PROGRESS REPORT

ON

PART I - TWELVE INCH FLAT PLATE TESTS

PART II - ASPECT RATIO PROGRAM

BY

S. T. CARPENTER, W. P. ROOP, E. KASTEN and A. ZELL

SWARTHMORE COLLEGE
Under Bureau of Ships Contract NObs-45521

Transmitted through
NATIONAL RESEARCH COUNCIL'S
COMMITTEE ON SHIP STEEL
Advisory to
SHIP STRUCTURE COMMITTEE
under
Bureau of Ships, Navy Department
Contract NObs-50148

Division of Engineering and Industrial Research
National Research Council
Washington, D. C.
December 15, 1949
Chief, Bureau of Ships  
Code 343  
Navy Department  
Washington 25, D. C.

Dear Sir:

Attached is Report Serial No. SSC-35 entitled "Twelve Inch Flat Plate Tests." This report has been submitted by the contractor as a Progress Report of the work done on Research Project SR-98 under Contract NObs-45521 between the Bureau of Ships, Navy Department and Swarthmore College.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Steel, 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,

R. F. Mehl, Chairman  
Committee on Ship Steel

RFTmwh
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PROGRESS REPORT

NAVY SHIPS CONTRACT NORS-45521

PROJECT SR-98

PART I

TWELVE INCH FLAT PLATE TESTS

PART II

ASPECT RATIO PROGRAM

FROM: DIVISION OF ENGINEERING
SWARTHMORE COLLEGE
SWARTHMORE, PA.

REPORT PREPARED BY:

SAMUEL T. CARPENTER
WENDELL P. ROOP
EWALD KASTEN
ADOLPH ZELL

STRUCTURAL LABORATORY
SWARTHMORE COLLEGE
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ABSTRACT

Part I of this report states the test results for the following steels: "W", S-9, S-12, and S-22. The tests of Part I are tension tests run at various temperatures on specimens 24" long, 12" wide and 3/4" thick, having a central internal notch one-quarter of the width of the plate with ends of the notch 0.010 inch wide made by a jeweler's hack-saw. The load was applied in the direction of rolling. The report contains tables giving the load at first visible crack, at maximum load, and at the failure load, together with the energies computed to these loads. Load elongation curves for each specimen tested are included, together with diagrams showing maximum load, vs. temperature and diagrams showing energy to maximum load vs. temperature. The character of the fracture as determined by the percentage of shear failure is also given.

The transition temperature zones of these steels on the basis of both energy considerations and the mode of the fracture are reported.

Part II of this report describes the aspect ratio program now under way to determine the effect of plate width and thickness on transition temperature.
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- Fig. 1-S-22 to Fig. 7-S-22 inclusive
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PROGRESS REPORT

on

Tension Tests of Flat Internally-Notched Plates

PART I

TWELVE INCH FLAT PLATE TESTS

The results presented in Part I represent a continuation of the investigation of 12" wide full-thickness specimens of steel plates tested with temperature as a variable. Each specimen contained a centrally located internal notch 3" wide terminating with a jeweler's hack-saw cut 1/8" long and 0.010" wide. (See Fig. 1). All tests were made with tension loading applied in the direction of rolling. The techniques employed in carrying out these tests have been reported in a previous paper.

The physical behavior of the steels with respect to maximum loads, strain energy and mode of fracture was investigated with the principal purpose of establishing transition temperatures based upon 24" long and 12" wide by 3/4" thick specimens.

The steels tested and reported are designated as "W", "S-9", "S-12" and "S-22".

The chemical analysis of these steels is as follows:

Chemical Analysis²

<table>
<thead>
<tr>
<th>Code</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Al</th>
<th>N</th>
<th>Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>.21</td>
<td>.52</td>
<td>.23</td>
<td>.006</td>
<td>.005</td>
<td>Fully-killed</td>
</tr>
<tr>
<td>S-9</td>
<td>.18</td>
<td>.50</td>
<td>.07</td>
<td>.002</td>
<td>.004</td>
<td>Semi-killed</td>
</tr>
<tr>
<td>S-12</td>
<td>.19</td>
<td>.77</td>
<td>.07</td>
<td>.04</td>
<td>.004</td>
<td>Semi-killed, fine grained</td>
</tr>
<tr>
<td>S-22</td>
<td>.19</td>
<td>.77</td>
<td>.09</td>
<td>.006</td>
<td>.004</td>
<td>&quot;  &quot; coarse &quot;</td>
</tr>
</tbody>
</table>

*Numerals refer to reference in Bibliography
S-9 is an A.S.T.M.-A7-46 steel. It is to be noted that S-12 and S-22 which are nominally ABS Class B steels are from the same heat.

Results of tensile tests of these steels are as follows:

<table>
<thead>
<tr>
<th>Code</th>
<th>Yield Point (P.S.I.)</th>
<th>Ultimate P.S.I.</th>
<th>% Elongation in 8&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>37,230</td>
<td>62,540</td>
<td>30.3</td>
</tr>
<tr>
<td>S-9</td>
<td>32,600</td>
<td>57,900</td>
<td>34.5</td>
</tr>
<tr>
<td>S-12</td>
<td>34,700</td>
<td>64,100</td>
<td>28.0</td>
</tr>
<tr>
<td>S-22</td>
<td>35,000</td>
<td>63,800</td>
<td>32.0</td>
</tr>
</tbody>
</table>

**Specimen Identification**

The locations of the specimens in the plate are shown on the figures giving load and energy data for each steel. The specimen marked S-12-8 identifies specimen No. 8 from the plate of S-12 steel. A similar notation is used for the S-9 and S-22 steels.

The notation for the specimens of "W" steel is similar except that W-32-8 identifies specimen No. 8, from plate No. 32 of "W" steel.

**INSTRUMENTATION**

Elongation Measurement: To determine strain energy it was necessary to measure the elongation of the test specimens. The gage length was established as three-quarters of the width of the plate, or 9" with the ends of the gage length 4½" above and below the notch. The instrument developed permitted a determination of the elongations of the plate in both the elastic and plastic range. Bakelite SR-4 gages are used in these instruments. The elongations were measured over twelve separate gage lines. Five of the gage lines were
on each of the 12" faces of the plate and two of the gage lines were on the edges. The five gage lines on the face of the plate were located as follows: one at the longitudinal centerline of plate, two 1/2" either side of the centerline, and two 3 3/4" either side of the centerline. The elongation for each gage line was determined separately.

**Preparation of Notch:** Careful attention was given to the preparation of the notch. The accepted procedure at all laboratories where wide full-thickness plate tests have been made has been to use a jeweler's hack-saw to establish the acuity of the notch. To provide uniform acuity, the width of the last 1/8 of an inch of the notch on both sides of the internal notch was specified to be 0.010 inch. A jig-saw was utilized to make the jeweler's hack-saw cut.

**Temperature Control Chamber:** The temperature control chamber was made of Plexiglas, so that the specimen and instruments would be visible at all stages of the test. Strip heaters were installed to give temperatures above that of the laboratory. Cooling was obtained by blowing air over dry ice and conducting this cool air to the Plexiglas box by insulated ducts.

**Measurement of Temperature:** The temperature was determined by the use of thermocouples. Three thermocouples are mounted on each specimen, one in the 3/4" drill hole in the center of the plate, one 5/8" above the notch in the center of the plate, and the third one located 1/8" from the end of the notch immediately above the junction of the standard and jeweler's hack-saw cuts. A fourth thermocouple determined the ambient temperature within the box.

The temperature at the 3/4" drill hole has been used in interpreting all tests.

**LOAD ELONGATION CURVES**

The load elongation curves for each specimen are shown in Appendix "A".
The elongation used is the average of all twelve gages over the established nine inch gage length.

The areas under the load elongation curve represent total strain energy. The strain energy absorbed by the specimen to the first visible crack is designated as $E_1$. The strain energy to maximum load and to failure are designated as $E_1$ and $E_2$ respectively. $E_2 - E_1$ represents the strain energy necessary to propagate the fracture after the maximum load.

RESULTS

**W** Steel

Fig. 2 shows the fracture surfaces for all specimens of the **W** steel. Table I gives the load, at and the energy in inch pounds to, the first visible crack, maximum load, and failure. It also gives the temperature and type of failure in terms of the percentage of shear failure within the 9 in. net width.

Fig. 3 shows the maximum load plotted as ordinates with temperature as abscissas. In Fig. 4 the energy to maximum load is plotted as the ordinate with temperature as the abscissa, and Fig. 5 is a plot of the percentage of shear failure in the various specimens of **W** steel.

The transition temperature based upon the energy to maximum load lies in a temperature zone between 40 and 60°F. Based upon the appearance of the fracture, the transition temperature would lie close to 50°F.

**S-9 Steel**

The fracture surfaces of the specimens of S-9 steel are shown in Fig. 6. Table II records the energy in inch pounds to the first visible crack, to maximum load, and to failure. It also gives the type of fracture in terms of percent of shear. Fig. 7 is a plot of maximum load vs. temperature. Fig. 8 represents
energy to maximum load vs. temperature, and Fig. 9 is a plot of percent shear vs. temperature.

The maximum loads observed for cleavage specimens are on an average about 50,000 pounds less than for a ductile specimen. A consideration of the energy to maximum load would place the transition temperature in a zone of from 50 to 75°F. The character of the fracture as determined by the percent of shear indicates the same transition temperature zone.

S-12 Steel

The fracture surfaces of the S-12 specimens are shown in Fig. 10. Table III, which gives the load at, and energy in inch pounds to, the first visible crack, maximum load, and failure, also gives the type of failure in terms of the percent of shear. Fig. 11 shows the maximum loads as ordinates with temperature as abscissa. Fig. 12 is a plot of the energy to maximum load vs. temperature. Fig. 13 represents the plot of the percent of shear failure vs. temperature.

It is to be noted that with the exception of specimen No. 7, the maximum load is quite uniform throughout the entire temperature range. Fig. 12 showing energy to maximum load vs. temperature does not provide a good criterion for the establishment of the transition temperature zone, since the energy level for cleavage specimens remains nearly as high as for a completely ductile specimen. It is to be noted that of all the specimens tested, only specimen No. 7 represented a complete cleavage failure. Insufficient specimens prevented the temperature range being lowered to procure a number of specimens in complete cleavage. A consideration of energy to maximum load does not permit a positive statement regarding the transition temperature. The transition temperature as determined from the appearance of the fracture is fairly definite and indicates that the transition temperature may be between 10 and 30°F. The total energy to failure.
would indicate the transition temperature as being between 10 and 20°F.

The cleavage fractures for the S-12 steels are extremely rough and ragged, showing a pronounced chevron pattern. This is a departure from the general cleavage surface noted for other steels tested in this laboratory. The ductile specimens show a trace of fissuring at mid-thickness. Hence, the S-12 steel shows two essential departures from the norm, namely, that the energy to maximum load for either the ductile or cleavage failures is essentially the same, and that the cleavage surface is more irregular.

The S-12 steel and the S-22 steel reported subsequently may be compared. The difference between S-12 steel and the S-22 steel, which are from the same heat, is one of fine and coarse grained practice, the S-12 being of the fine grained practice.

In passing, it should be stated that the energy to maximum load for the S-22 steel is discretionary and that the appearance of the brittle cleavage fracture represents the normal appearance noted for other steels.

**S-22 Steel**

The fractures of the S-22 steel are shown in Fig. 14. Table IV gives the load at, and energy in inch pounds to, the first visible crack, maximum load, and failure. It also gives the type of fracture in terms of percentage of shear failure. Fig. 15 shows the maximum loads as ordinates with temperature as abscissas. Fig. 16 represents energy to maximum load vs. temperature. Fig. 17 represents a plot of the percent of shear failure vs. temperature.

The transition temperature zone as determined from energy to maximum load appears to be quite sharply defined and lies between 55 and 60°F. The appearance of the fractures would indicate the transition temperature at about 60°F. These statements concerning transition temperature are based upon a limited number of
tests, and must be considered as tentative only.

The maximum load for specimens failing completely in cleavage was about 50,000 lbs, lower than for specimens failing completely in shear.

<table>
<thead>
<tr>
<th>Code</th>
<th>Based on Energy to Max. Load</th>
<th>Based on appearance of fracture as defined by % of shear</th>
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<td>W</td>
<td>40 to 60°F</td>
<td>50°F</td>
</tr>
<tr>
<td>S-9</td>
<td>50 to 75°F</td>
<td>50 to 75°F</td>
</tr>
<tr>
<td>S-12</td>
<td>indefinite</td>
<td>10 to 30°F</td>
</tr>
<tr>
<td>S-22</td>
<td>55 to 60°F</td>
<td>60°F</td>
</tr>
</tbody>
</table>
The aspect ratio program is a study of the effects of width and thickness, using centrally notched tensile specimens, on energy absorption and transition temperature. The thickness of any specimens is the as-rolled thickness and thicknesses to be investigated are 1/2", 3/4", 1" and 1 1/2". The steel is a semi-killed steel and all thicknesses are rolled from the same heat.

The aspect ratio (AR) is defined as the width of the specimen divided by the thickness of the plate. Fig. 18, showing a typical specimen, explicitly defines this term. In Fig. 18 the notch layout is shown, and it should be particularly noted that the notch terminates with a drill hole instead of a jeweler's hack-saw cut. The diameter of the drill hole is directly proportional to the thickness of the plate and the diameters for particular thicknesses are shown.

Preliminary considerations indicated that geometric similitude should be adhered to in planning the aspect ratio program, and that similitude would necessitate a varying notch radius. Laboratory tests indicated that a drill hole of 3/64" diameter in a plate 3/4" thick would provide a notch acuity sufficiently sharp to give transition temperatures near those already found by using specimens having notches terminating with a jeweler's hack-saw cut.

Specimens with equal aspect ratios are geometrically similar in all respects. They may be dissimilar only in the metallurgical constituency of the as-rolled plate. To investigate the effect of width of plate with a given as-rolled thickness, the aspect ratio studies extend over a range of from an AR of 4 to an AR of 20.
Fig. 19 indicates the scope of the tentative program. Not all of the specimens shown on Fig. 19 are to be tested at this time. An exploratory program consists of the following aspect ratios in the various thicknesses.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Aspect Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2&quot;</td>
<td>4, 8, 16, 20</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>4, 8, 12, 16</td>
</tr>
<tr>
<td>1&quot;</td>
<td>4, 8</td>
</tr>
<tr>
<td>1½&quot;</td>
<td>4, 6</td>
</tr>
</tbody>
</table>

In order to utilize a limited amount of steel and to secure information relative to changes due to position of the specimens within the plate, the available steel plates have been laid out as shown on Figs. 20, 21, 22, and 23.

Our testing program at this time has not been in effect long enough to present the results of this program. It is anticipated that in an early Progress Report some of the results of this program can be reported.
ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions and assistance of the following laboratory personnel:


The work has been under the general supervision of S. T. Carpenter, Chairman of the Division of Engineering.

Captain W. P. Roop, USN, (Ret) has acted in the capacity of consultant.
BIBLIOGRAPHY


FIG. 1
NOTCH LAYOUT
SWARTHMORE COLLEGE
FIG. 2 "W" STEEL

PHOTOGRAPH OF FRACTURE SURFACES
**TABLE I**

"W" Steel

Test Specimens 12" wide x 3/4" thick, with standard notch

The notch is 3" wide and has at its extremities a cut 1/8" long and 0.010" wide made with a jeweler’s hack,

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>W-32-11</td>
<td>21</td>
<td>4,000</td>
<td>257,800</td>
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<td>48,000</td>
<td>309,300</td>
<td>0.00</td>
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<td>W-32-12</td>
<td>36</td>
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<td>253,000</td>
<td>67,500</td>
<td>346,000</td>
<td>71,000</td>
<td>340,600</td>
<td>3,500</td>
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<td>W-32-9</td>
<td>43</td>
<td>5,300</td>
<td>250,800</td>
<td>40,000</td>
<td>306,000</td>
<td>40,000</td>
<td>306,000</td>
<td>0.00</td>
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<tr>
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<td>8,700</td>
<td>256,000</td>
<td>120,000</td>
<td>345,700</td>
<td>158,000</td>
<td>330,000</td>
<td>38,000</td>
</tr>
<tr>
<td>W-32-15</td>
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<td>253,600</td>
<td>125,500</td>
<td>345,500</td>
<td>300,200</td>
<td>22,000</td>
<td>174,700</td>
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<td>346,800</td>
<td>292,300</td>
<td>30,500</td>
<td>184,800</td>
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<td>150,000</td>
<td>160,000</td>
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<tr>
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<td>142,600</td>
<td>340,700</td>
<td>not obtained</td>
<td>---</td>
<td>100</td>
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<td>W-33-16</td>
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<td>129,700</td>
<td>338,500</td>
<td>317,000</td>
<td>126,000</td>
<td>187,300</td>
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<td>109,700</td>
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<td>244,800</td>
<td>61,000</td>
<td>135,100</td>
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<tr>
<td>W-32-1</td>
<td>81</td>
<td>not obtained</td>
<td>102,700</td>
<td>263,600</td>
<td>345,000</td>
<td>263,600</td>
<td>71,500</td>
<td>160,900</td>
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<tr>
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<td>8,000</td>
<td>250,000</td>
<td>110,000</td>
<td>342,100</td>
<td>282,500</td>
<td>55,000</td>
<td>172,500</td>
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</tbody>
</table>
FIG. 3
MAX. LOAD VS TEMPERATURE
W-32 STEEL
SWARTHMORE COLLEGE
9-30-49

FIG. 4
ENERGY TO MAX. LOAD VS TEMPERATURE
W-32 STEEL
SWARTHMORE COLLEGE
9-30-49
FIG. 5

PERCENTAGE SHEAR
VS
TEMPERATURE

W-32 STEEL
SWARTHMORE COLLEGE
10-1-49
FIG. 6  "S-9" STEEL

PHOTOGRAPH OF FRACTURE SURFACES
<table>
<thead>
<tr>
<th>Spec. No.</th>
<th>Deg. F</th>
<th>To Visible Crack Energy E in. lbs</th>
<th>Load in. lbs</th>
<th>To Maximum Load Energy E₁ in. lbs</th>
<th>Load in. lbs</th>
<th>To Failure Energy E₂ in. lbs</th>
<th>Load in. lbs</th>
<th>Energy E₂ - E₁ in. lbs</th>
<th>% Shear</th>
</tr>
</thead>
<tbody>
<tr>
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<td>92</td>
<td>13,600</td>
<td>229,600</td>
<td>118,200</td>
<td>326,600</td>
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<td>191,900</td>
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<td>159,300</td>
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<tr>
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<td>12,000</td>
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<td>336,500</td>
<td>333,600</td>
<td>51,000</td>
<td>202,700</td>
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<td>325,000</td>
<td>49,000</td>
<td>200,000</td>
<td>100</td>
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</table>
FIG. 7
MAX. LOAD VS. TEMPERATURE
S-9 STEEL
SWARTHMORE COLLEGE
10-11-49

FIG. 8
ENERGY TO MAX. LOAD VS TEMPERATURE
S-9 STEEL
SWARTHMORE COLLEGE
10-11-49
FIG. 9

PERCENT SHEAR VS. TEMPERATURE
S-9 STEEL
SWARTHMORE COLLEGE
10-12-49

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<td>17</td>
<td>18</td>
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DIRECTION OF ROLLING

TEMPERATURE

% SHEAR

TEMPERATURE °F

0 20 40 60 80 100

0 50 100
FIG. 10 "S-12" STEEL

PHOTOGRAPH OF FRACTURE SURFACES
### TABLE III

**Code S-12 Fine Grain**

Test specimens 12" wide x 3/4" thick, with standard notch

The notch is 3" wide and has at its extremities a cut 1/8" deep made with a .010" Jeweler's hack-saw

<table>
<thead>
<tr>
<th></th>
<th></th>
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<td>100</td>
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<td>8</td>
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<td>258,200</td>
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<td>363,000</td>
<td>290,000</td>
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<td>180,000</td>
<td>100</td>
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<tr>
<td>15</td>
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<td>128,000</td>
<td>366,400</td>
<td>300,000</td>
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<td>296,000</td>
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<td>194,000</td>
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<td>253,000</td>
<td>97,000</td>
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<td>97,000</td>
<td>366,500</td>
<td>0</td>
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<tr>
<td>7</td>
<td>7</td>
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<td>30</td>
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<td>220,000</td>
<td>305,000</td>
<td>112,000</td>
<td>30</td>
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<tr>
<td>11</td>
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<td>259,000</td>
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<td>14</td>
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<td>376,300</td>
<td>86,900</td>
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</tbody>
</table>
FIG. 11

MAX. LOAD VS. TEMPERATURE
5-12 STEEL
SWARTHMORE COLLEGE
9-22-49

FIG. 12

ENERGY TO MAX. LOAD VS. TEMPERATURE
5-12 STEEL
SWARTHMORE COLLEGE
9-21-49
FIG 13
PERCENTAGE SHEAR
VS.
TEMPERATURE
S-12 STEEL
SWARTHMORE COLLEGE
9-21-49
FIG. 14 "S-22" STEEL

PHOTOGRAPH OF FRACTURE SURFACES
TABLE IV

Code S-22 (Coarse grain)

Test specimens 12" wide x 3/4" thick, with standard notch

The notch is 3" wide and has at its extremities a cut 1/8" deep made with a .010" Jeweler's hack-saw

<table>
<thead>
<tr>
<th>Spec. No.</th>
<th>Deg.</th>
<th>To Visible Crack Energy $E_1$ in.in. lbs.</th>
<th>Load in.lbs.</th>
<th>To Maximum Load Energy $E_2$ in.in. lbs.</th>
<th>Load in.lbs.</th>
<th>To Failure Energy $E_2 - E_1$ in.in. lbs.</th>
<th>Load in.lbs.</th>
<th>% Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>70</td>
<td>5,600</td>
<td>247,800</td>
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<td>375,000</td>
<td>330,000</td>
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<tr>
<td>8</td>
<td>60</td>
<td>2,500</td>
<td>234,000</td>
<td>104,800</td>
<td>376,500</td>
<td>334,000</td>
<td>40,000</td>
<td>229,200</td>
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<tr>
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<td>60</td>
<td>7,500</td>
<td>253,500</td>
<td>130,500</td>
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<td>320,000</td>
<td>31,500</td>
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<td>210,000</td>
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<td>308,500</td>
<td>29,000</td>
<td>308,500</td>
<td>0</td>
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</table>
FIG. 15

MAX. LOAD
VS.
TEMPERATURE
S-22 STEEL
SWARTHMORE COLLEGE
9-21-48

FIG. 16

ENERGY TO
MAX. LOAD
VS.
TEMPERATURE
S-22 STEEL
SWARTHMORE COLLEGE
9-21-48
FIG. 17

PERCENTAGE SHEAR VS. TEMPERATURE
S-22 STEEL
SWARTHMORE COLLEGE
9-21-49
ASPECT RATIO = \( \frac{W}{t} \)

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<th>t</th>
<th>Dia. of Drill Holes</th>
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</thead>
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<td>( \frac{1}{32} )&quot;</td>
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<td>( \frac{3}{64} )&quot;</td>
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<td>( \frac{1}{16} )&quot;</td>
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<td>( \frac{3}{32} )&quot;</td>
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<tr>
<td>( \frac{1}{2} )&quot;</td>
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</table>

FIG. 18
TYPICAL SPECIMEN
SWARTHMORE COLLEGE
9-6-49
<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>1/2&quot;</th>
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<th>1½&quot;</th>
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<td>25&quot;</td>
<td>30&quot;</td>
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</table>

**FIG. 19**

*ASPECT RATIO PROGRAM*

*SWARTHMORE COLLEGE*

*9-6-49*
FIG. 20
1/2 PLATE LAYOUT
SWARTHMORE COLLEGE
9-7-49

FIG. 21
3/4 PLATE LAYOUT
SWARTHMORE COLLEGE
9-7-49
FIG. 1-S9
LOAD vs ELONGATION
5-9-7
TEMP. 60°F 100% SHEAR
SMARTMORE COLLEGE
10-17-49

FIG. 2-S9
LOAD vs ELONGATION
5-9-7
TEMP. 40°F 0% SHEAR
SMARTMORE COLLEGE
10-14-49

FIG. 3-S9
LOAD vs ELONGATION
5-9-6
TEMP. 60°F 100% SHEAR
SMARTMORE COLLEGE
10-17-49

FIG. 4-S9
LOAD vs ELONGATION
5-9-7
TEMP. 40°F 0% SHEAR
SMARTMORE COLLEGE
10-13-49
FIG. 5-S9
LOAD vs ELONGATION
5-9-10
TEMP 75°F 100% SHEAR
SWARTHMORE COLLEGE
10-17-49

FIG. 6-S9
LOAD vs ELONGATION
5-9-11
TEMP 95°F 100% SHEAR
SWARTHMORE COLLEGE
10-17-49

FIG. 7-S9
LOAD vs ELONGATION
5-9-12
TEMP 80°F 100% SHEAR
SWARTHMORE COLLEGE
10-13-49

FIG. 8-S9
LOAD vs ELONGATION
5-9-16
TEMP 75°F 75% SHEAR
SWARTHMORE COLLEGE
10-19-49
Fig. 9-S9

Load vs Elongation

S-9-18

Temp. 57°F  0% shear
Swarthmore College
10-15-49
FIG. 5-S12
LOAD VS ELONGATION
5-12-7
TEMP 70° 0% SHEAR
SWARTHMORE COLLEGE
9-23-49

FIG. 6-S12
LOAD VS ELONGATION
5-12-8
TEMP 60° 10% SHEAR
SWARTHMORE COLLEGE
9-23-49

FIG. 7-S12
LOAD VS ELONGATION
5-12-9
TEMP 0°F 30% SHEAR
SWARTHMORE COLLEGE
9-28-49

FIG. 8-S12
LOAD VS ELONGATION
1-13-10
TEMP 0°F 5% SHEAR
SWARTHMORE COLLEGE
9-27-49
FIG. 9-S12
LOAD vs ELONGATION
5-12-11
TEMP 30°F 8% SHEAR
SWARTHMORE COLLEGE
9-27-49

FIG. 10-S12
LOAD vs ELONGATION
5-12-12
TEMP 30°F 100% SHEAR
SWARTHMORE COLLEGE
9-27-49

FIG. 11-S12
LOAD vs ELONGATION
5-12-14
TEMP 30°F 4% SHEAR
SWARTHMORE COLLEGE
9-27-49

FIG. 12-S12
LOAD vs ELONGATION
5-12-15
TEMP 30°F 100% SHEAR
SWARTHMORE COLLEGE
9-27-49