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PROGRESS REPORT

ON

CORRELATION OF LABORATORY TESTS WITH FULL SCALE SHIP PLATE FRACTURE TESTS

BY

C. WAGNER AND E. P. KLIER

Pennsylvania State College
Under Bureau of Ships Contract NObs-31217

COMMITTEE ON SHIP CONSTRUCTION

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

NATIONAL RESEARCH COUNCIL

ADVISORY TO

SHIP STRUCTURE COMMITTEE

UNDER

Bureau of Ships, Navy Department
Contract NObs-34231

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Chief, Bureau of Ships
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Dear Sir:

Attached is Report Serial No. SSC-22 entitled "Correlation of Laboratory Tests with Full Scale Ship Plate Fracture Tests." This report has been submitted by the contractor as a progress report of the work done on Research Project SR-96 under contract NObs-31217 between the Bureau of Ships, Navy Department and the Pennsylvania State College.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Industrial 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,

C. Richard Soderberg

C. Richard Soderberg, Chairman
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Enclosure

Preface

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals who were actively associated with the research work. 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 Department, Bureau of Ships, Contract
NObs-31217, Project SR-96

CORRELATION OF LABORATORY TESTS WITH FULL SCALE SHIP PLATE FRACTURE TESTS

By: C. Wagner
E. P. Klier

MINERAL INDUSTRIES EXPERIMENT STATION
SCHOOL OF MINERAL INDUSTRIES
THE PENNSYLVANIA STATE COLLEGE
STATE COLLEGE, PENNSYLVANIA

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ABSTRACT

The present report summarizes the work done on a series of edge-notched tensile bars prepared from the project steels.

Evidence is presented to show that for the test specimen used, reasonable agreement exists between the transition temperatures obtained on the basis of per cent fibrous fracture and the transition temperatures for the large plate tension tests.

It is further shown that there is lack of agreement between transition temperatures based on fracture appearance and transition temperatures based on energy absorption for this test.

Lateral contraction measurements and total elongation measurements are given and show general conformity with energy absorption measurements, although much scatter of the data precludes a strict comparison.

LIST OF FIGURES

INTRODUCTION

Among the various tension tests developed at the University of California for the study of brittle fracture in ship plate steels[1], one employing a 3-inch wide edge-notched flat plate bar appeared to offer definite promise of correlation with the 72-inch wide plate internally notched tension test. This test bar while quite small, was still relatively large for laboratory use and actually was too large to be broken in a testing machine with 60,000 pound capacity. It appeared advisable to investigate this type of test using smaller test section sizes.

In the original tests[1] the method of determining transition temperature was based solely on fracture appearance. In the present testing program, it appeared advisable to obtain load-elongation curves in addition, for from the data of Tipper[2] change in length values remain nearly constant for the different testing temperatures for specimens of this type. This would indicate that the energy absorption is little affected on passing through the transition temperature for this test bar, since the load does not decrease.

The following have constituted the staff contributing to the completion of the work:

J. R. Low, Jr.	Technical Representative
M. Gensamer	Technical Advisor
F. C. Wagner	Supervisor
L. E. Colteryahn	Investigator
E. P. Klier	Investigator
D. E. Nulk	Investigator
M. A. Bishop	Research Assistant
E. Marks	Research Assistant
E. Tevlin	Drafting
D. W. Pease	Technical Labor
H. Colyer	Technical Labor
P. A. Vonada	Technical Labor

1,2 - See Bibliography

Steels:

The project steels studied have been listed and described in an earlier report[3]. All steels with the exception of F, G, and H have been studied in this investigation. The notation Bn (2) in figures 7, 16, 25, 34, 43, 52 and Appendix A is used because the plate of steel from which the specimens described herein were taken had a higher transition temperature in the slow bend test than those from the plate of Bn steel which was first tested. The steel from this latter plate may then be designated as Bn (1).

Testing Program:

Preliminary tests were conducted to determine the optimum specimen geometry with respect to adaptation of the test to a 60,000 pound capacity tensile machine. Figures 1 and 2 show the specimen finally adopted. Preliminary tests of 3/4" thick plate specimens having 1/2", 5/8", and 3/4" wide cross sections indicates that the 5/8" was the maximum width which could be tested without exceeding the capacity of the available testing machine.

The effect of notch radius was not exhaustively studied, but a few specimens having a 5/64" diameter round notch and also several with 0.01" radius V-notches were tested. The 5/8" width was maintained for all of these tests. The experimental results in terms of fracture type were essentially the same as those obtained for a 1/32" wide sawcut notch. Specimens with the sawcut notch were subsequently used exclusively because of the convenience with which this notch could be machined.

Tests at various temperatures were performed on the steels mentioned above for the sawcut notch and the transition range was determined according to energy absorption, fracture appearance, elongation, and maximum lateral contraction.

Specimen Preparation:

As described above, the specimen type used for the majority of these tests was a symmetrically notched flat tensile specimen with a cross section of 5/8" x the plate thickness (3/4"). The specimens were first shaped to the outer dimensions of 6" x 2-3/4" and were then laid out to allow the drilling of the 1" diameter holes and the sawing of the notches. The holes were reamed to size after drilling to produce a slide fit on the hardened steel supporting pins.

Two 1/4" diameter holes with center to center distance of 1 inch were drilled in one edge of the specimen, (see Fig. 1). These were used for the attachment of a wedge extensometer to the specimen. Figure 2 is a photograph of a specimen showing an edge and a side view of an unbroken specimen and also a side view of a broken specimen illustrating the appreciable elongation of the pin holes due to deformation around the pins.

After machining, a two inch gage length was marked off on the center line of the flat side of the specimen for final elongation measurements.

Testing Equipment:

The equipment used for testing consisted of pin and clevis connections for holding the specimen, an adaptor for attaching the wedge extensometer to the edge of the specimen, and a container for the coolant which could be lowered to allow removal or insertion of the specimen.

This equipment is illustrated in Figures 3 and 4, which show the testing assembly with the coolant container lowered for specimen change and in position for testing, respectively.

Testing Procedure:

The pins were inserted in the holes in the specimen while the coolant container was lowered as shown in Figure 3. At the same time the extensometer attachment was clamped to the edge of the specimen and the extensometer wedge was connected to the drum-type recorder. The coolant container was then raised to surround the specimen and filled with either water or an acetone and dry ice mixture, depending on the temperature of testing. After a period of ten minutes at the testing temperature, the specimen was broken using a cross-head movement of one inch per minute. During the test, the load vs. elongation curve was autographically recorded on the drum type recorder.

After the specimen was broken, the coolant medium was drained from the container, and the container was lowered to permit removal of the specimen. The measurements of lateral contraction in plate thickness at the fracture, elongation over two inches, and percent fibrous fracture were then made.

Representation of Data:

From the autographic load vs. elongation curves as illustrated in Figure 63, values of yield load (defined here as the first departure from the initial straight line portion of the curve), maximum load, and total energy absorption as determined from the area under the curve, were obtained. These values were plotted as a function of temperature, as were values of maximum change in plate thickness at the fracture surface, final elongation over a two inch gage length along the center line of the specimen, and percent fibrous fracture.

Curves were drawn only for the percent fibrous fracture data because of the pronounced scatter existing in the other sets of data described above. These curves were superimposed on the plots of data for the lateral contraction measurements, the energy absorption measurements, and the elongation measurements.

A transition temperature for each steel was selected from the percent fibrous fracture versus temperature curves as that temperature which corresponded to 50% fibrous fracture. These transition temperatures are listed in Table I in comparison with transition temperatures for the 72" wide flat plate tests as selected at 50% of maximum energy absorption.

A tabulation of all data is included in the appendix at the end of the report.

Results:

Transition curves (Figures 5-13) attained by visual estimate of the percent fibrous fracture are only in fair agreement with those obtained in the large plate tests, all of the steels tending to have a higher transition temperature in the present test with the exception of the results for Steel Br and Steel E. It can be noted here that the transition temperature for Steel Br is exceedingly low, which is in agreement with slow bend tests on this plate of steel[4].

It is evident from an examination of Figures 14 to 22, that the energy absorption vs. temperature data do not, for most of the steels, show transitions in the same temperature regions as the per cent fibrous fracture vs. temperature curves.

For the energy absorption values obtained, only steel Br shows a transition temperature coinciding with that based on fracture appearance, while the other data indicate energy transitions at temperatures considerably below the fracture appearance transition.

As mentioned previously, no specific values for energy transition temperatures were selected because of scattered data.

The discrepancies between the two modes of transition temperature representation are made evident by an examination of the data for Steels Dr and Dn. For the fracture-appearance data the transition temperature is above $+40^{\circ}F$ for both steels. From the energy absorption data the transition temperature appears to be about $-40^{\circ}F$.

The plotted data from lateral contraction measurements (Figures 23 to 31) and elongation measurements (Figures 32 to 40) are for the most part in agreement with each other. Certain discrepancies do exist, however, as is evident from an examination of the elongation curves for Steels C and Dn. Because of the nature of the fractures and the difficulty experienced in matching the broken specimens for elongation measurements it is believed that the data for the elongation measurements must be subject to much scatter.

Graphs showing yield point versus temperature and maximum load versus temperature are presented in Figures 41 to 49 and Figures 50 to 58 respectively. In both cases, the load value shows a tendency to increase as the temperature decreases. There was no instance of a sharp decrease in load on yielding at any temperature with this type of test.

Typical examples of mixed fracture surfaces are shown schematically in the drawings of Figures 59 to 62. The sequence illustrates the general pattern of change of fibrous fracture surface as it increases on a percentage basis from a "thumbnail" pattern at the edges of the specimen as shown in Figure 59, through successive "hourglass" patterns as in Figures 60 and 61, to a nearly completely fibrous fracture as in Figure 62.

Discussion of Results:

One aspect of the above results is of particular interest. This is the lack of agreement between the energy absorption and lateral contraction results and the fracture type results. In general it is accepted that a granular appearing fracture is not associated with appreciable toughness. But the above data indicate the exact contrary. This is particularly true for those steels which indicate appreciable energy absorption at the lower temperatures of testing, namely Steels H, Dr and Dn. It is evident that a basic inconsistency exists in these test data unless a factor not considered is operative in these tests. Such a factor may be the effect of strain on the transition temperature. It has been shown that prestrain markedly elevates the energy transition temperature in the standard Charpy keyhole test[3]. It has been shown further that this pretreatment is not essentially a strain aging process. That is, the alteration of the metal in the process of straining is such as to lead to an appreciable elevation of the transition temperature with little or no elapsed time between straining and testing. It is believed that this effect is operative in the present test.

Thus the possibility of three different test results exists, depending on the temperature range. First at high temperatures, ductile behavior (with attendant high energy absorption) and fibrous fracture are obtained. Second, in an intermediate temperature range, ductile behavior is still obtained, but the plastic strain during the course of the test elevates the transition temperature for cleavage failure, so that when fracture finally occurs it is of the cleavage type. The third case occurs when a temperature is reached which is low enough for cleavage fracture without prior strain. At this temperature, brittle behavior with low energy absorption, and cleavage fracture are obtained.

Conclusions:

1. For the edge-notched bar tension tests two transition ranges are observed - one associated with change in fracture type, the other with drop-off in energy absorption. The transition temperature determined from fracture appearance is in approximate agreement with the 72-inch wide plate test results,

while that determined from energy absorption is not.

2. The discrepancies between the transition temperatures given by energy absorption and fracture appearance data have been indicated as being due to a displacement of the fracture appearance transition to higher temperatures through prestrain arising during the course of initial loading of the test bar.

3. The transition temperature obtained for Steel Br is consistent with that obtained for the slow bend test.

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4. Wagner, F. C., and Klier, E. P., Progress Report "Correlation of Laboratory Tests with Full Scale Ship Plate Fracture Tests", U. S. Navy, NObs-31217, Serial No. SSC-18, May 1948.
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Table I

Comparison of Estimated Transition Temperatures of Edge-Notched Tension Tests and 72" Wide Internally Notched Tension Tests

Type of Test	Specimen Orientation	Transition Temperature Criterion	Transition Temperature – °F Steel E	C	A	Dr	Dn	Bn	Br	Q	H	N
1. 72" Wide Tension	- -	50% of max. energy absorption Ref. 1 & 5	100	90	35	30	28	31	32	–	20	-45
2. Edge-Notched Tension	Longitudinal	50% fibrous fracture	100	125	95	75	40	95	-30	45	75	–
difference (2.-1.)			0	+35	+60	+45	+12	+64	-62	--	+55	–
3. 12" Wide Tension (Swarthmore Data)	"	Lowest Temp. for 100% Fibrous Fract.	106	116	58	--	20	25	14	--	--	–
4. Edge-Notched Tension	"	"	110	130	110	80	40	100	-20	80	100	–
difference (4.-3.)			4	14	52	--	20	75	-34	--	--	–

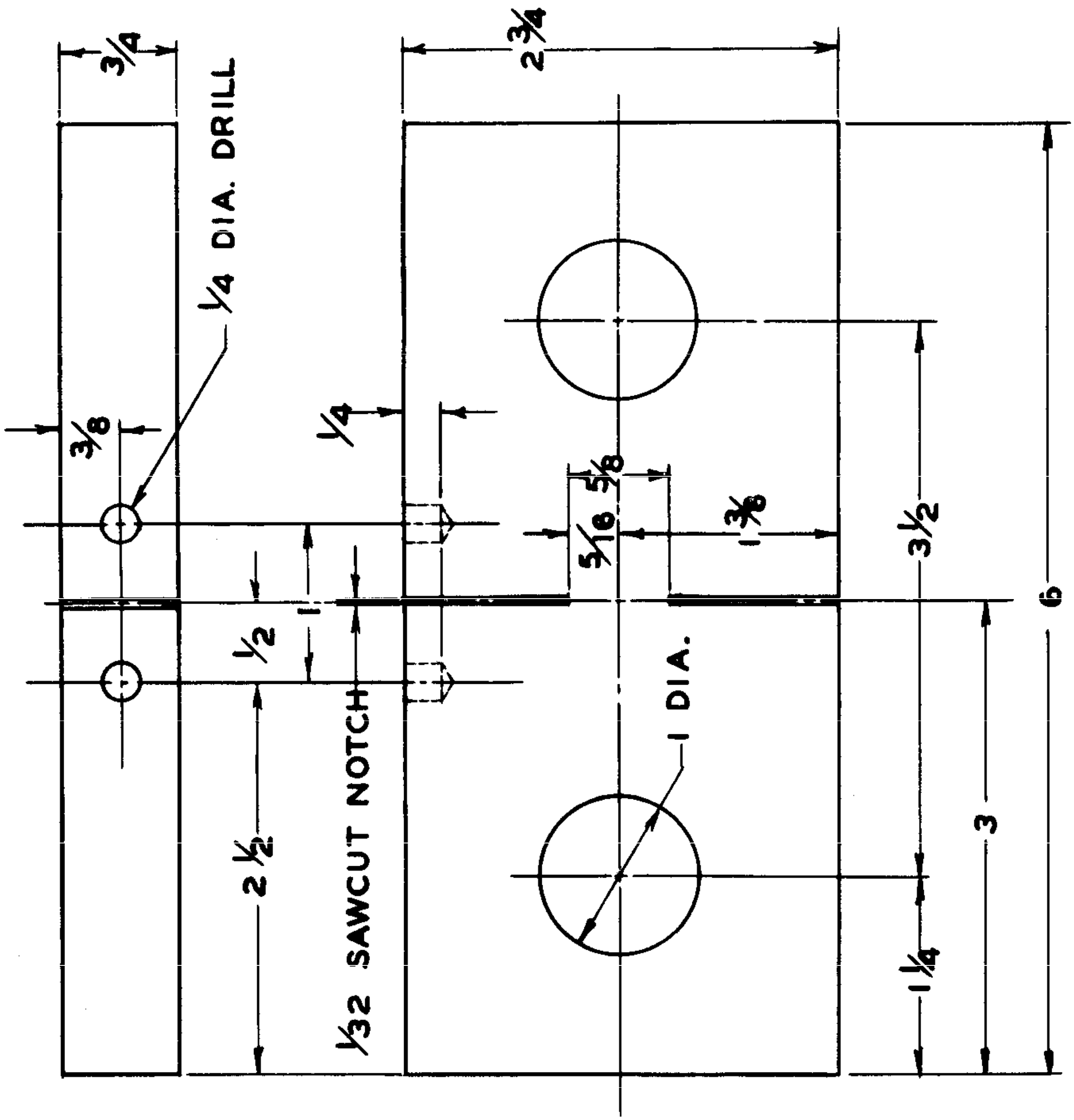
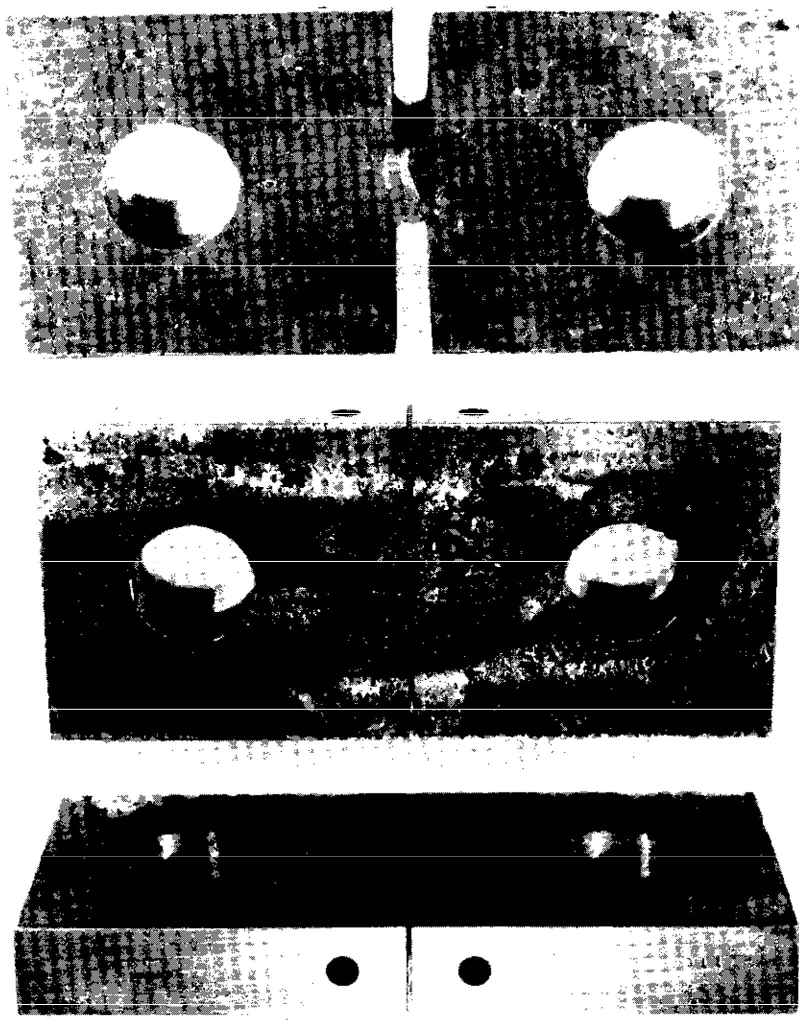
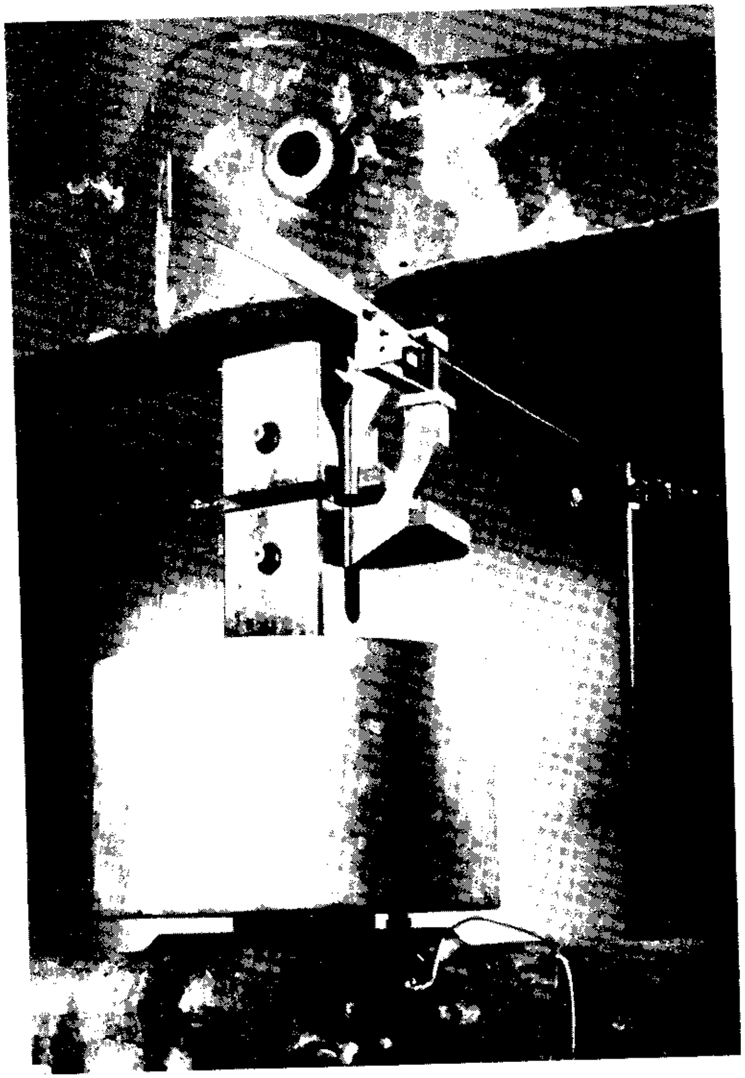

3/4
1/4 DIA. DRILL
3/8
1/4
2 3/4
5/8
5/16
1 3/8
3 1/2
6
1/2
1
2 1/2
1/32 SAWCUT NOTCH
1 DIA.
3
1 1/4

FIG. 1



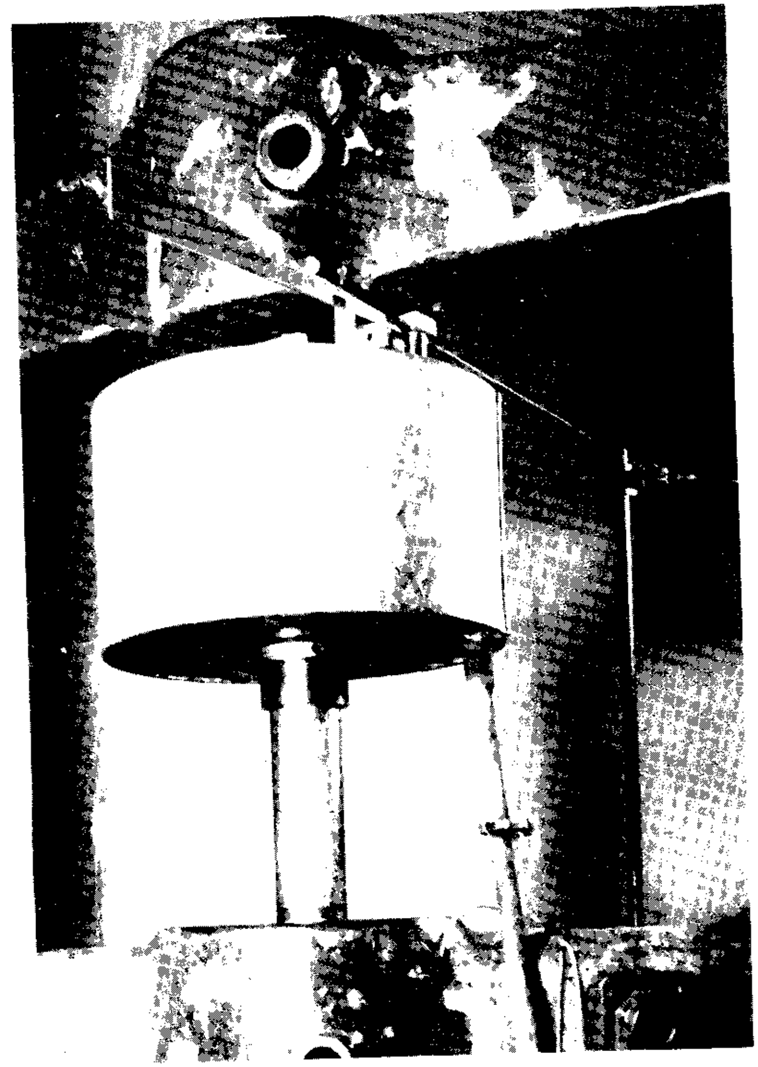
Photograph of Test Specimens

Fig. 2



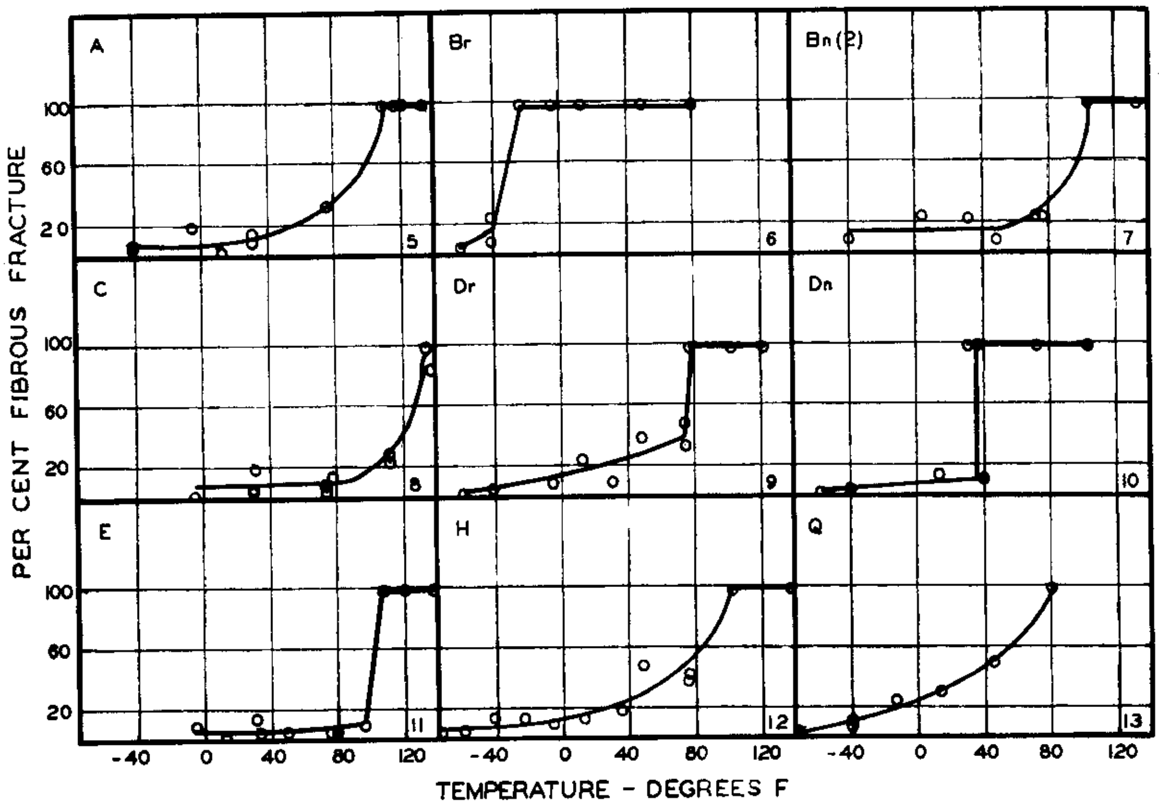
Testing Assembly, Coolant
Container Lowered

Fig. 3

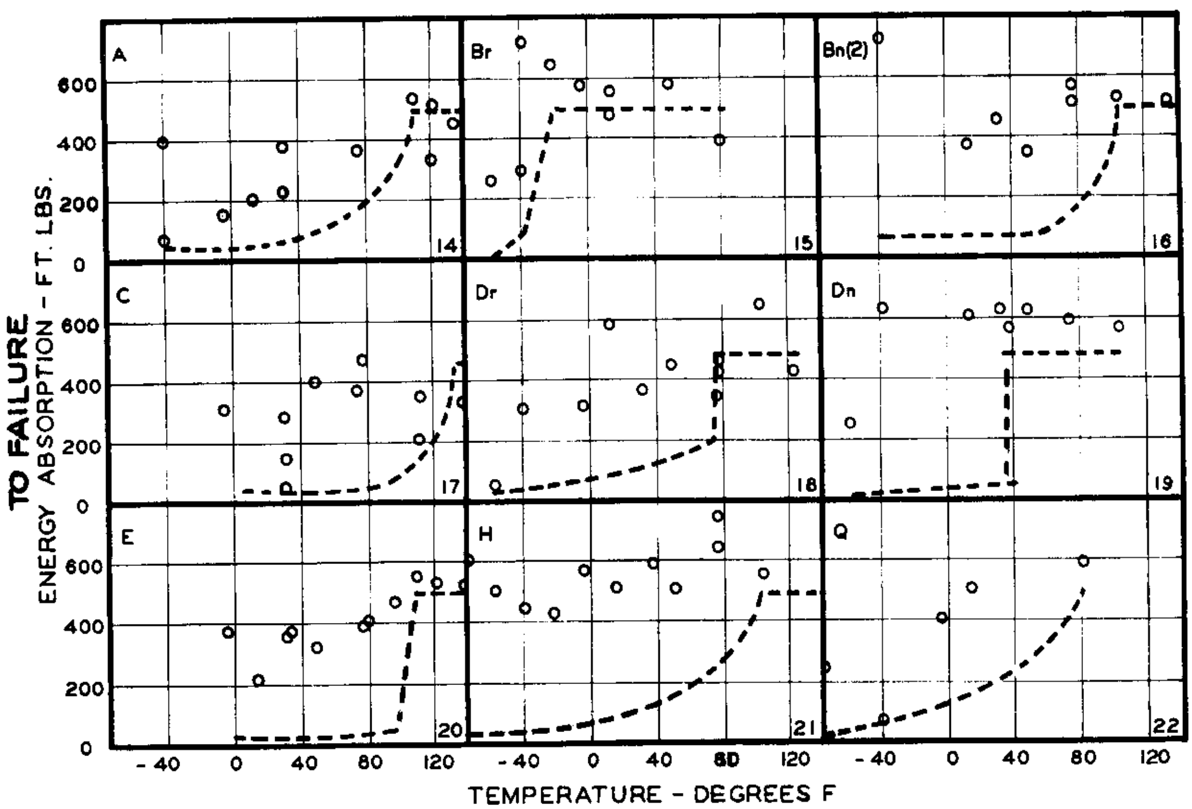


Testing Assembly in position
for Testing

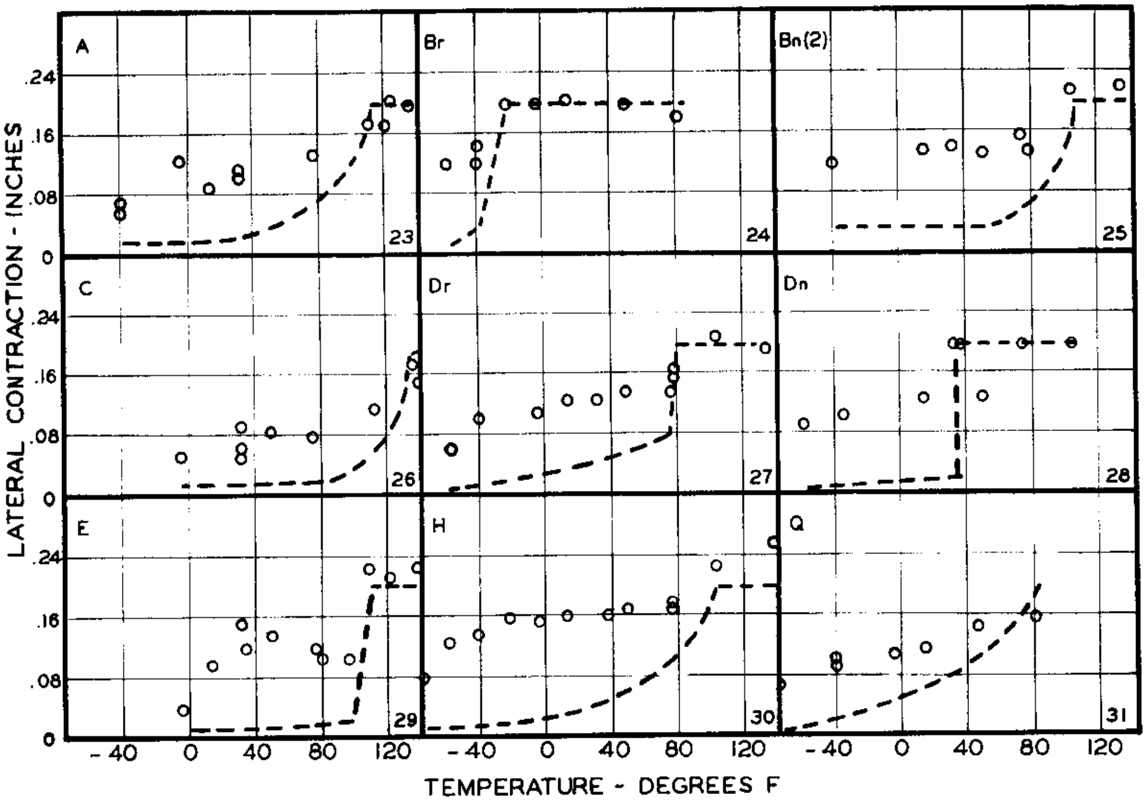
Fig. 4



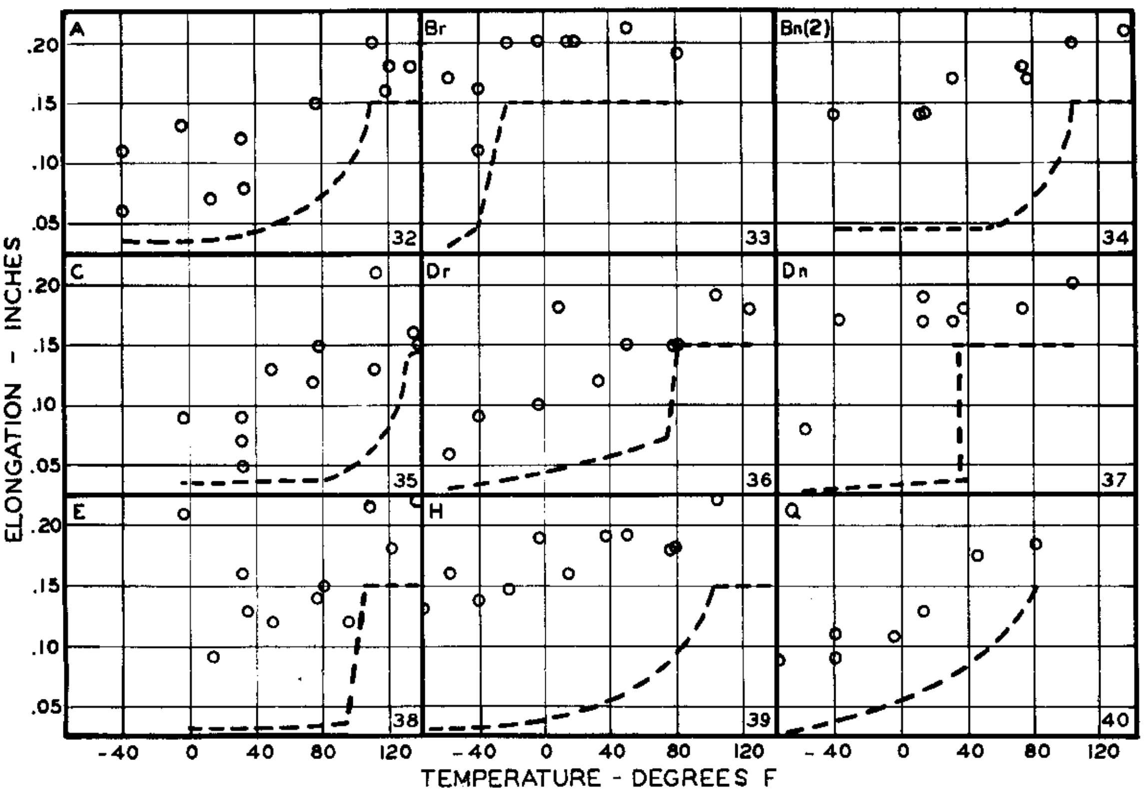
FIGURES 5-13 - FIBROUS FRACTURE VS TEMPERATURE



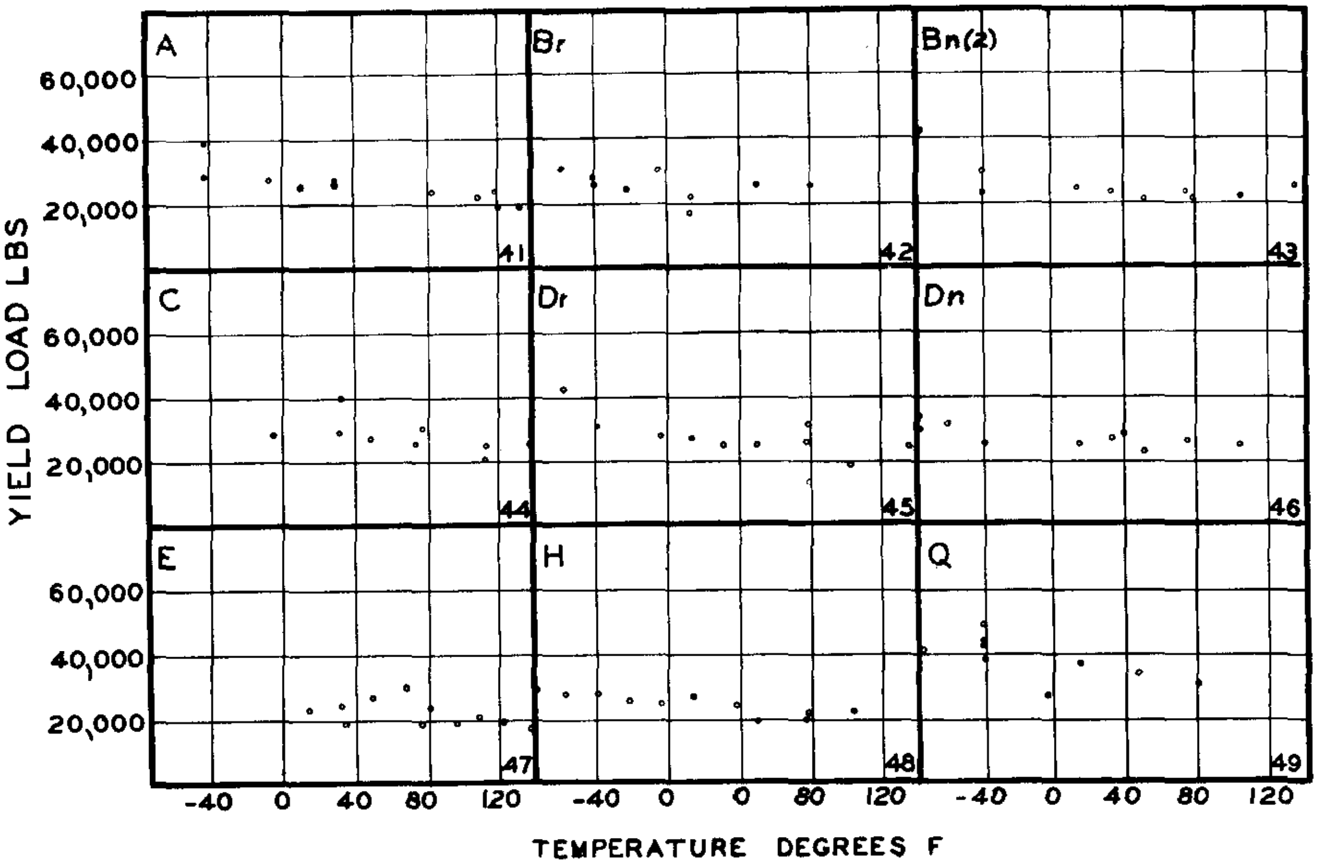
FIGURES 14-22 - ENERGY ABSORPTION VS TEMPERATURE
DASHED CURVES REPRESENT TRANSITION DATA BASED ON PER CENT FIBROUS FRACTURE.



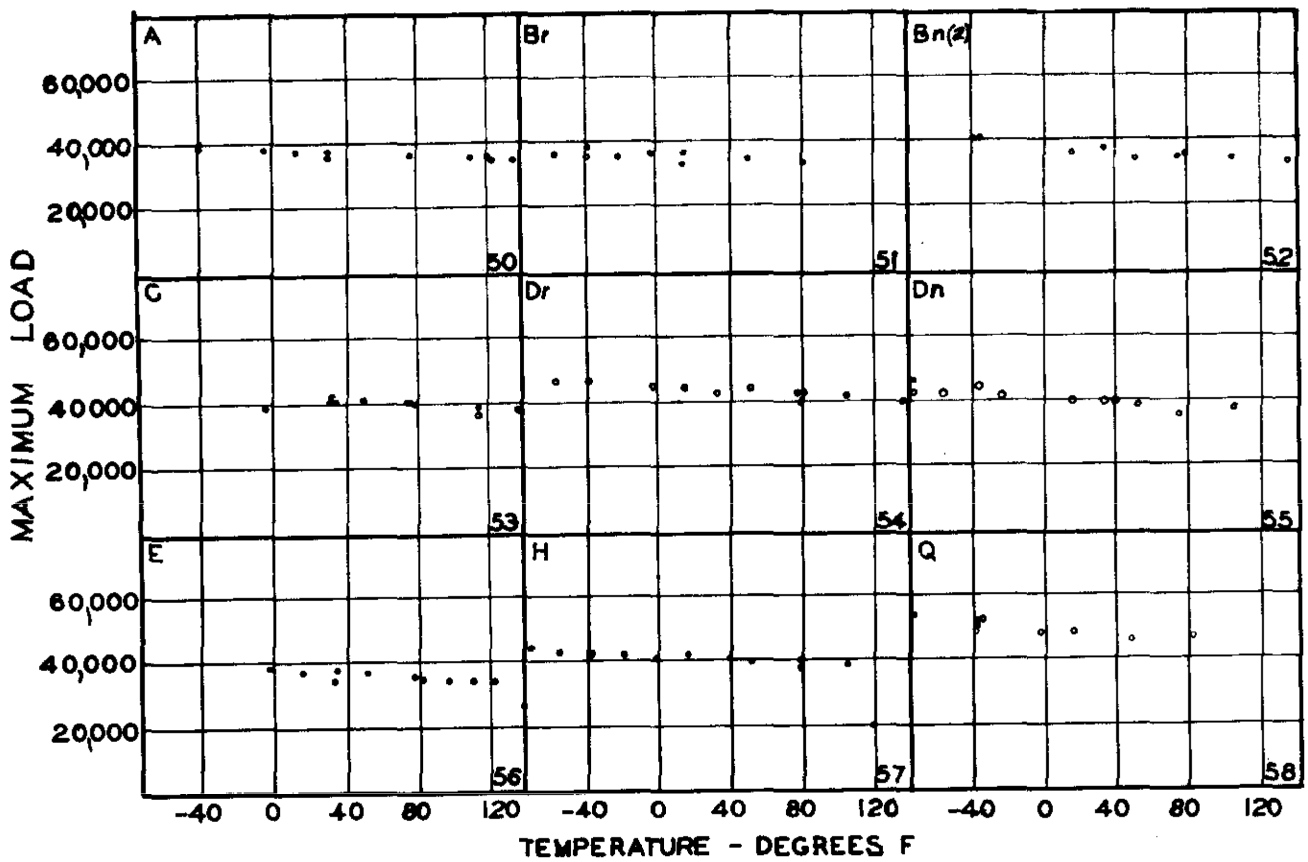
FIGURES 23-31 - LATERAL CONTRACTION VS TEMPERATURE
DASHED CURVES REPRESENT TRANSITION DATA BASED ON PER CENT FIBROUS FRACTURE.



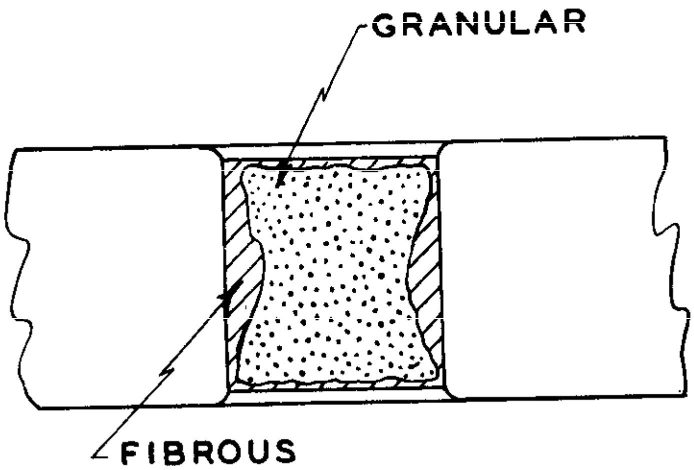
FIGURES 32-40 - ELONGATION VS TEMPERATURE
DASHED CURVES REPRESENT TRANSITION DATA BASED ON PER CENT FIBROUS FRACTURE.



FIGURES 41-49 - YIELD LOAD VS TEMPERATURE

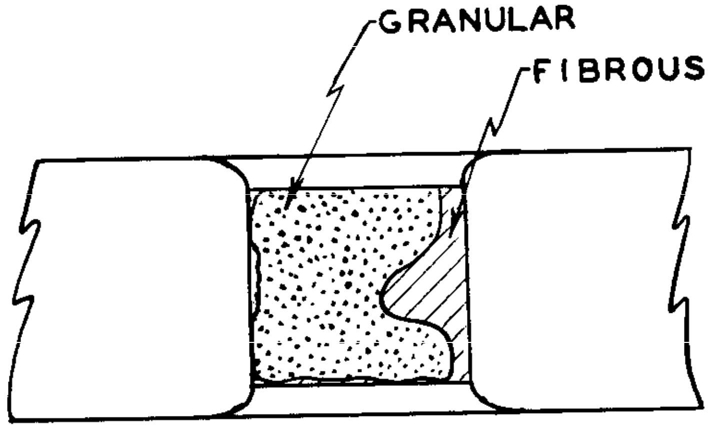


FIGURES 50-58 - MAXIMUM LOAD VS TEMPERATURE

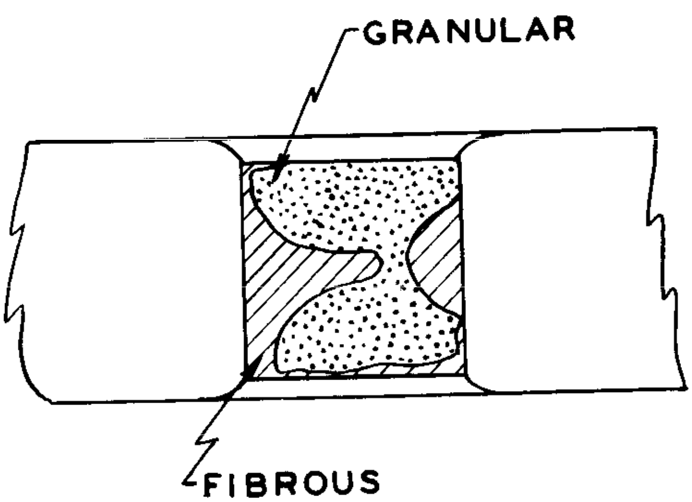


STEEL C
TEMPERATURE 113 °F

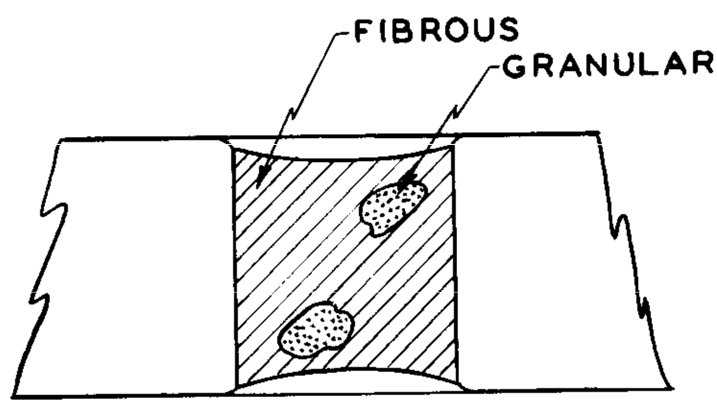
FIGURE 59



STEEL Bn
TEMPERATURE 77 °F
FIGURE 60

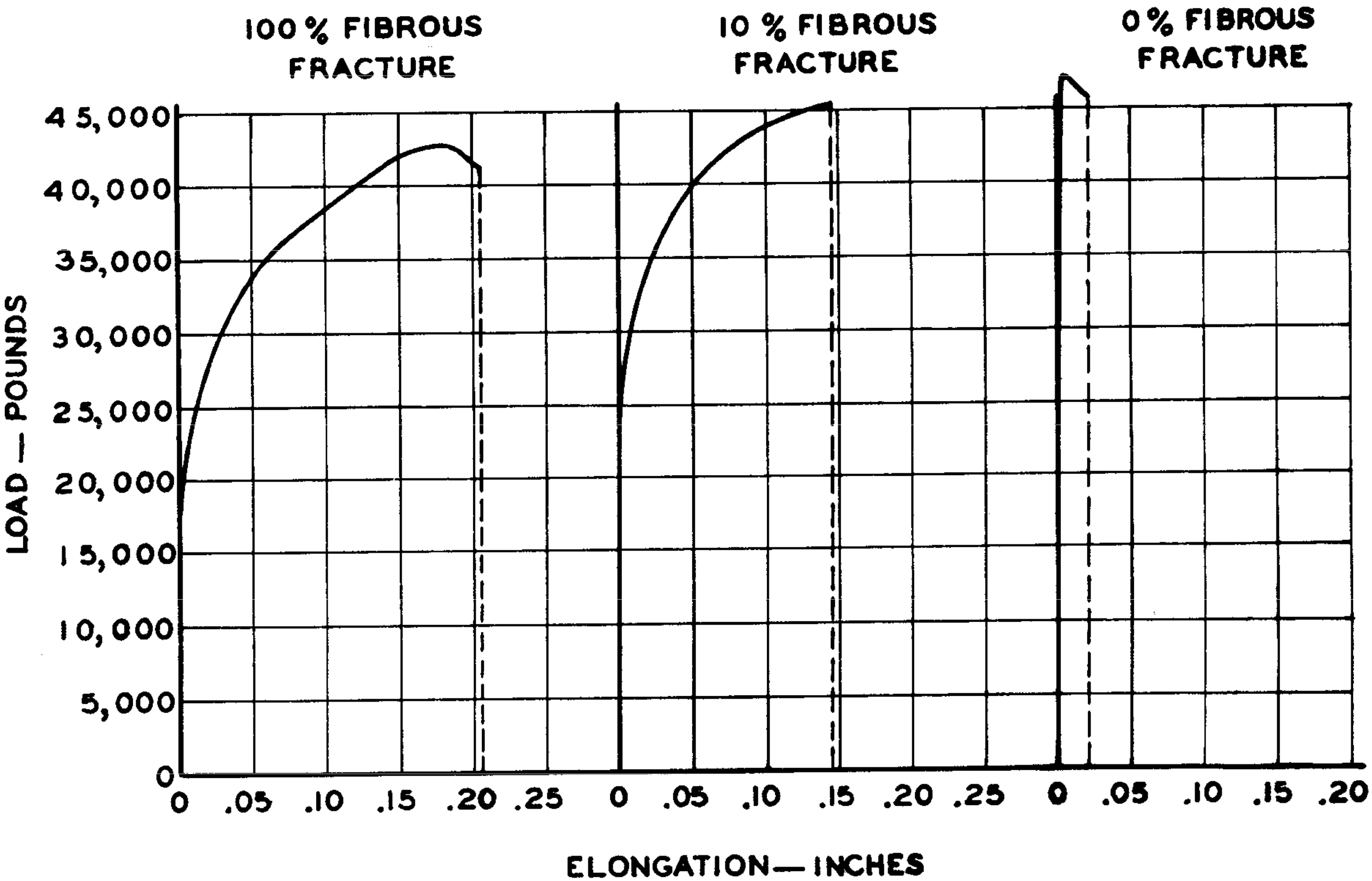


STEEL Dr
TEMPERATURE 79 °F
FIGURE 61



STEEL C
TEMPERATURE 140 °F
FIGURE 62

TYPICAL LOAD-ELONGATION DIAGRAMS FOR EDGE NOTCHED TENSION TEST — STEEL DR.



FIGURES 63

APPENDIX A

SUMMARY OF DATA

Temp. °F	Elong. 2"G.L.	Max. Load	Yield Load	Lateral Contraction	% Fibrous Fracture	Energy Absorption	Spec. No.
				Steel A			
134	.18	35,600	18,500	.194	100	447	A-5
122	.18	36,050	18,500	.200	100	513	A-12
120	.16	36,100	23,500	.169	100	323	A-10
111	.20	36,250	22,000	.173	100	536	A-4
77	.15	37,050	23,200	.130	35	366	A-6
32	.08	38,550	26,500	.099	10	221	A-1
32	.12	38,450	27,500	.109	10	374	A-7
14	.07	38,800	26,000	.088	2	203	A-2
14	.13	39,250	28,000	.120	20	149	A-8
-40	.06	39,975	39,800	.054	0	66	A-9
-40	.11	40,500	29,000	.066	0	390	A-11
				Steel Br			
81	.19	34,000	24,500	.181	100	391	Br-3
50	.21	35,000	24,600	.194	100	575	Br-11
14	.20	34,000	16,000	---	----	478	Br-1
14	.20	37,600	21,000	.206	100	549	Br-4
-4	.20	37,650	29,000	.198	100	568	Br-10
-22	.20	36,350	23,500	.199	100	638	Br-12
-40	.11	36,400	27,500	.120	10	292	Br-2
-40	.16	39,700	25,000	.140	25	719	Br-15
-58	.17	37,050	30,000	.119	5	258	Br-13
-70	.11	40,900	32,500	.098	0	501	Br-16
				Steel Bn(2)			
134	.21	34,100	24,500	.218	100	519	Bn-1
104	.20	35,400	20,800	.214	100	527	Bn-6
77	.17	36,700	20,500	.134	25	563	Bn-5
73	.18	36,000	22,500	.153	25	510	Bn-3
50	.14	35,200	20,000	.137	10	342	Bn-7
32	.17	38,350	22,200	.143	15	446	Bn-2
14	.14	37,750	24,000	.135	15	378	Bn-4
-40	.14	41,050	29,000	.119	10	724	Bn-11
-40	.14	41,950	22,000	.086	5	637	Bn-12
-70	.11	42,750	37,500	.095	5	237	Bn-13

Temp. °F	Elong. 2"G.L.	Max. Load	Yield Load	Lateral Contraction	%Fibrous Fracture	Energy Absorption	Spec. No.
				Steel C			
158	.22	37,650	21,000	--	100	417	C-17
140	.15	38,750	25,000	.148	85	326	C-18
126	.16	38,800	------	.172	100	---	C-7
113	.11	39,750	25,000	----	15	354	C-15
113	.13	37,900	20,500	.115	15	209	C-20
79	.15	40,300	30,800	----	15	465	C-11
75	.12	41,200	25,500	.075	10	376	C-8
50	.13	41,400	27,500	.082	5	400	C-13
32	.05	41,950	------	.067	0	142	C-6
-32	.09	42,500	29,000	.093	20	287	C-14
-32	.07	41,950	40,000	.050	2	49	C-19
-40	.09	39,900	28,500	.051	0	307	C-21
-70	.08	40,450	40,350	.026	0	183	C-22
				Steel Dr			
134	.18	40,900	24,000	.190	100	422	Dr-15
104	.19	42,100	19,500	.211	100	649	Dr-14
79	.15	40,500	30,500	.166	100	461	Dr-1
79	.15	43,100	13,000	.152	50	435	Dr-8
77	.21	42,500	25,000	.137	35	350	Dr-12
50	.15	44,200	24,500	.134	40	448	Dr-9
32	.12	42,950	24,500	.122	10	364	Dr-6
14	.18	44,600	26,500	.125	25	593	Dr-2
-4	.10	45,600	27,000	.108	10	310	Dr-7
-40	.09	47,600	30,500	.104	5	308	Dr-3
-58	.06	47,200	42,000	.062	0	58	Dr-11
-70	.08	47,800	47,800	.074	0	401	Dr-13
				Steel Dn			
104	.20	38,800	24,500	.199	100	472	Dn-10
74	.18	37,250	26,000	.194	100	498	Dn-6
50	.19	39,400	22,500	.123	10	530	Dn-5
37	.18	40,100	28,000	.195	100	472	Dn-2
32	.17	40,950	26,200	.198	100	531	Dn-11
14	.17	41,100	25,000	.121	15	511	Dn-1
-37	.17	45,400	24,500	.106	5	538	Dn-7
-58	.08	43,750	31,000	.092	2	254	Dn-4
-60	.10	43,900	29,500	.093	0	560	Dn-12
-60	.12	46,600	34,000	.092	5	676	Dn-14
-70	.09	47,000	31,500	.091	10	658	Dn-13

Temp. °F	Elong. 2"G.I.	Max. Load	Yield Load	Lateral Contraction	% Fibrous Fracture	Energy Absorption	Spec. No.
				Steel E			
138	.22	26,600	17,500	.225	100	527	E-3
122	.18	34,350	19,500	.210	100	537	E-16
110	.21	35,050	20,500	.221	100	555	E-12
97	.12	35,100	19,500	.104	10	464	E-10
82	.15	35,650	23,500	.103	5	405	E-2
77	.14	36,250	18,500	.117	5	396	E-13
50	.12	36,700	27,600	.135	5	328	E-11
34	.13	38,000	19,500	.114	5	363	E-4
32	.16	35,250	25,000	.150	15	355	E-15
14	.09	37,500	23,500	.097	2	219	E-5
-4	.16	38,600	30,000	.034	10	375	E-14
				Steel H			
212	.21	36,550	20,500	.247	100	487	H-15
104	.22	39,300	22,500	.224	100	560	H-10
77	.18	39,950	21,700	.167	40	643	H-13
77	.18	40,450	20,000	.175	40	743	H-14
50	.19	40,500	19,500	.169	50	508	H-12
37	.19	41,550	24,000	.155	20	585	H-5
14	.16	42,450	27,000	.160	15	510	H-1
-4	.19	41,750	25,000	.151	10	577	H-4
-22	.15	43,000	26,000	.157	15	429	H-2
-40	.14	42,900	28,000	.137	15	442	H-6
-58	.16	43,500	28,000	.126	5	510	H-3
-76	.13	45,200	29,000	.079	0	609	H-13
				Steel Q			
82	.16	48,300	31,000	.198	100	594	Q-5
47	.15	47,500	34,000	.146	50	---	Q-6
14	.13	49,900	37,500	.119	33	516	Q-1
-4	.11	49,750	27,500	.109	25	403	Q-2
-40	.09	49,900	49,400	.100	8	---	Q-3
-40	.11	51,850	38,500	.106	10	79	Q-10
-40	.08	52,600	42,000	.077	0	455	Q-13
-40	.09	53,650	43,500	.063	0	728	Q-14
-70	.09	54,200	44,500	.070	0	400	Q-11
-70	.11	57,300	44,500	.076	10	523	Q-12
-76	.09	54,800	41,500	.071	3	244	Q-4