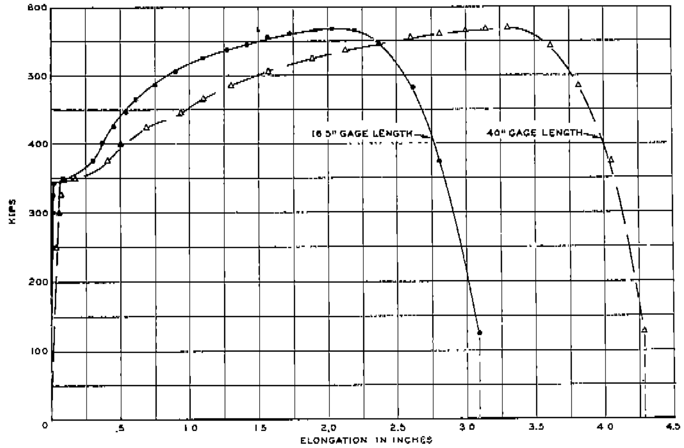


LEGEND.

SPECIMEN SIZE 15" X 40" X 3/4"

FIG 57-C
LOAD-ELONGATION DIAGRAM
TYPE X2 SPECIMEN
DN-X2D8 15°F

SWARTHMORE COLLEGE

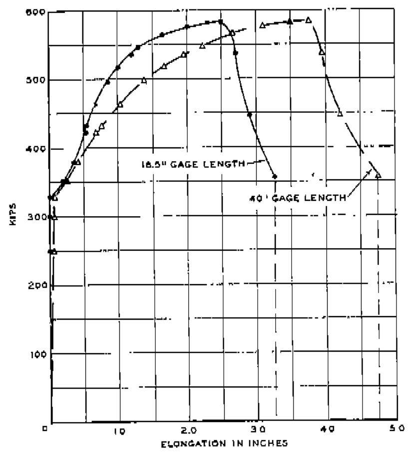


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"

FIG. 58-C
LOAD-ELONGATION DIAGRAM
TYPE X3 SPECIMEN
DN-X3E9 55°F

SWARTHMORE COLLEGE

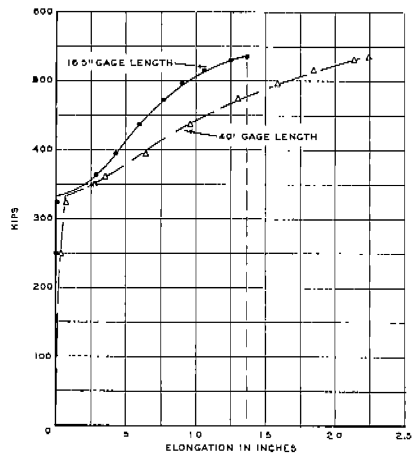


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4

FIG 59-C
LOAD-ELONGATION DIAGRAM
TYPE X3 SPECIMEN
DN-X3D12 45°F

SWARTHMORE COLLEGE

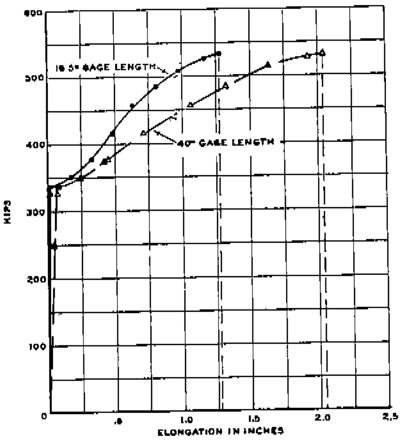


LEGEND

SPECIMEN SIZE 15" X 40" X 3/4

FIG. 60-C
LOAD-ELONGATION DIAGRAM
TYPE X3 SPECIMEN
DN-X3E6 40°F

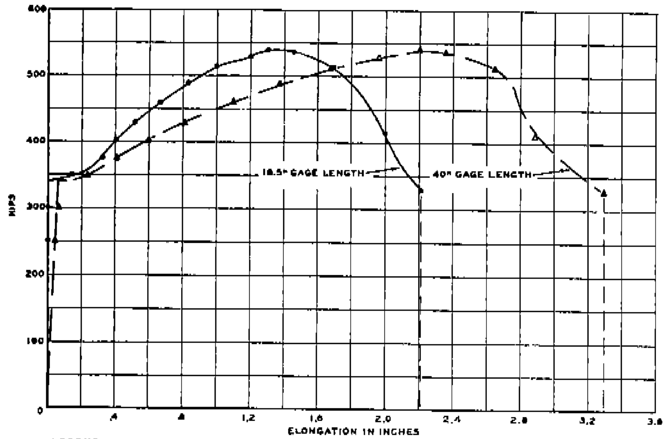
SWARTHMORE COLLEGE



LEGEND

SPECIMEN SIZE 15" X 40" X 3/4"

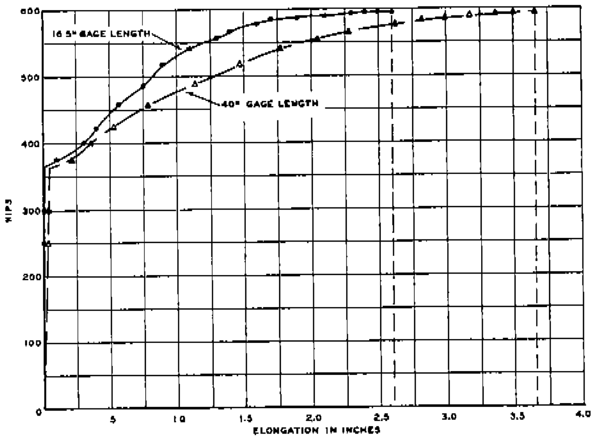
FIG. 61-C
LOAD-ELONGATION DIAGRAM
TYPE X3 SPECIMEN
DN-X3E7 40°F
SWARTHMORE COLLEGE



LEGEND:

SPECIMEN SIZE: 15" X 40" X 3/4"

FIG. 62-C
LOAD-ELONGATION DIAGRAM
TYPE X3 SPECIMEN
DN-X3E3 30°F
SWARTHMORE COLLEGE



LEGEND

SPECIMEN SIZE. 15" X 40" X 3/4"

FIG. 63-C
LOAD-ELONGATION DIAGRAM
TYPE X3 SPECIMEN
DN-X3E4 20°F
SWARTHMORE COLLEGE

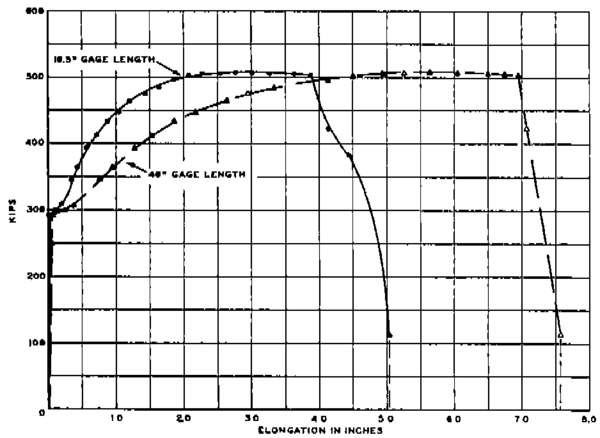


FIG. 64-C
LOAD-ELONGATION DIAGRAM
TYPE Y SPECIMEN
DN-Y - ʋI 40°F
SWARTHMORE COLLEGE

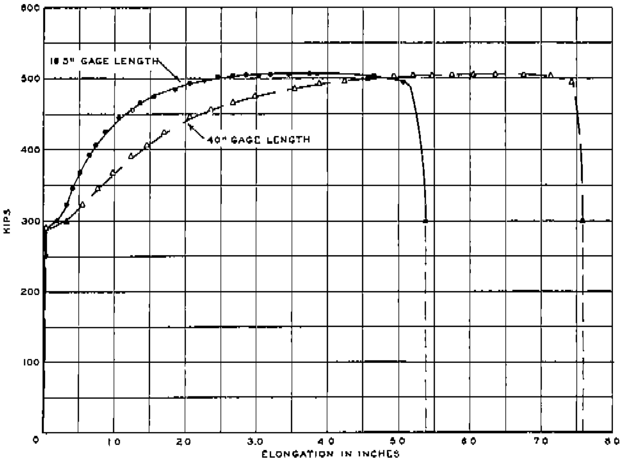


FIG. 65-C
LOAD-ELONGATION DIAGRAM
TYPE Y SPECIMEN
DN-Y - F12 30°F
SWARTHMORE COLLEGE

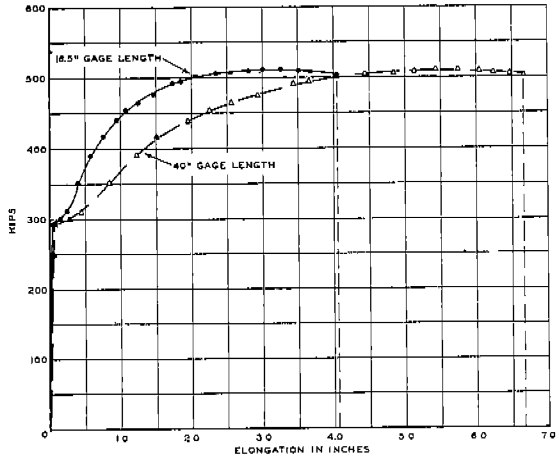


FIG. 66-C
LOAD-ELONGATION DIAGRAM
TYPE Y SPECIMEN
DN-Y - F13 20°F
SWARTHMORE COLLEGE

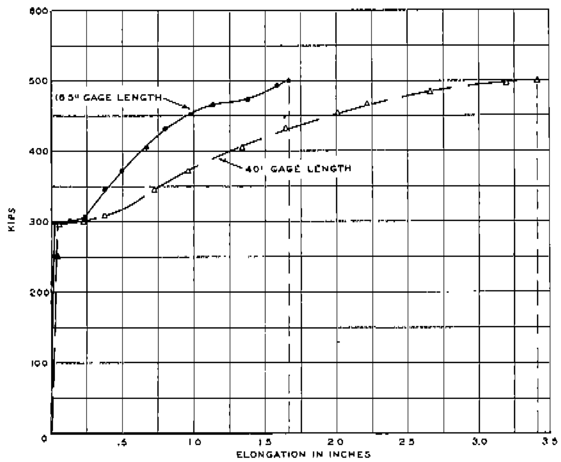


FIG. 67-C
LOAD-ELONGATION DIAGRAM
TYPE Y SPECIMEN
DN-Y - G3 0°F
SWARTHMORE COLLEGE

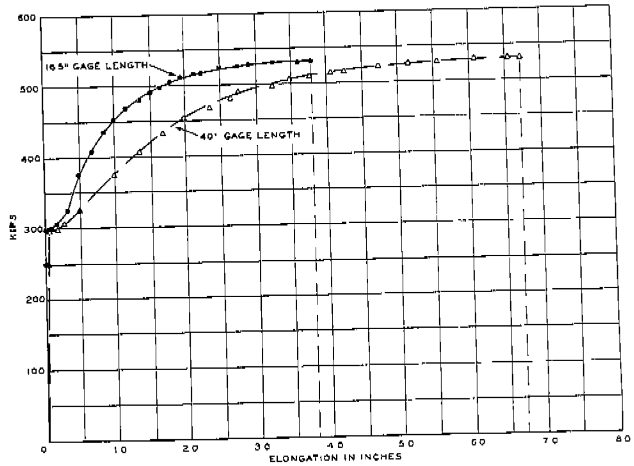


FIG. 68-C
LOAD-ELONGATION DIAGRAM
TYPE Y SPECIMEN
DN-Y-G10 0°F
SWARTHMORE COLLEGE

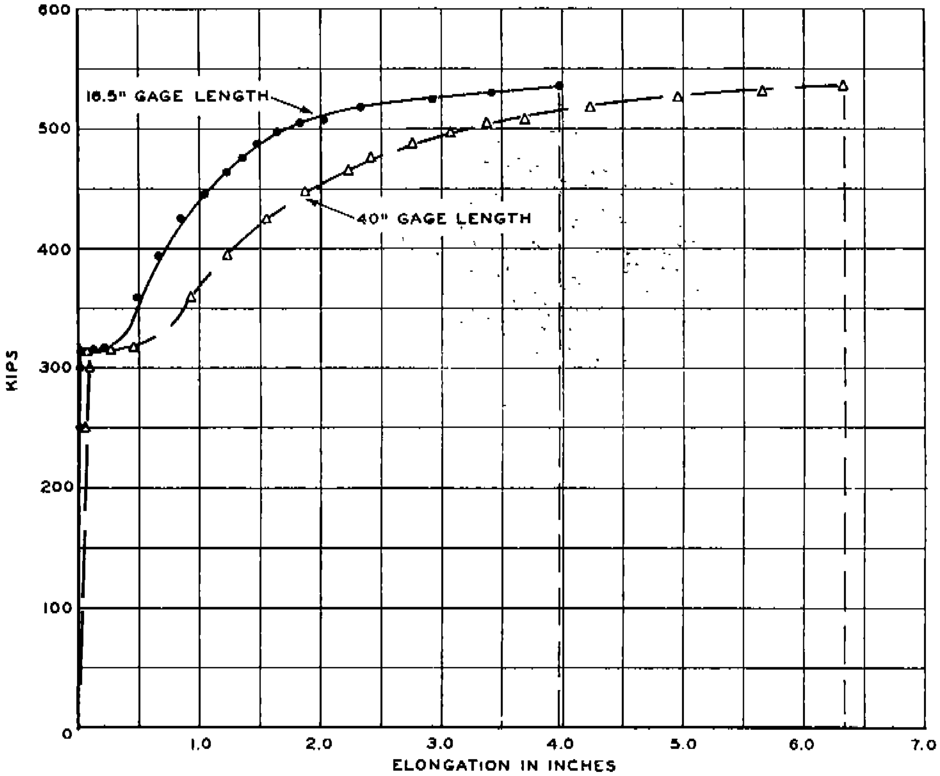


FIG. 69-C

LOAD-ELONGATION DIAGRAM

TYPE Y SPECIMEN

DN-Y - G2 -10°F

SWARTHMORE COLLEGE

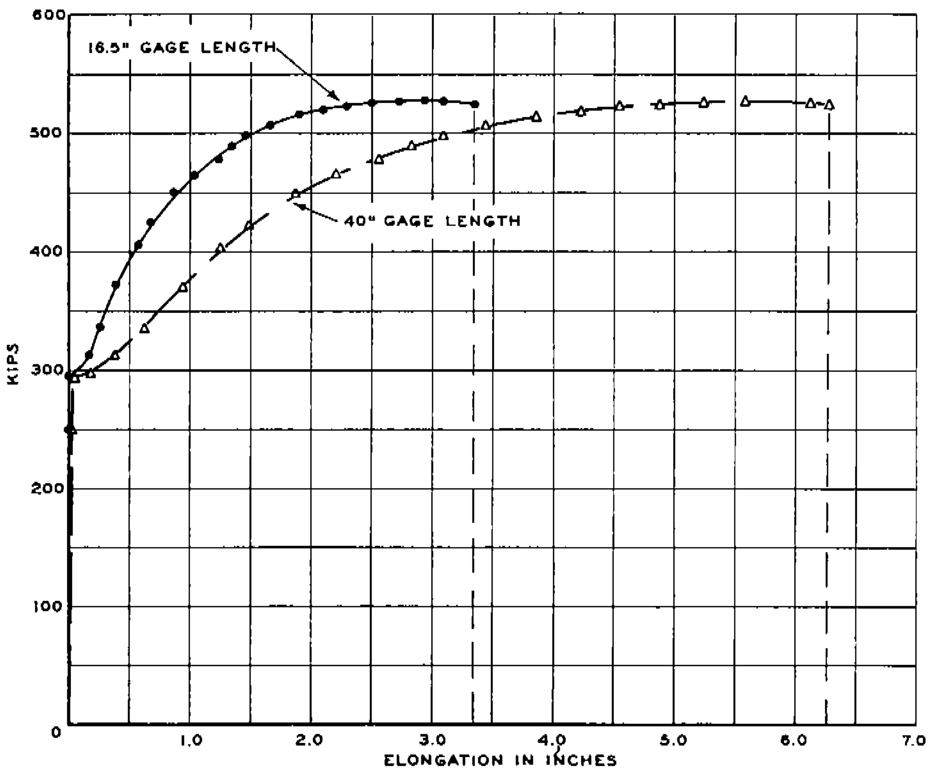


FIG. 70-C

LOAD-ELONGATION DIAGRAM

TYPE Y SPECIMEN

DN-Y-G9 -10°F

SWARTHMORE COLLEGE

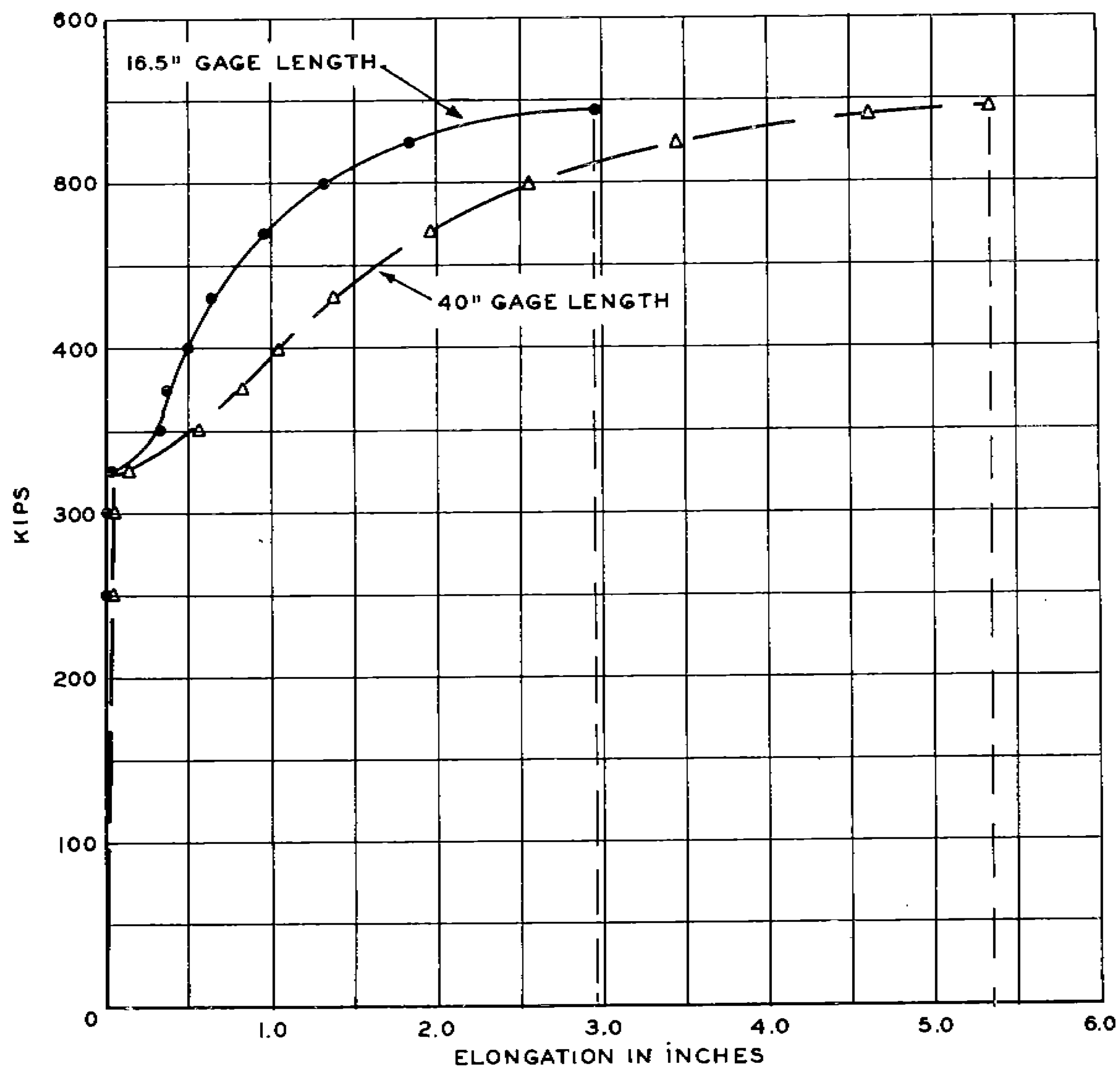


FIG. 71-C
LOAD-ELONGATION DIAGRAM
TYPE Y SPECIMEN
DN-Y - F9 -30°F
SWARTHMORE COLLEGE