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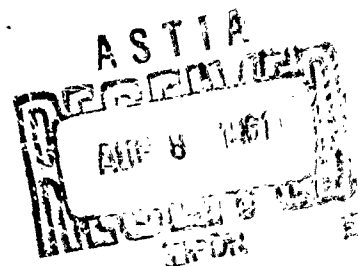
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## TECHNICAL PROGRESS REPORT

CONTRACT DA-36-034-ORD-3296 RD

ORDNANCE CORPS PROJECT NUMBER—OMS 5010.1180 800.51.03

PREPARED FOR

U. S. ARMY ORDNANCE DISTRICT  
PHILADELPHIA, PA.

UNDER

TECHNICAL SUPERVISION—FRANKFORD ARSENAL  
CONTROL NO. A5180

# DEVELOPMENT OF HIGH PERFORMANCE ROCKET MOTOR CASE

QUARTERLY REPORT NUMBER 12

Period—April 1, 1961 to June 30, 1961

PRODUCT DEVELOPMENT DEPARTMENT

THE BUDD COMPANY

Philadelphia 32, Pennsylvania



PHILADELPHIA 32, PA.

## PRODUCT DEVELOPMENT

### ENGINEERING QUARTERLY PROGRESS REPORT NUMBER 12

Period: April 1, 1961 to June 30, 1961

Contract: DA-36-034-ORD-3296RD

Ordnance Corps. Project Number:  
OMS-5010-1180800-51-03

ROCKET MOTOR CASE DEVELOPMENT

Control Number A-5180

Prepared by:

Approved by: W B Dean  
Manager-Product Development Dept.

Reviewed by:

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## PREFACE

This progress report is submitted in conformance with the requirements of U.S. Army Ordnance Contract DA-36-034-ORD-3296 RD dated June 21, 1960, for the development of a high performance rocket motor case. The work to be performed by The Budd Company is to initiate and conduct a development program, the ultimate objective of which will result in a high performance rocket motor case, capable of being fabricated with reasonable ease, which will utilize the maximum strength potential of available materials. This will be accomplished through proper selection of materials, design of joints, and improvement of fabricating techniques.

Acknowledgment is made of the contribution to this report of Messrs. J. L. Herring and W. J. Hauck of The Budd Co., Product Development Dept.

## INTRODUCTION

This is the twelfth progress report covering the work being conducted under Contract DA 36-034-ORD-3296RD by The Budd Company. The report will include work accomplished during the quarterly period April 1, 1961 to June 30, 1961 and will serve as the monthly report for June, 1961.

Evaluation of material selected for possible application to rocket motor cases continued during the quarterly period. This work included evaluation of Ti-13V-11Cr-3Al alloy and data is included in this report. Data on fracture energy testing and retests of stress corrosion specimens without edge seal protection is reported on JLS 300 alloy. Retesting of the initial heats 20% and 25% Nickel Steels incorporating modified heat treatments to improve mechanical properties was accomplished during the quarter. Results of tensile tests on AM 359 material is reported.

Testing of uniaxial weld joint specimens of AM 355-PH 15-7 Mo material, utilizing a combination of resistance and fusion welding, was accomplished during the quarter and results are included in this report. Work on uniaxial fusion welded butt joints employing tungsten inert arc process and electron beam processes continued during the quarter.

During the period a method of free state fusion butt welding cylindrical sections, having weld lines

preferentially oriented in a helical pattern, was developed. A discussion of this work is included in this report.

#### MATERIALS EVALUATION

Evaluation testing was completed on Ti-13V-11Cr-3Al alloy, JLS 300, and initial heats of 20%-25% Nickel Steel. Transverse and longitudinal tensile tests only were made on the AM 359 to confirm data obtained from results at Allegheny Ludlum. Evaluation is in process on the Ti-6Al-6V-2Sn alloy. Preliminary samples of aus-rolled low alloy steels have been received. These samples were taken from 3 different heats. We plan to make a preliminary evaluation of these samples to obtain tensile and fracture energy data. This will involve approx. 12 specimens. Based on results of this data, a selection will be made of a heat for complete evaluation.

The Ti-8Al-10V alloy ordered for evaluation was received late in June and will be evaluated. The modified analysis of 20% and 25% Nickel steel have not been received to date but is expected within the next few days. Armco PH 12-8-6 alloy is also expected shortly.

#### Discussion of Fracture Energy Testing

High strength sheet metals behave in a brittle manner in the presence of small flaws. This behavior is related to the type and geometry of the flaw, the environmental temperature, the state of stress and the metallurgical condition of the material. Pressure

vessels made from these materials also behave in a brittle manner in the presence of flaws. Quantitative data on the effects of changes in the parameters of the brittle behavior are required to provide design, fabrication and inspection criteria for manufacture of reliable vessels.

The test used to measure the brittle behavior characteristics must be relatively simple, practical to produce and economical to make. To meet these conditions, the recommendations of the ASTM Committee on Fracture Testing of High Strength Sheet Materials were followed. The center notch test specimen, in lieu of the edge notch specimen was selected on the basis of better reproducibility and economy.

The dimensions and tolerances used for the specimen are illustrated in Drawing E 2434-0014 Figure 1. It will be noted that the symmetry control and tolerances are related to the pin holes, and that the perpendicularity of the notch with relation to the tension stress line is tightly held. These conditions were established to minimize bending stresses during test and to provide reproducible test results.

The processes for preparation of the test specimens were developed to assure that only elastic deformation occurred during any operation, except for the fatigue crack initiation. This minimized changes in the fracture characteristics as a result of prior plastic deformation, as would occur during roll or press straightening. The

**REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT.**

DRAWING NO. REV.  
E2434-0014

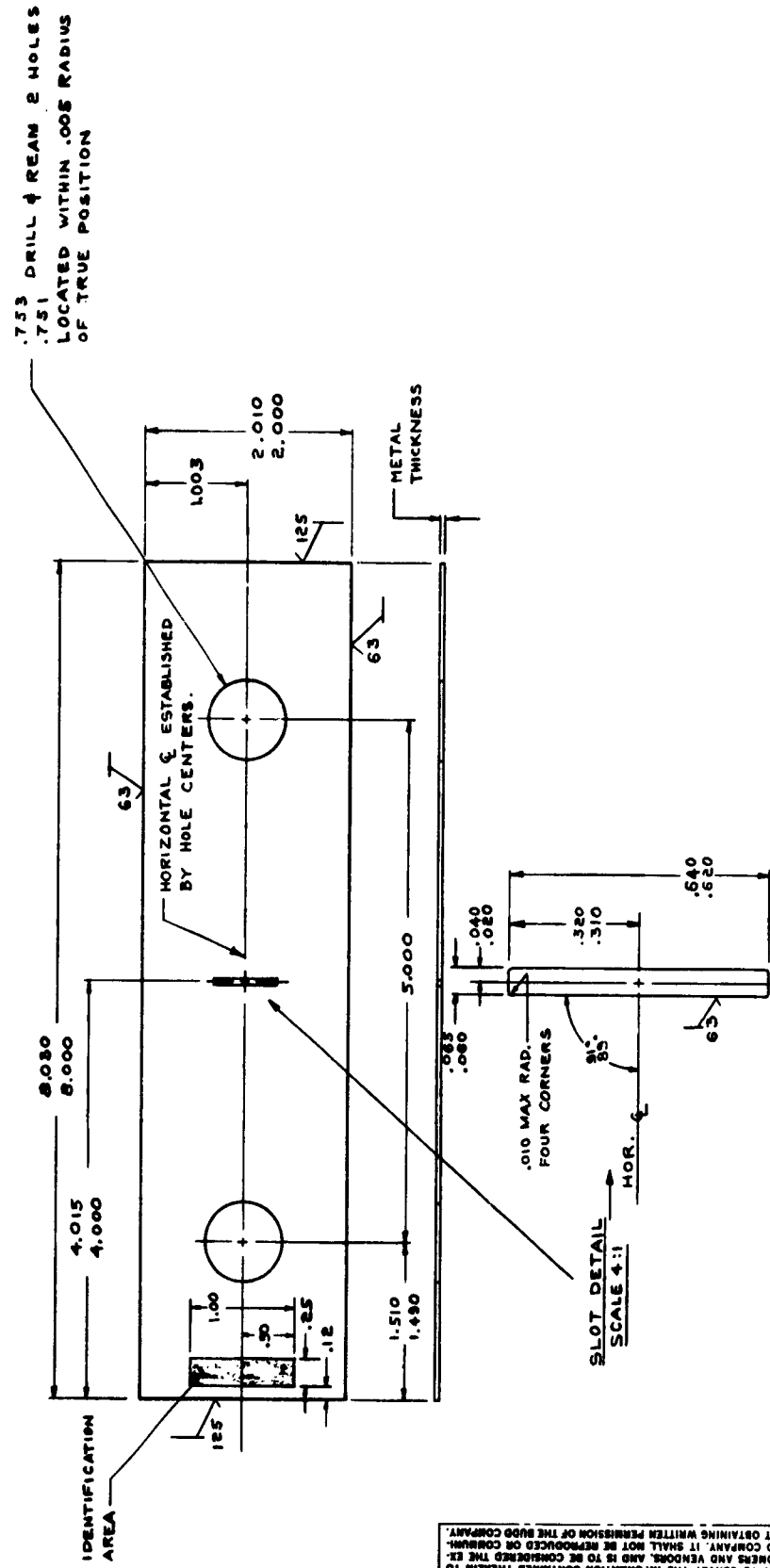
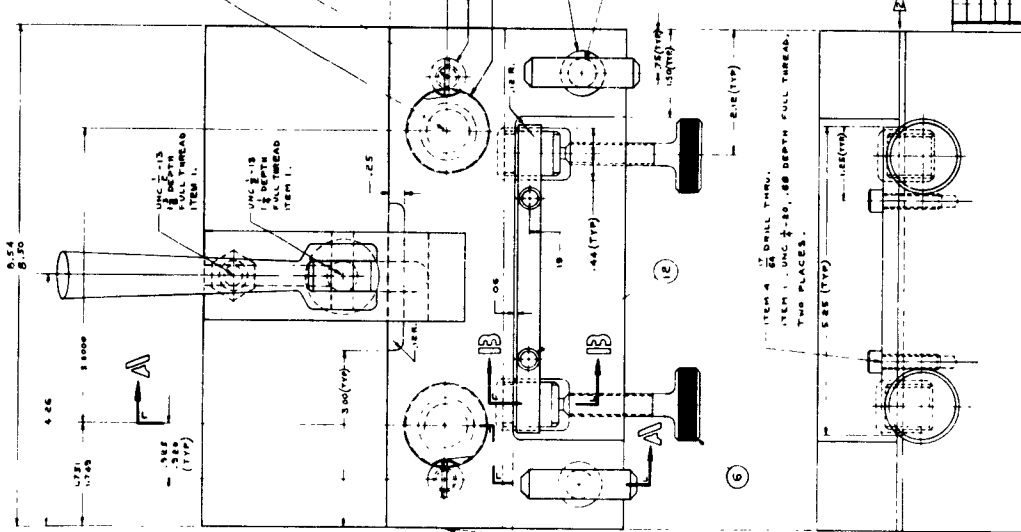
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**FIGURE 1**

test specimen preparation sequence is as follows:

1. Square shear, oversize blank from sheet. Dye penetrant inspect to assure that edge flaws will clean up on subsequent processing.
2. Shape to outline dimensions required by Figure 1, and deburr.
3. Clean
4. Heat treat, where required.
5. Drill pin holes using the jig shown in Figure 2, deburr and clean.
6. Machine the center notch using the electric spark discharge process and the fixturing shown in Figure 3.
7. Clean, debur and inspect the notch at 50X, using a Kodak Optical Comparator.
8. Fatigue crack using high stress low cycle tension fatigue as shown in Figure 4.

Measurements of test specimens indicate that dimensional control and symmetry were satisfactory. The notch radius varies from 0.001" to 0.005". This is adequate for subsequent fatigue cracking. The angle of the notch with respect to the center line established by the pin holes was held to less than 30 minutes from 90°. The length of the notch varies from 0.600" to 0.608", and its shift, left or right from the tension centerline was less than .005 inches total. The pin hole diameters are within the .004" tolerance allowed. These controls

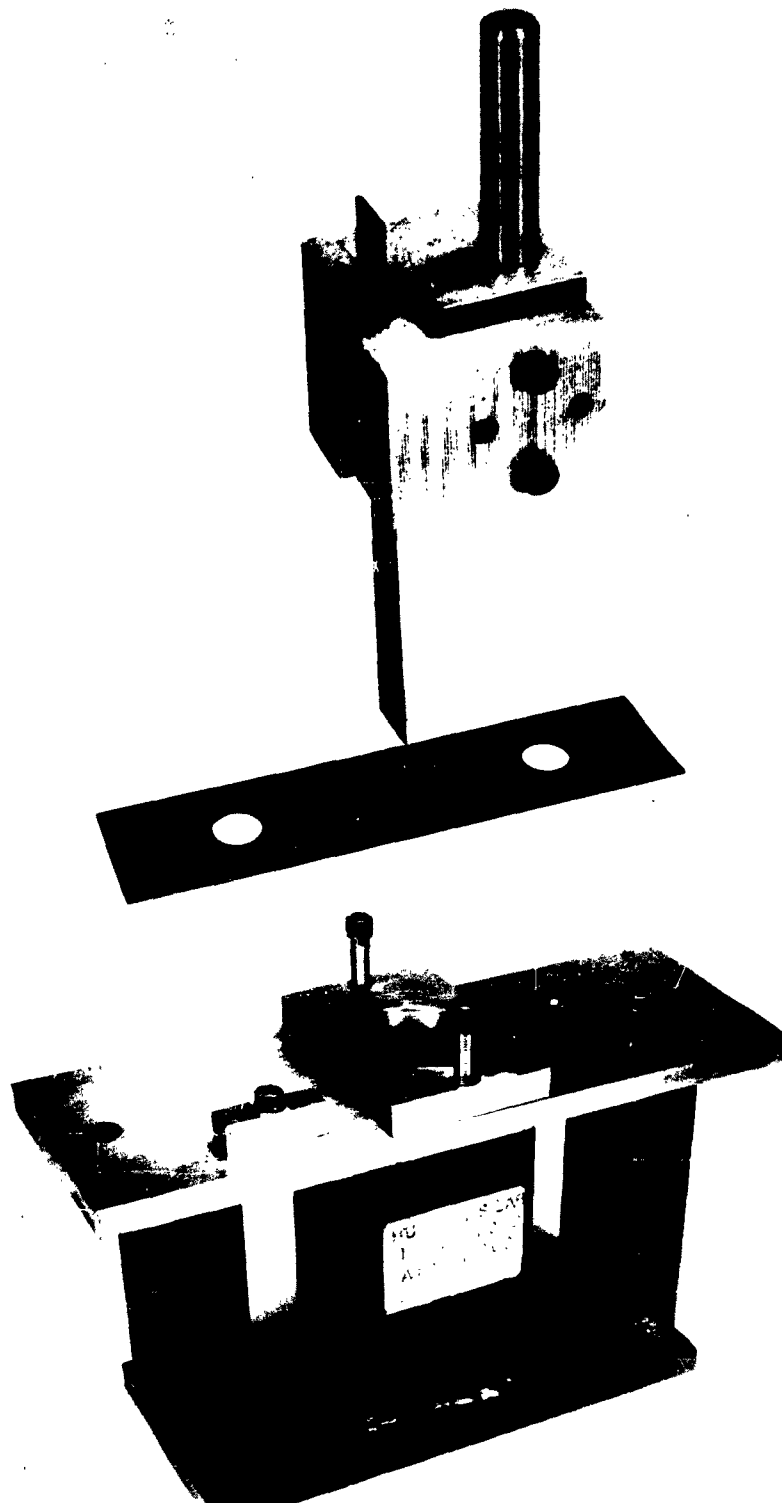


## FIGURE 2

| QTY. | PRICE NO. | DESCRIPTION       | UNIT | AMOUNT | DATE | BY | REMARKS |
|------|-----------|-------------------|------|--------|------|----|---------|
| 1    |           | 1 CAM CLAMP ASBY. | EA   | 1.00   |      |    |         |
| 1    |           | 1 RETAINER        | EA   | 1.00   |      |    |         |
| 1    |           | 1 SLIDE BLOCK     | EA   | 1.00   |      |    |         |
| 1    |           | 1 TOP PLATE       | EA   | 1.00   |      |    |         |
| 1    |           | 1 DRAKE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
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| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
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| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 NUT             | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASHER          | EA   | 1.00   |      |    |         |
| 1    |           | 1 SCREW           | EA   | 1.00   |      |    |         |
| 1    |           | 1 PLATE           | EA   | 1.00   |      |    |         |
| 1    |           | 1 BUSH            | EA   | 1.00   |      |    |         |
| 1    |           | 1 WASH            | EA   | 1.00   |      |    |         |

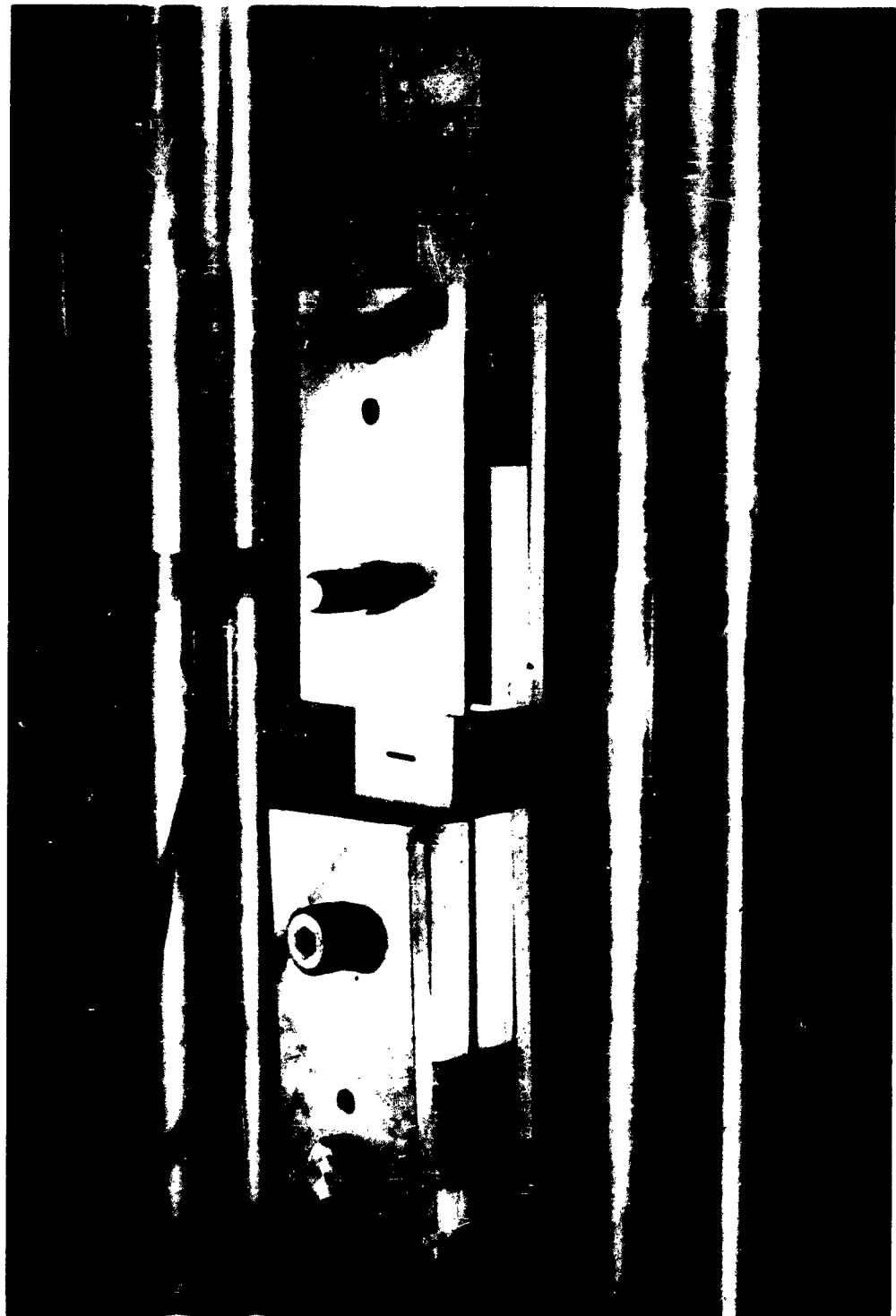
WALL NOT SHOWN

FLOOR JOIST



Electrode and holder, Fracture Energy Specimen and Holding fixture for electrode discharge Spark Machining of Center Notch.

FIG. 3



Fixturing for Tension-Tension fatigue Crack initiation of Center Notch Fracture Energy Specimen. Broken Specimen used to illustrate 90° angle between crack and fatigue stress.

provide adequate alignment for test.

The fatigue crack length is controlled by visual observation. When the crack initially becomes visible the test machine is immediately shut down. The remaining cycles occurring after shut-down cause the crack to propagate to the required length. The specimen is then placed under a low static tension and the surface length of the cracks measured. Table I is a summary of fatigue load cycles vs. crack sizes for three different alloys. It will be noted that the visible crack length determined during the fatigue test, and the length of the same crack determined from examination of the fractured specimen show good correlation. The fatigue crack initiates at the center of the notch tips and it propagates normal to the longitudinal center line of the specimen. The amount of deviation from a 90° direction is almost unmeasurable. This condition of crack initiation has occurred for the Ti-13V-11Cr-3Al, Ti-6Al-6V, 25 Nickel, AM 355, and JLS 300 alloys tested to date. (of 44 specimens fatigue cracked, 42 were satisfactory). Two specimens broke in half during the fatigue cracking operation.

The fracture energy tests are made at room temperature using a 60,000 pound hydraulic universal testing machine. The ink staining technique recommended by the ASTM Committee is used for measurement of slow crack growth. The important aspects of the test are proper

# FRACTURE ENERGY TESTS - FATIGUE CRACK OBSERVATIONS

| Material and Condition     | Specimen Number | Fatigue Conditions |                  |                    | Measurement of Crack length After fracture |              |
|----------------------------|-----------------|--------------------|------------------|--------------------|--------------------------------------------|--------------|
|                            |                 | Load (100 lbs.)    | Cycles (1800Cpm) | Crack length (in.) | (in.) Side 1                               | (in.) Side 2 |
| JLS 300, CRT               | FNBL - 1        | 0 to 23            | 2500             | .03                | .025                                       | .03          |
| 340,000 psi Yield Str.     | FNBL - 2X       | 0 to 23            | 6100             | .06                | .04                                        | .06          |
| Ti, 6Al, 6V, 2Sn. Annealed | LABL - 2        | 0 to 26.4          | 12000            | .085               | .080                                       | .080         |
|                            | LABT - 2        | 0 to 26.4          | 12000            | .075               | .080                                       | .080         |
| Ti, 13V, 11Cr, 3Al         | DC1             | 0 to 200           | 5850             | .030               | .040                                       | .060         |
| Sol. Ann. + Aged 72Hrs.    | AML             | 0 to 20            | 7100             | .020               | .040                                       | .040         |
|                            | FC2             | 0 to 20            | 11300            | .030               | .040                                       | .040         |

(1) Longest edge length of fatigue crack observed, after fracture, on surfaces of fracture, or surfaces of fatigue energy specimen

alignment of the specimen, sufficient but not excess ink, and controlled application of the tension load. Axial alignment is obtained through use of the pin grips shown in Figure 5. The amount of ink required is determined by experience. The specimen is strained using approximately a 0.010 inches per minute cross head speed, until fracture occurs.

Calculation of the fracture energy properties is done in accordance with the procedures published in the ASTM Bulletin, Jan., 1960 and discussed in detail in report No. 9 under testing procedures.

Fracture energy data is reported for the alloys tested during the period under each alloy heading in the report.

#### Specimen Identification

A newly revised specimen identification chart is shown in Table 2.

#### Data on Ti 13V-11Cr-3Al

In past reports we have included a general discussion of most of the materials which are being evaluated in this program. The all-beta titanium alloy has been on the commercial market since mid-1958 and in the last three years a large amount of data have been gathered on the processing, testing, and fabricating of this alloy. Therefore, the discussion of the basic material will be brief, with the assumption that most readers of these reports will have had an opportunity to learn elsewhere



Pin Loading Fixture  
For Center Notch  
Fracture Energy Tests

FIG. 5

### SPECIMEN IDENTIFICATION

Specimen number consists of a four letter group and one digit.  
The sequence is as follows:

| Material | Condition | Specimen<br>Type | Direction | No.in Group |
|----------|-----------|------------------|-----------|-------------|
|----------|-----------|------------------|-----------|-------------|

| <u>Materials</u>                      | <u>Code<br/>Letter</u> |                                                    | <u>Code<br/>Letter</u> |
|---------------------------------------|------------------------|----------------------------------------------------|------------------------|
| AM - 357                              | A                      | Sheet Tensile                                      | A                      |
| AM - 359                              | B                      | Fracture Energy, Center                            |                        |
| 25% Ni                                | C                      | Notched                                            | B                      |
| 20% Ni                                | D                      | Sheet Tensile, "As Welded"                         | C                      |
| Ti-13V-11Cr-3Al                       | E                      | Sheet Tensile, Weld Dep.                           |                        |
| JLS - 300                             | F                      | Removed                                            | D                      |
| 25% Ni (Mod.)                         | G                      | Tensile Shear, Resist                              |                        |
| 20% Ni (Mod.)                         | H                      | Weld                                               | E                      |
| Armco 12-8-6                          | K                      | Fracture Energy, Center                            |                        |
| Ti-6Al-6V-2Sn                         | L                      | Notched                                            | F                      |
| Ti-8Al-10V                            | M                      | Bend Specimen, Base                                |                        |
| Ausrolled steel A-1                   | N                      | Metal                                              | G                      |
| Ausrolled steel A-3                   | O                      | Bend Specimen, Welded,                             |                        |
| Ausrolled steel B-2                   | P                      | Weld Dept. Removed                                 | H                      |
|                                       |                        | Stress Corrosion, Resist                           |                        |
|                                       |                        | Weld                                               | K                      |
|                                       |                        | Dimensional Change                                 |                        |
|                                       |                        | Specimen                                           | L                      |
| Annealed                              | A                      |                                                    |                        |
| SCCRT                                 | B                      | Arc Welding Plates                                 | M                      |
| CRT                                   | C                      | Photomicrographic Mounts                           | N                      |
| SCT                                   | E                      | Photomacrographic Mounts                           | O                      |
| Ti, Single Age, 48 Hrs.               | F                      | Tensile Spec. Cleaning                             | P                      |
| Ti, Single Age, 72 Hrs.               | G                      | Sheet Tensile, >58 RC                              | R                      |
| Cold Rolled & Aged,<br>200,000 psi    | J                      | Tensile, Resist Weld,                              |                        |
| Cold Rolled & Aged,<br>230,000 psi    | K                      | Criss-Cross                                        | S                      |
| 25% and 20% Ni,<br>Stand. Heat Treat  | L                      | Electron Beam, 90° Butt                            |                        |
| Cold Rolled and Aged                  | N                      | Weld Tensile                                       | T                      |
| PH 12-8-6, Stand.<br>Heat Treat       | P                      |                                                    |                        |
| 20% Ni, Isothermal<br>Heat Treat      | R                      |                                                    |                        |
| 25% Ni, Double<br>Sub-Zero Cool       | S                      |                                                    |                        |
| Cold Rolled 25%                       | T                      |                                                    |                        |
| Quenched + Tempered                   | U                      |                                                    |                        |
| Quenched, Subzero<br>Cooled + Temper. | W                      |                                                    |                        |
|                                       |                        | <u>DIRECTION</u>                                   |                        |
|                                       |                        | Indicated as L (longitudinal)<br>or T (transverse) |                        |

**TABLE 2**

about the basic characteristics of the alloy.

Discussion and data in this report will be based on the results of the processing, testing, and fabrication experience gained at The Budd Company in this phase of the current program.

The beta titanium alloy is known by various names depending on the producer. It carries such designations as VCA-beta, 13-11-3, Ti-120 VCA and Ti-13V-11Cr-3Al. In this report the alloy will be referred to as Ti-13V-11Cr-3Al which is used by the producer of our test material and which is a self descriptive title.

#### Compositions of Materials Tested

Sheet stock, in various gages from 0.030" to 0.080", was purchased from Titanium Metals Corporation of America. We received seven different heats of material for our test program. This complicated the evaluation and required additional tensile tests to substantiate the properties of each heat. Table 3 shows the seven heat numbers and the chemical composition of each heat as reported by the producer. Also shown is the analysis of the filler wire used for arc welding.

#### Physical Properties of Ti 13V-11Cr-3Al

Density - 0.175 lb./cu. inch

Coef. of Thermal Expansion -  $5.9 \times 10^{-6}$  in./in./°F  
(Room Temp. to 1000°F)

Specific Heat - 0.13 BTU/lb./°F (to 200°F)

Poisson's Ratio - 0.304

CHEMICAL COMPOSITION OF Ti 13V-11Cr-3Al  
SEVEN COMMERCIAL HEATS

| Heat Number                | C            | Fe   | V            | Cr           | Al         | N <sub>2</sub> | H <sub>2</sub> | O <sub>2</sub> |
|----------------------------|--------------|------|--------------|--------------|------------|----------------|----------------|----------------|
| M9583                      | 0.024        | 0.19 | 13.4         | 11.1         | 2.8        | 0.023          | 0.017          | .133           |
| M9584                      | 0.019        | 0.16 | 13.5         | 10.6         | 2.8        | 0.025          | 0.013          | .131           |
| M9571                      | 0.026        | 0.18 | 13.4         | 11.3         | 2.8        | 0.021          | 0.018          | .100           |
| M9853                      | 0.027        | 0.20 | 13.5         | 11.2         | 2.8        | 0.025          | 0.005          | .128           |
| D31                        | 0.024        | 0.19 | 13.4         | 10.9         | 2.9        | 0.020          | 0.007          | .120           |
| D575                       | 0.020        | 0.15 | 13.4         | 10.7         | 3.0        | 0.031          | 0.007          | .125           |
| D260                       | 0.025        | 0.17 | 13.4         | 11.0         | 2.9        | 0.022          | 0.017          | .142           |
| Filler Wire<br>TIG Welding | 0.01         | 0.19 | 13.0         | 10.3         | 2.9        | 0.02           | 0.0065         | 0.13           |
| Analysis<br>Range          | 0.05<br>Max. | -    | 12.5<br>14.5 | 10.0<br>12.0 | 2.5<br>3.5 | 0.08<br>Max.   | 0.02<br>Max.   | 0.20<br>Max.   |

#### Modulus of Elasticity (room temp.)

Solution Annealed -  $14.7 \times 10^6$  psi.

Aged -  $16.0 \times 10^6$  psi.

#### Thermal Conductivity

4.0 BTU/hr./ft<sup>2</sup>/°F/ft. - @ 70°F

8.2 BTU/hr./ft<sup>2</sup>/°F/ft. - @ 800°F

#### Melting Practice

Each heat of beta titanium in this program has been double melted using the consumable electrode process for better control of the metallic and interstitial additions. The potential contamination by oxygen, nitrogen and hydrogen is minimized by the use of a vacuum in both the primary and secondary melting.

#### Heat Treatment

One distinct advantage of the Ti 13V-11Cr-3Al alloy is the lack of a requirement for a high temperature quench. Material may be purchased in the solution annealed or solution treated condition and may be strengthened with a simple aging treatment at a moderate temperature, usually between 800°F and 900°F. Solution annealing by the fabricator may be done at 1425°F + 25°F for 10 to 30 minutes. Quenching from this temperature is not required. Air cooling has proven to be satisfactory to obtain maximum strength after aging.

Above 800°F titanium has a strong tendency toward contamination by air. Therefore, an inert atmosphere has been used for all treatments above this temperature.

The length of time used for aging is usually between 10 to 100 hours depending on the properties required. Figure 6 is a reproduction of a chart published by Titanium Metals Corporation showing the tensile values that may be expected at various aging times at 900°F. On this same chart we have inserted the minimum and maximum tensile and yield strengths determined by our own testing group with specimens aged to 48 and 72 hours. Our results were uniformly scattered between these limits and the average values fall somewhat below the published curves.

Aging at 900°F was done in a 12 inch diameter by 12 inches high cylindrical retort using a constant 10 CFH flow of argon. The outside atmosphere was effectively excluded by use of a sand seal located at the top of the retort. Temperature was maintained within  $\pm 10^\circ\text{F}$ . A very light oxide which formed during aging was removed by a light sand blasting.

#### Tensile Properties

The tensile properties of annealed material are shown in Table 4. Three of the four heats of annealed stock were tested in this condition. The values are reasonably consistent and are normal for solution annealed Ti 13V-11Cr-3Al.

Material was also received in the cold rolled only, and cold rolled and aged conditions. The cold rolled only titanium was tested as received and after aging.

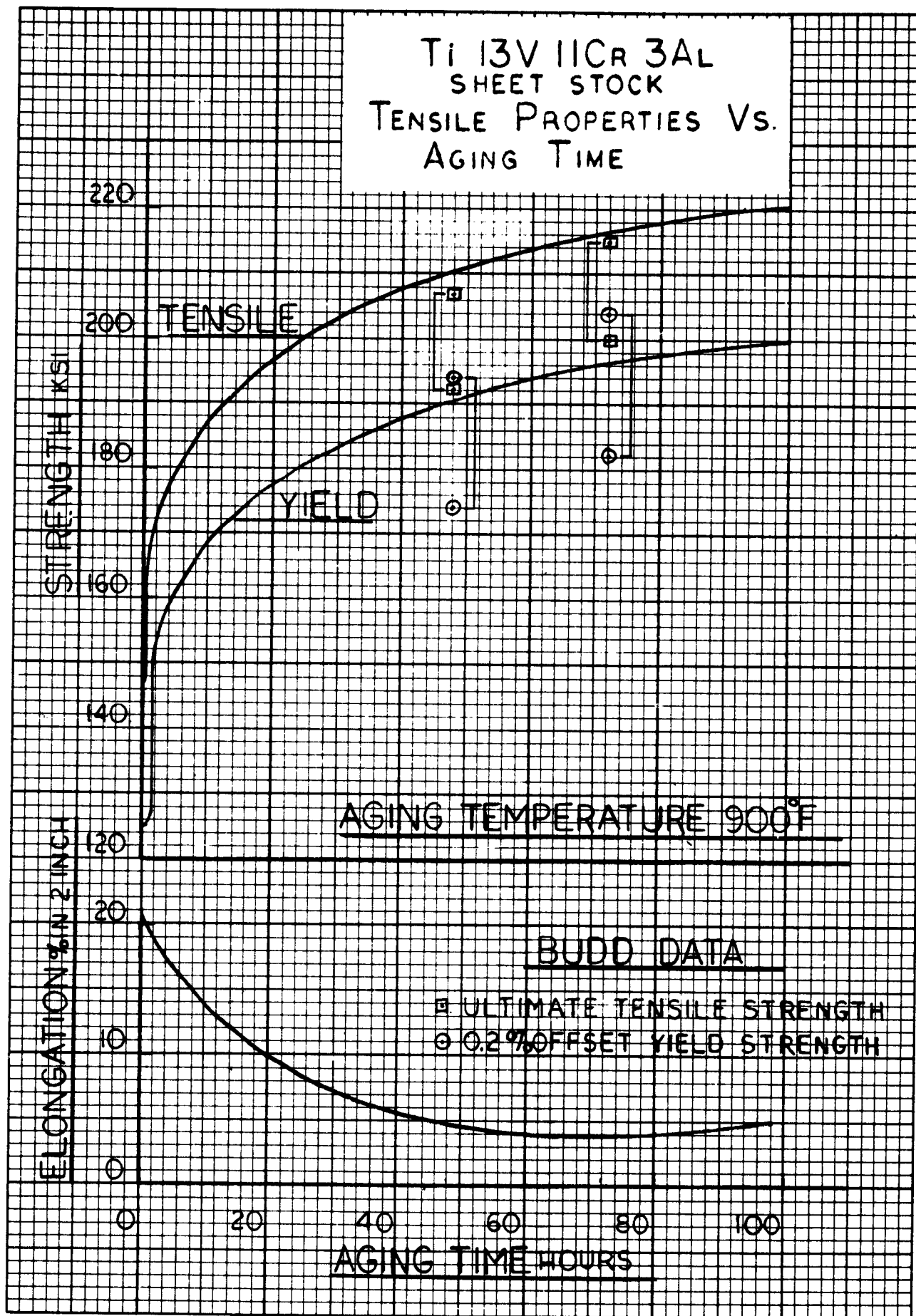


FIG. 6

# MECHANICAL PROPERTIES OF Ti 13V-11Cr-3Al

## MILL ANNEALED

## GAGE AND HEAT NOS. AS NOTED

| Condition                               | Spec. No.        | Direct. | Yield Strength<br>.2% Offset<br>KSI | Ult. Tensile<br>Strength<br>KSI | % Elong.<br>in<br>2 Inches | Rockwell<br>Hardness |
|-----------------------------------------|------------------|---------|-------------------------------------|---------------------------------|----------------------------|----------------------|
| Annealed<br>0.060" Sheet<br>Ht.No.D31   | EAAL-1<br>EAAT-1 | L<br>T  | 133                                 | 135                             | 28                         | C31                  |
| Annealed<br>0.060" Sheet<br>Ht.No.M9583 | EAAL-2<br>EAAT-2 | L<br>T  | 133<br>138                          | 134<br>139                      | 21<br>19                   | C32                  |
| Annealed<br>0.080" Sheet<br>Ht.No.M9584 | EAAL-3<br>EAAT-3 | L<br>T  | 140<br>135                          | 141<br>136                      | 14.5<br>21.5               | C32                  |

TABLE 4

The results of these tests are shown in Table 5. The aging at 900°F proved to be very effective in improving the cold rolled only properties. The limited number of tests indicates little difference in tensile values and hardness when aged at 16, 48 and 72 hours. The specimens aged at 16 hours exhibited better ductility. However, this material was from a different heat.

Four heats of annealed stock were tested after aging at 900°F for 48 and 72 hours. The tensile values are shown in Tables 6 and 7. The minimum and maximum strengths are also shown superimposed on the Properties vs. Aging Time diagram (Figure 6). The figures obtained are lower than the producer's chart indicates. However, a band of values would probably overlap the points obtained in our tests. The 72 hour aging time, on an average, improved the tensile strength and yield strength 4% and 6%, respectively.

All of the 72 hour aged tensile specimens and six of the 48 hour aged tensile specimens were tested using "V" grips in the Universal testing machine. The specimens used for testing (dwg. no. 2434-0002) failed in tension across the area of the pin holes. This failure occurred despite careful preparation and polishing of the inner surface of the hole and despite the fact that the net cross section of the specimen at the hole was 86% greater than the cross-section of the specimen in the gage length.

# MECHANICAL PROPERTIES OF Ti 13V-11Cr-3Al

| COLD ROLLED                                                                        | Condition | Spec. No. | Direct. | 0.030"-0.032" GAGE                  |                                 | HEAT NOS. AS NOTED         |                      |  |
|------------------------------------------------------------------------------------|-----------|-----------|---------|-------------------------------------|---------------------------------|----------------------------|----------------------|--|
|                                                                                    |           |           |         | Yield Strength<br>.2% Offset<br>KSI | Ult. Tensile<br>Strength<br>KSI | % Elong.<br>in<br>2 Inches | Rockwell<br>Hardness |  |
| Cold Rolled 25%<br>Ht.No. M9571<br>0.030" Sheet                                    | L         | ETAL-1    | L       | 152                                 | 160                             | 8.5                        | C34                  |  |
|                                                                                    |           | ETAT-1    | T       | 155                                 | 172                             | 8                          |                      |  |
| Cold Rolled 25%<br>Aged@Budd Co.<br>900°F, 48 Hrs.<br>Ht.No. M9571<br>0.030" Sheet | L         | ENAL-1    | L       | 200                                 | 216                             | 5                          | C43                  |  |
|                                                                                    |           | ENAT-1    | T       | 212                                 | 223                             | 2                          |                      |  |
| Same as Above<br>Aged 72 Hrs.                                                      | L         | ENAL-2    | L       | 201                                 | 217                             | 4                          | C43                  |  |
|                                                                                    |           | ENAT-2    | T       | 206                                 | 211                             | 1                          |                      |  |
| Cold Rolled<br>Aged @ Mill<br>900°F, 16 Hrs.<br>Ht.No.D260<br>0.032" Sheet         | L         | ENAL-3    | L       | 199                                 | 215                             | 9                          | C44                  |  |
|                                                                                    |           | ENAL-3    | T       | 209                                 | 222                             | 5.5                        |                      |  |

MECHANICAL PROPERTIES OF Ti 13V-11Cr-3Al

SOLUTION ANNEALED, AGE HARDENED 900°F, 48 HRS. HEAT NOS. AS NOTED 0.060 GAGE

| Heat No.  | Spec. No. | Direct. | Yield Strength<br>.2% Offset<br>KSI | Ult. Tensile<br>Strength<br>KSI | % Elong.<br>in<br>2 Inches | Rockwell<br>Hardness |
|-----------|-----------|---------|-------------------------------------|---------------------------------|----------------------------|----------------------|
| D31       | EFAL-1    | L       | 185                                 | 206                             | 8                          | C43 - 44             |
| Sheet 15  | EFAT-1    | T       | 187                                 | 206                             | 9                          |                      |
| D31       | EFAL-2    | L       | 180                                 | 199                             | 6.5                        | C44                  |
| Sheet 16  | EFAT-2    | T       | 189                                 | 206                             | 7                          |                      |
| M9853     | EFAL-3    | L       | 194                                 | 206                             | 3                          | -                    |
| Sheet 13  | EFAT-3    | T       | -                                   | 207                             | 1*                         |                      |
| M9583     | EFAL-4    | L       | 176                                 | 192                             | 7                          | -                    |
| Sheet 12  | EFAT-4    | T       | 182                                 | 200                             | 4.5                        |                      |
| M9584     | EFAL-5    | L       | 183                                 | 199                             | 5.5                        | -                    |
| Sheet 1-1 | EFAT-5    | T       | 174                                 | 193                             | 7.5                        |                      |

\* Broke Outside of Gage Length

MECHANICAL PROPERTIES OF Ti 13V-11Cr-3Al  
SOLUTION ANNEALED, AGE HARDENED 900°F, 72 HRS. HEAT NOS. AS NOTED 0.060 GAGE

| Heat No.   | Spec. No. | Direct. | Yield Strength<br>.2% Offset<br>KSI | Ult. Tensile<br>Strength<br>KSI | % Elong.<br>in<br>2 Inches | Rockwell<br>Hardness |
|------------|-----------|---------|-------------------------------------|---------------------------------|----------------------------|----------------------|
| D31        | EGAL-1    | L       | 188                                 | 210                             | 6                          |                      |
| Sheet 1    | EGAT-1    | T       | 200                                 | 215                             | 2.5                        |                      |
| D31        | EGAL-2    | L       | 184                                 | 208                             | 8                          |                      |
| Sheet 15   | EGAT-2    | T       | 188                                 | 209                             | 6.5                        |                      |
| D31        | EGAL-3    | L       | 183                                 | 206                             | 8                          |                      |
| Sheet 16   | EGAT-3    | T       | 193                                 | 212                             | 4                          |                      |
| M9853      | EGAL-4    | L       | 200                                 | 207                             | 1*                         |                      |
| Sheet 13   | EGAT-4    | T       | 204                                 | 211                             | 1*                         |                      |
| M9583      | EGAL-5    | L       | 182                                 | 200                             | 5                          |                      |
| Sheet 12   | EGAT-5    | T       | 184                                 | 200                             | 1*                         |                      |
| M9584      | EGAL-6    | L       | 191                                 | 207                             | 2.5*                       |                      |
| Sheet 1-1  | EGAT-6    | T       | 183                                 | 203                             | 8                          |                      |
| 0.080 Gage |           |         |                                     |                                 |                            |                      |

\* Broke Outside of Gage Length

TABLE 7

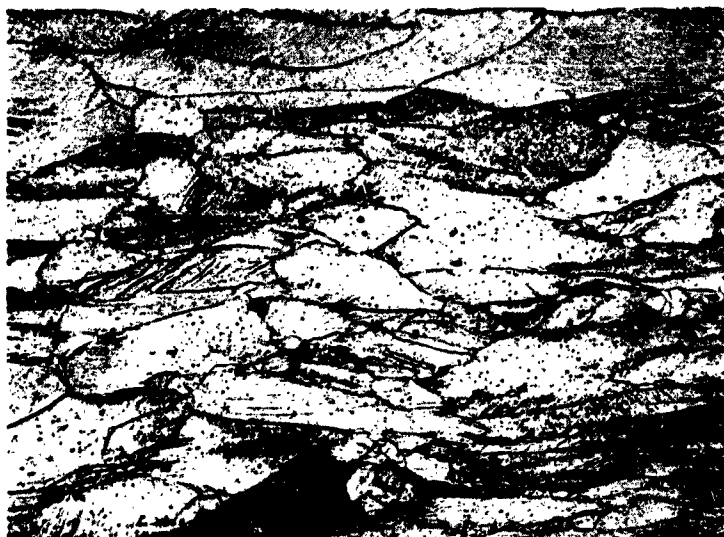
### Photomicrographs

The microstructures of material in various conditions are shown in Figures 7 through 11. The annealed material shown in Figure 7 exhibits elongated grains in the longitudinal direction despite the recrystallization of annealing. The very fine secondary phase which is only slightly visible in the annealed specimen EANL-1, Figure 6 is considerably more pronounced in the aged condition, as shown in Figure 8. Specimen EGNL-2 is a 2000X magnification of this structure. This secondary phase is most likely acicular alpha Ti forming in the otherwise all beta grains.

The cold rolled only material in Figure 9 shows a grain structure similar to the solution annealed material. However, the sharply defined grains are elongated and strain lines are present as the result of the cold deformation.

Cold rolling and aging for 16 hours produced the structures shown in Figure 10. The elongated beta grains showing strain markings are typical. Not resolved in this photomicrograph is the acicular alpha phase that would be expected in the same manner as experienced with annealed and aged only material.

Material aged to 48 hours at 900°F after cold rolling as seen in Figure 11 shows the same general grain structure. However, the secondary alpha phase appears to be more nodular in form and there is little



Longitudinal

100X Mag.

Specimen EANL - 1



Transverse

100X Mag.

Specimen EANT - 1

Ti 13V-11Cr-3Al

Ht. No. D31

0.060" Gage

Solution Annealed

Etchant: 2% HF + 40% HNO<sub>3</sub> + H<sub>2</sub>O



Longitudinal 100X Mag.  
Specimen EGNL - 1



Longitudinal 2000X Mag.  
Specimen EGNL - 2

Ti 13V-11Cr-3Al 0.060" Gage  
Ht. No. D31 Solution Annealed + Aged 900°F, 72Hrs.  
Etchant: 2% HF + HNO<sub>3</sub> + H<sub>2</sub>O

FIGURE 8



Longitudinal

250X Mag.

Specimen ETNL - 1



Transverse

250X Mag.

Specimen ETNT - 1

Ti 13V-11Cr-3Al

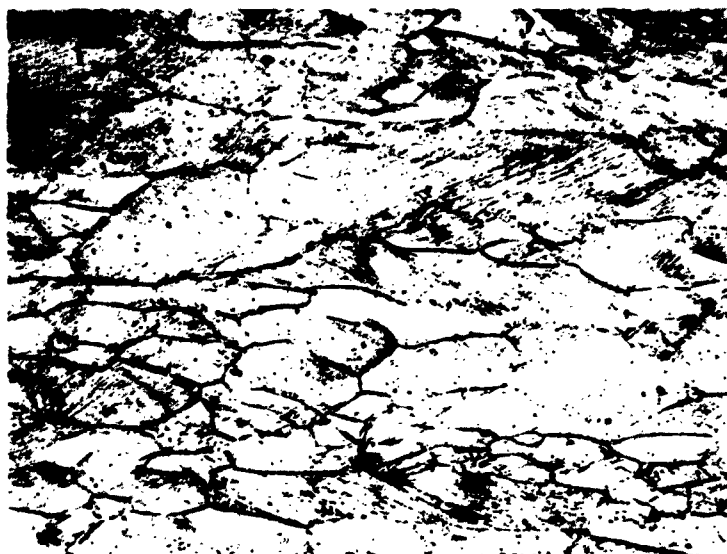
Ht. No. M-9571

Etchant: 2% HF + 40% HNO<sub>3</sub> + H<sub>2</sub>O

0.030" Gage

Cold Rolled 25%

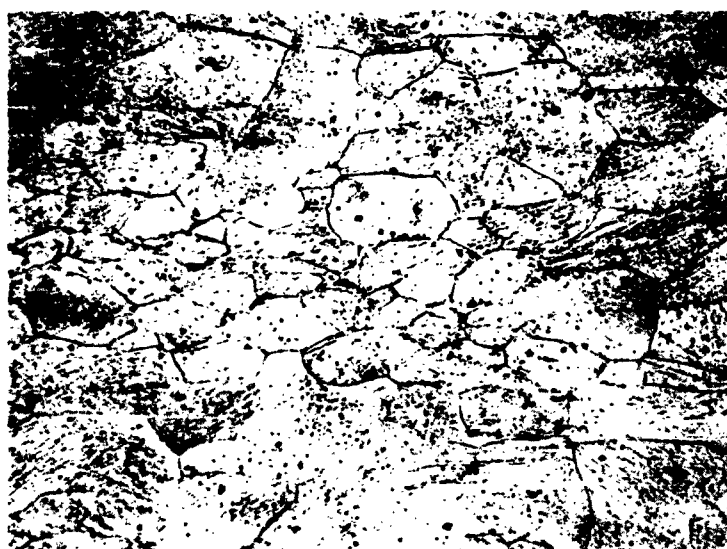
FIGURE 9



Longitudinal

250X Mag.

Specimen ENNL - 6



Transverse

250X Mag.

Specimen ENNT - 6

Ti 13V-11Cr-3Al

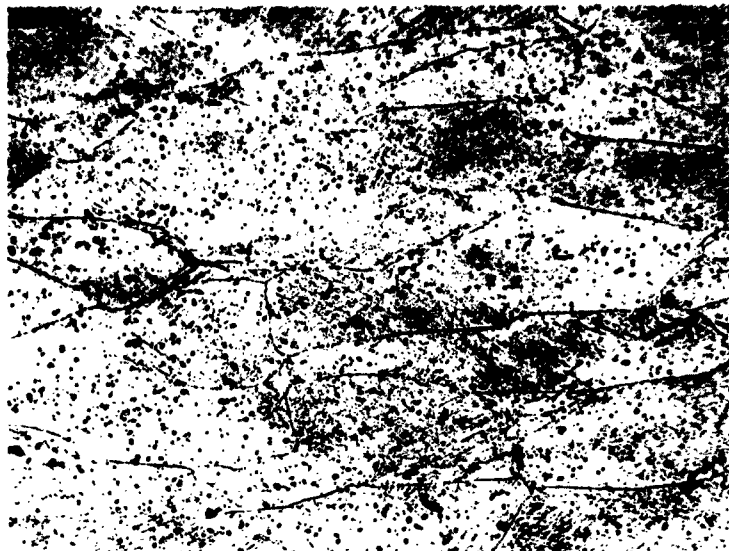
0.034" Gage

Ht.No. D260

Cold Rolled + Aged 900°F, 16Hrs.

Etchant: 2% HF + 40% HNO<sub>3</sub> + H<sub>2</sub>O

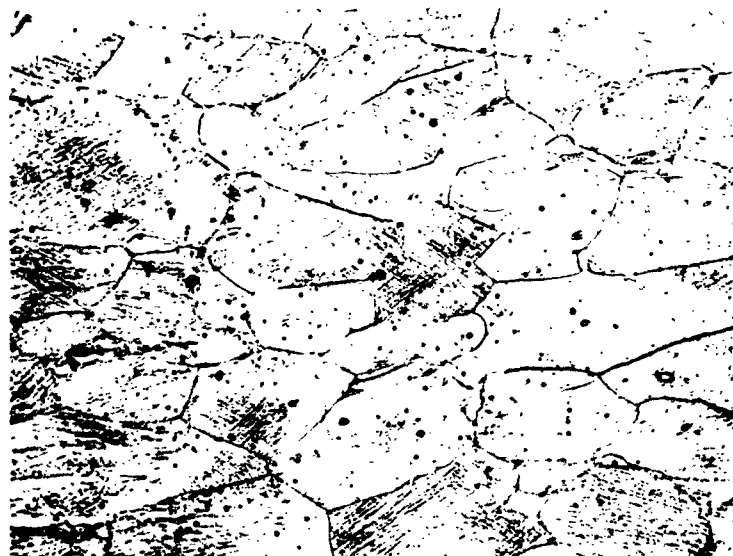
FIGURE 10



Longitudinal

250X Mag.

Specimen ENNL - 1



Transverse

250X Mag.

Specimen ENNT - 1

Ti 13V-11Cr-3Al

0.030" Gage

Ht. No. M9571

Cold Rolled + Aged 900°F, 48Hrs.

Etchant: 2% HF + 40% HNO<sub>3</sub> + H<sub>2</sub>O

FIGURE 11

evidence of the accicular structure at this magnification. There also appears to be some grain boundary precipitant.

### Fracture Energy

The fracture energy values of the Ti 13V-11Cr-3Al was measured in various heat treated, and cold rolled and aged conditions. Our method of testing is discussed elsewhere in this report. The specimen used is the center notch type (dwg. no. 2434-0014) initially cracked by a high stress, low cycle tensile fatigue process. The testing procedure used has been outlined in Quarterly Report No. 9.

The fracture energy data obtained from the testing of specimens from various heats of Ti 13V-11Cr-3Al are shown in Tables 8, 9 and 10. Tables 8 and 9 show the properties of material which had been solution annealed and aged at 900°F for 72 hours. Table 10 presents data on material which had been cold rolled and aged at 900°F for 16 and 48 hours.

Material taken from three different sheets of one heat (D31) and a single sheet of another heat (M9584) exhibited relatively good  $K_{C1}$  values in the longitudinal direction. These values on an average were 33 to 54% better than the transverse figures. The critical crack index values are, of course, more widely spread between the longitudinal and transverse directions.

The other two heats of solution annealed and aged material (nos. M9853 and M9583) developed relatively

FRACTURE ENERGY PROPERTIES OF Ti 13V-11Cr-3Al  
SOLUTION ANNEALED, AGED 900°F, 72 HRS.      CENTER NOTCHED SPECIMEN (DWG. NO. 2434 - 0014)

| Heat No.<br>and Gage | Spec.<br>No. | Direct. | Yield Strength<br>KSI<br>$\sigma_{ys}$ | Ult. Strength<br>KSI<br>$\sigma_{ult}$ | %El.<br>in<br>2 Inches | $K_{Cl}$<br>PSI $\sqrt{\text{Inch}}$ | $\frac{\sigma_{ys}}{d \times 10^6}$ | $\frac{K_{Cl}^2}{\pi d^2 \sigma_{ys}}$ |
|----------------------|--------------|---------|----------------------------------------|----------------------------------------|------------------------|--------------------------------------|-------------------------------------|----------------------------------------|
| D31                  | EGBL-1       | L       | 188                                    | 210                                    | 6                      | 72,200                               | 1.07                                | .047                                   |
| Sht.1                | EGBL-7       | L       | 188                                    | 210                                    | 6                      | 70,800                               | 1.07                                | .045                                   |
| .062                 | EGBT-1       | T       | 200                                    | 215                                    | 2.5                    | 45,300                               | 1.14                                | .017                                   |
|                      | EGBT-7       | T       | 200                                    | 215                                    | 2.5                    | 47,100                               | 1.14                                | .018                                   |
| D31                  | EGBL-2       | L       | 184                                    | 208                                    | 8                      | 73,000                               | 1.05                                | .050                                   |
| Sht.15               | EGBL-8       | L       | 184                                    | 208                                    | 8                      | 73,400                               | 1.05                                | .050                                   |
| .062                 | EGBT-2       | T       | 188                                    | 209                                    | 6.5                    | 54,700                               | 1.08                                | .027                                   |
| D31                  | EGBL-3       | L       | 183                                    | 206                                    | 8                      | 76,500                               | 1.05                                | .055                                   |
| Sht.16               | EGBL-9       | L       | 183                                    | 206                                    | 8                      | 69,300                               | 1.05                                | .045                                   |
| .062                 | EGBT-3       | T       | 193                                    | 212                                    | 4                      | 54,800                               | 1.10                                | .026                                   |
|                      | EGBT-8       | T       | 193                                    | 212                                    | 4                      | 52,800                               | 1.10                                | .024                                   |

TABLE 8

FRACTURE ENERGY PROPERTIES OF Ti 13V-11Cr-3Al  
SOLUTION ANNEALED, AGED 900°F, 72 HRS.      CENTER NOTCHED SPECIMEN (DWG. NO. 2434 - 0014)

| Heat No.<br>and Gage | Spec.<br>No. | Direct. | Yield Strength<br>KSI<br>$\sigma_{ys}$ | Ult. Strength<br>KSI<br>$\sigma_{ult}$ | %El.<br>in<br>2 Inches | $K_{Cl}$<br>PSI $\sqrt{\text{inch}}$ | $\frac{\sigma_{ys}}{d} \times 10^6$ | $\frac{K_{Cl}^2}{\pi \sigma_{ys}^2}$ |
|----------------------|--------------|---------|----------------------------------------|----------------------------------------|------------------------|--------------------------------------|-------------------------------------|--------------------------------------|
| M9853                | EGBL-4       | L       | 200                                    | 207                                    | 1*                     | 49,100                               | 1.144                               | .019                                 |
| Sht.13               | EGBL-10      | L       | 200                                    | 207                                    | 1*                     | 46,000                               | 1.144                               | .017                                 |
| .060                 | EGBT-4       | T       | 204                                    | 211                                    | 1*                     | 33,700                               | 1.20                                | .009                                 |
|                      | EGBT-9       | T       | 204                                    | 211                                    | 1*                     | 33,500                               | 1.17                                | .009                                 |
| M9583                | EGBL-5       | L       | 182                                    | 200                                    | 5                      | 49,800                               | 1.04                                | .024                                 |
| Sht.12               | EGBL-11      | L       | 182                                    | 200                                    | 5                      | 48,600                               | 1.04                                | .023                                 |
| .062                 | EGBT-5       | T       | 184                                    | 200                                    | 1*                     | 40,600                               | 1.05                                | .016                                 |
|                      | EGBT-10      | T       | 184                                    | 200                                    | 1*                     | 40,400                               | 1.05                                | .015                                 |
| M9584                | EGBL-6       | L       | 183                                    | 203                                    | 8                      | 67,000                               | 1.05                                | .043                                 |
| Sht.1-1              | EGBL-12      | L       | 183                                    | 203                                    | 8                      | 72,000                               | 1.05                                | .049                                 |
|                      | EGBT-6       | T       | 191                                    | 207                                    | 2.5*                   | 50,600                               | 1.09                                | .022                                 |
|                      | EGBT-11      | T       | 191                                    | 207                                    | 2.5*                   | 50,600                               | 1.09                                | .022                                 |

\* Tensile Specimen Broke Outside of Gage Length

TABLE 9

FRACTURE ENERGY PROPERTY OF Ti 13V-11Cr-3Al  
COLD ROLLED AND AGED 900°F      CENTER NOTCHED SPECIMEN (DWG. NO. 2434 - 0014)

| Heat No.<br>and Gage                               | Spec.<br>No. | Direct. | Yield Strength<br>KSI<br>$\sigma_{ys}$ | Ult. Strength<br>KSI<br>$\sigma_{ut}$ | %El.<br>in<br>2 Inches | $K_{Cl}$ | $\frac{\sigma_{ys}}{d} \times 10^6$ | $\frac{K_{Cl}^2}{\pi \sigma_{ys}^2}$ |
|----------------------------------------------------|--------------|---------|----------------------------------------|---------------------------------------|------------------------|----------|-------------------------------------|--------------------------------------|
| Aged 16Hrs. ENBL-3<br>Ht.No.D260<br>.028"          |              | L       | 199                                    | 215                                   | 9                      | 72,000   | 1.14                                | .041                                 |
| Aged 48Hrs. ENBL-1<br>Ht.No.9571<br>Sht.1<br>.029" |              | L       | 200                                    | 216                                   | 5                      | 66,000   | 1.14                                | .041                                 |

TABLE 10

low values in both rolling directions. The analysis of the material, as reported by the supplier does not offer a reason for this difference.

The cold rolled and aged specimens developed relatively good  $K_{C1}$  values in the longitudinal direction. Transverse specimens will be tested at a later date.

All the specimens tested had yield strength to density ratios greater than one million. The  $K_{C1}$  values and the critical crack index figures are generally superior to these values reported for high strength Q and T steels at the equivalent yield strength to density ratio.

#### Bend Testing

The results of bending specimens in the annealed, cold rolled and aged, and aged conditions are shown in Tables 11 and 12. The annealed material required a 1T to 2.3T bend radius when bent through 135° in a closed punch and die. Cold rolling to 25% reduction increased the bend radius to 3T. Aging after cold rolling markedly increased the bend radius requirements. The 48 hour aging produced 17T and greater bend radii values for 0.030 inch gage material.

The material aged at 900°F for 72 hours could not be accurately tested. The largest bend die in the set has a 0.500 inch radius. Indications were that both the 0.060 inch and 0.080 inch thick sheet stock required bend radii considerably greater than 8.3T and 6.3T,

BEND PROPERTIES OF Ti 13V-11Cr-3Al  
SPECIMENS BENT THROUGH 135° ANGLE IN CLOSED PUNCH AND DIE (DWG. NOS. 2434-0090-1-2)

| Ht. No.           | Gage | Direct. | Annealed |              | Aged 72 Hrs. 900°F |              |
|-------------------|------|---------|----------|--------------|--------------------|--------------|
|                   |      |         | Spec.No. | Min."T"Ratio | Spec.No.           | Min."T"Ratio |
| D31, Sht.1        | .061 | L       | EAGL-1   | 2.3T         | EGGL-1             | >>8.3T       |
|                   |      | T       | EAGT-1   | 2.0T         | EGGL-1             | >>8.3T       |
| D31, Sht.15       | .061 | L       | EAGL-2   | 1.0T         | EGGL-2             | 8.3T         |
|                   |      | T       | EAGT-2   | 2.0T         | EGGT-2             | >8.3T        |
| M-9583<br>Sht.12  | .061 | L       | -        | -            | EGGL-5             | >8.3T        |
|                   |      | T       | EAGT-5   | 2.0T         | EGGT-5             | >8.3T        |
| M-9584<br>Sht.1-1 | .084 | L       | -        | -            | EGGL-6             | >6.3T        |
|                   |      | T       | EAGT-6   | 1.5T         | EGGL-6             | >6.3T        |
| D31, Sht.16       | .060 | L       | -        | -            | EGGL-3             | >8.3T        |
|                   |      | T       | -        | -            | EGGT-3             | >8.3T        |
| M-9853<br>Sht.13  | .060 | L       | -        | -            | EGGL-4             | >8.3T        |
|                   |      | T       | -        | -            | EGGT-4             | >8.3T        |

"T" Ratio is the Radius of the Punch Divided by the Material Thickness

TABLE 11

# BEND PROPERTIES OF T1 13V-11Cr-3Al

SPECIMENS BENT THROUGH 135° ANGLE IN CLOSED PUNCH AND DIE (DWG. NOS. 2434-0090-1-2)

| Ht. No. Gage | Direct. | Cold Rolled 25% |                | Cold Rolled, Aged |                | Cold Rolled 25%       |          |
|--------------|---------|-----------------|----------------|-------------------|----------------|-----------------------|----------|
|              |         | Spec.No.        | Min. "T" Ratio | Spec.No.          | Min. "T" Ratio | Aged @ 900°F, 48 Hrs. | Spec.No. |
| M-9571       | L       | ETGL-1          | >3T            | -                 | -              | -                     | -        |
| Sht.1        | T       | ETGT-1          | >3.5T          | -                 | -              | -                     | -        |
| D260         | L       | -               | -              | ENGL-3            | >7T            | -                     | -        |
| Sht.2        | T       | -               | -              | ENGT-3            | >11T           | -                     | -        |
| M-9571       | L       | -               | -              | -                 | -              | ENGL-2                | 17T      |
| Sht.1        | T       | -               | -              | -                 | -              | ENGT-2                | >17T     |

"T" Ratio is the Radius of the Punch Divided by the Material Thickness

respectively. These values would most likely be in the neighborhood of the 17T radii required for the 0.030 inch specimens.

#### Resistance Welding, Annealed Ti 13V-11Cr-3Al

Specimens in the solution annealed condition were resistance spot welded according to the schedule shown in Figure 12. The following specimens were included in this study.

Tension Shear, Type E, Dwg. No. 2434 - 0004

Cross Tension, Type S, Dwg. No. 2434- 0012

Photomacrographs and hardness traverse, Type O

Photomicrograph, Type N

Stress Corrosion, Type K, Dwg. No. 2434-0011

The type E and S specimens were made from 0.060" sheet taken from heat 9853, Sheet 13. These types of tests were discussed in Report No. 10. The results of this work are shown in Table 13.

The material was prepared for welding by pickling in 40%  $H_2SO_4$  at room temperature, followed by thorough rinsing in running water and air drying. A final acetone wipe was used prior to welding to insure cleanliness because of a drilling operation done after pickling.

The Ti 13V-11Cr-3Al alloy in the annealed condition is readily resistance weldable. The weld nuggets formed prove to be sound and reproducible. The weld nugget extends to the limits of the electrode contact diameter and there is little or no heat affected zone detectable

MATERIALS RESEARCH LABORATORY

Resistance Welding Data Sheet

Date May 4, 1961

Project 5017

Welding Machine

Material and Gage

150 KVA Sciaky Single Phase

0.060" Ti-13V-11Cr-3Al (Code E)

Dekatron Pulse Counting  
Electrodes

Material Condition

5/8" Dia. RWMA, Group A, Class 3, Solution Anneal and Pickled  
2 1/2" Rad.

Welding Schedule

|                                   |                        |      |
|-----------------------------------|------------------------|------|
| Electrode Force, lbs.             | Phase Shift,%- - - - - | 48   |
| Net - - - - - 1500                | Squeeze Time Cycles    | 10   |
| Forge- - - - - None               | Hold Time Cycles       | 50   |
| Weld Cycles- - - - - 10           | Weld Diam., Ins. - - - | .234 |
| Impulses - - - - - 1              | HAZ Diam.. Ins.- - - - | .234 |
| Cooling Cycles - - - - - None     | Penetration,%- - - - - | 66   |
| Transformer Setting- - 2 Series 2 | Electrode Indent,% - - | 12.5 |

Remarks and Special Functions

Spec. No. EAO-1

MECHANICAL PROPERTIES  
RESISTANCE SPOT WELDED SPECIMENS  
Ti 13V-11Cr-3Al  
0.060" GAGE  
HT. NO. AS NOTED

| Condition                                              | Tensile (Type S Specimen) |           |              | Tensile-Shear (Type E Specimen) |            |              | $\frac{T}{TS}$ Ratio |
|--------------------------------------------------------|---------------------------|-----------|--------------|---------------------------------|------------|--------------|----------------------|
|                                                        | Spec. No.                 | Load lbs. | Type Failure | Spec. No.                       | Load, lbs. | Type Failure |                      |
| Solution Annealed<br>Ht. No. 9853<br>Sheet 13          | EAS-1                     | 3210      | Plug         | EAE-1                           | 4990       | Shear        |                      |
|                                                        | EAS-2                     | 3195      | Plug         | EAE-2                           | 5215       | Shear        |                      |
|                                                        | EAS-3                     | 2790      | Plug         | EAE-3                           | 5150       | Shear        |                      |
|                                                        | EAS-4                     | 2870      | Shear        | EAE-4                           | 5150       | Shear        |                      |
|                                                        | Aver.                     | 3016      |              | Aver.                           | 5061       |              | 59.5%                |
| Cold Rolled and<br>Aged @ 900°F, 8Hrs.<br>Ht. No. D575 | ENS-1                     | 1890      | Fract.*      | ENE-1                           | 4830       | Shear        |                      |
|                                                        | ENS-2                     | 2290      | Fract.*      | ENE-2                           | 5375       | Shear        |                      |
|                                                        | ENS-3                     | 2380      | Fract.*      | ENE-3                           | 5350       | Shear        |                      |
|                                                        | ENS-4                     | 2032      | Fract.*      | ENE-4                           | 5285       | Shear        |                      |
|                                                        | Aver.                     | 2149      |              | Aver.                           | 5210       |              | 41.1%                |

\* Specimen Fractured Across Area of Weld Due to Bending

TABLE 13

at the surface. The electrode indentation is normal for this gage material. Sheet separation is expected to be greater than normal because of the relative ease with which this alloy is forged during the welding cycle. Note the "fin" which is extruded between the sheets at the edge of the nugget, shown in the photomacrograph in Figure 13.

A micro hardness survey across the nugget is also shown in Figure 13. The hardness is relatively uniform from the base metal through the weld nugget. This is typical for solution treated beta titanium.

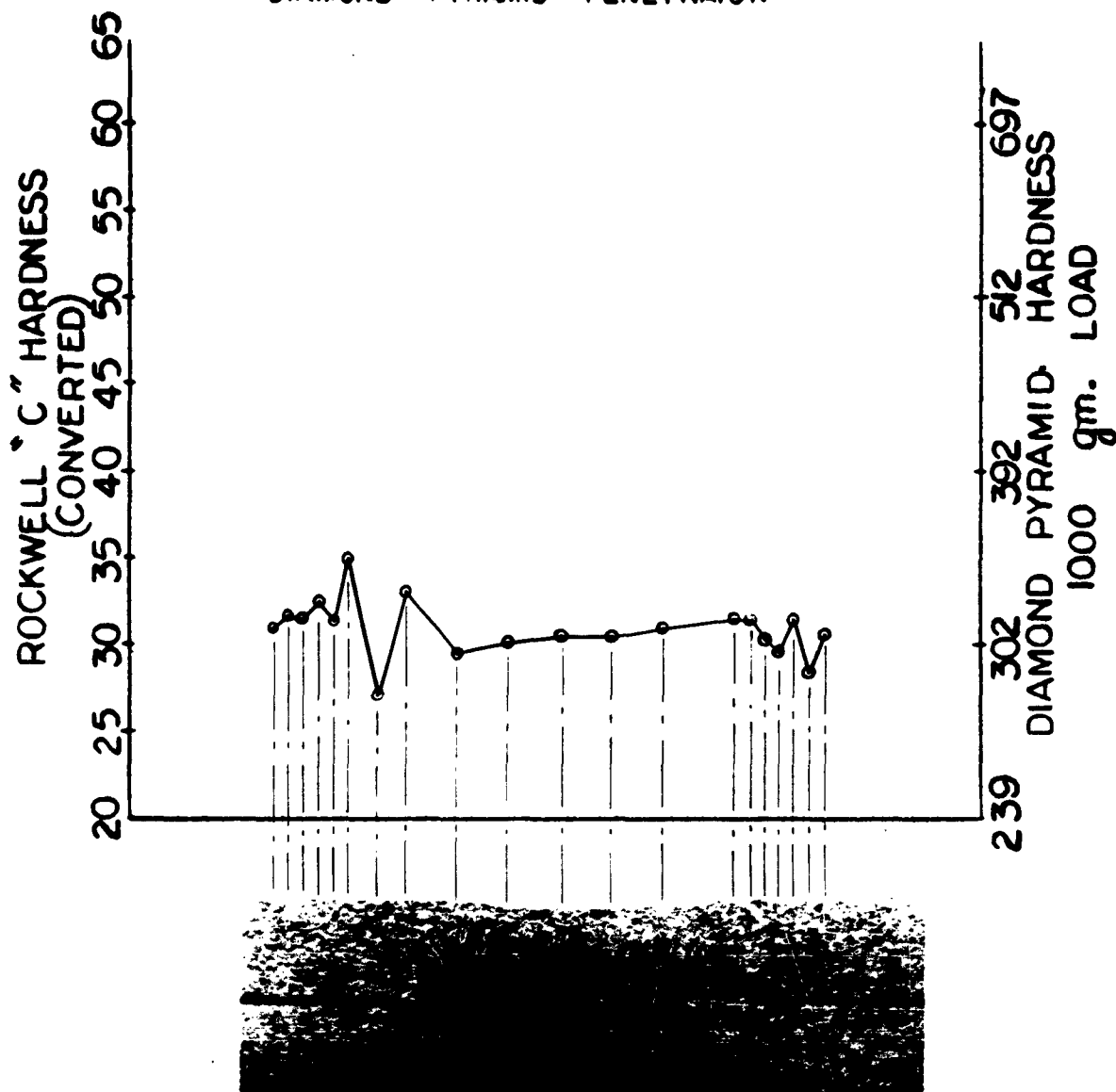
The photomicrographs of the heat affected zone and weld nugget of the resistance spot weld structure are shown as a composite in Figure 14. Specimen EAN-1 shows mostly weld nugget. The heat affected zone is shown by Specimen EAN-2. The large grain, equiaxed in the HAZ and columnar in the nugget is typical. The heat affected zone is narrow and blends into the base metal with no definite demarkation of the boundary. The grains are clean and free from grain boundary constituents.

#### Resistance Welding, Cold Rolled and Aged Ti 13V-11Cr-3Al

Ti 13V-11Cr-3Al in the cold rolled and aged condition was evaluated for resistance spot welding in a similar manner as the annealed material. The alloy in this condition was readily welded using the same welding schedule as for the solution annealed stock. This schedule and other pertinent data are shown in Figure 15.

# MICRO HARDNESS TRAVERSE

WELD CROSS SECTION  
KENTRON MICRO HARDNESS TESTER  
DIAMOND PYRAMID PENETRATOR



SPEC. NO. EA0-1 WELD TYPE Resistance Spot MAG. 10X  
ETCHANT 2% HF + 10% HNO<sub>3</sub> + H<sub>2</sub>O

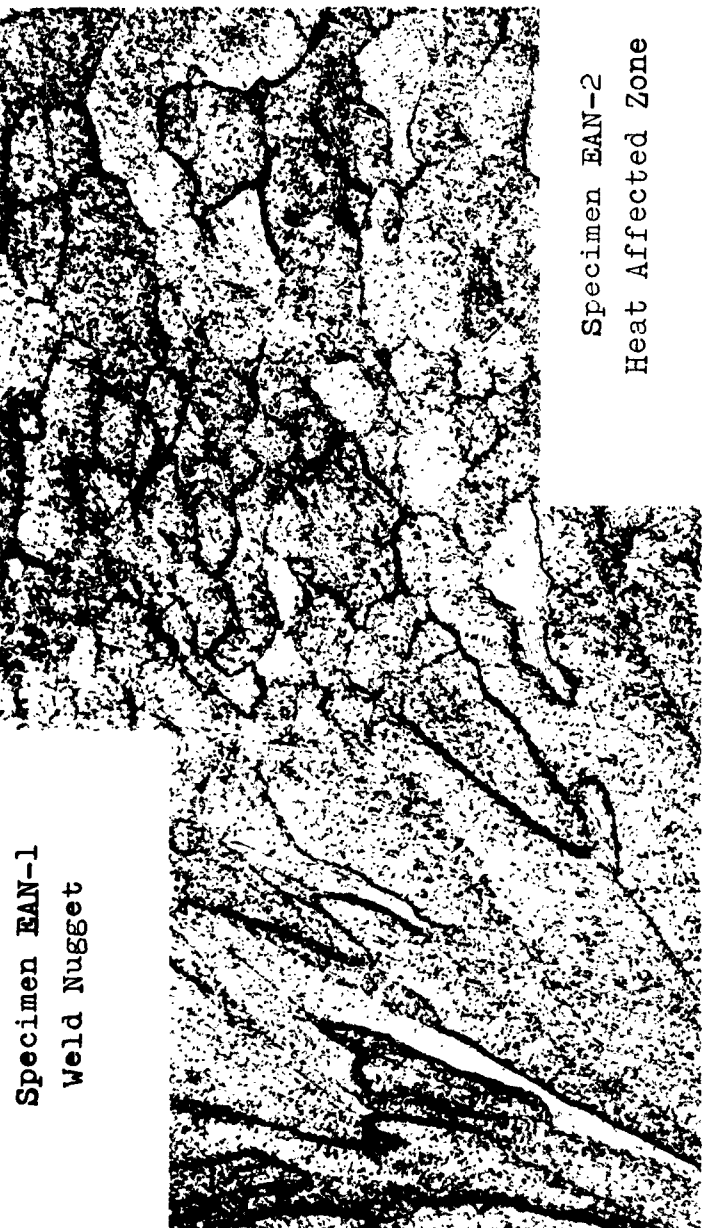
MATERIAL Ti 13V-11Cr-3Al GAGE .060"

CONDITION Solution Annealed,

WELD DIA. INS. 0.234 HAZ DIA. INS. 0.234

PENETRATION % 66 ELECTRODE INDENTATION % 12.5

FIG. 13



Specimen EAN-1  
Weld Nugget

Specimen EAN-2  
Heat Affected Zone

Ti 13V-11Cr-3Al, Annealed  
100X Mag.  
Resistance Spot Weld  
Etchant: 2% HF + 10% HNO<sub>3</sub>

Figure 14

MATERIALS RESEARCH LABORATORY

Resistance Welding Data Sheet

Date May 11, 1961

Project 5017

Welding Machine

150 KVA Single Phase AC with  
Dekatron Timing Control  
Electrodes

Material and Gage

0.060" Ti-13V-11Cr-3Al (Code E)

Material Condition

5/8" Dia. RWMA, Group A, Class 3; Cold Worked & Aged to 200 Kpsi Y.S.  
2 1/2" Rad.

Heat D575, Sht. #1

Welding Schedule

|                                          |                        |       |
|------------------------------------------|------------------------|-------|
| Electrode Force, lbs.                    | Phase Shift,%- - - - - | 48    |
| Net - - - - - 1500                       | Squeeze Time Cycles    | 50    |
| Forge- - - - -                           | Hold Time Cycles       | 50    |
| Weld Cycles- - - - - 10                  | Weld Diam., Ins. - - - | 0.236 |
| Impulses - - - - - 1                     | HAZ Diam.. Ins.- - - - | 0.280 |
| Cooling Cycles - - - - - None            | Penetration,%- - - - - | 68    |
| Transformer Setting- - <u>2 Series 2</u> | Electrode Indent,% - - | 7     |

Remarks and Special Functions

Spec. No. EJO - 1

Fig. 15

The weld diameters are the same for the two conditions. The heat affected zone is more distinct in the cold worked material. A photomacrograph of the cross-section of a typical nugget is shown in Figure 16. The hardness traverse in Figure 16 shows complete and essentially uniform annealing of the nugget material with a rapid transition to the base metal hardness in the heat affected zone.

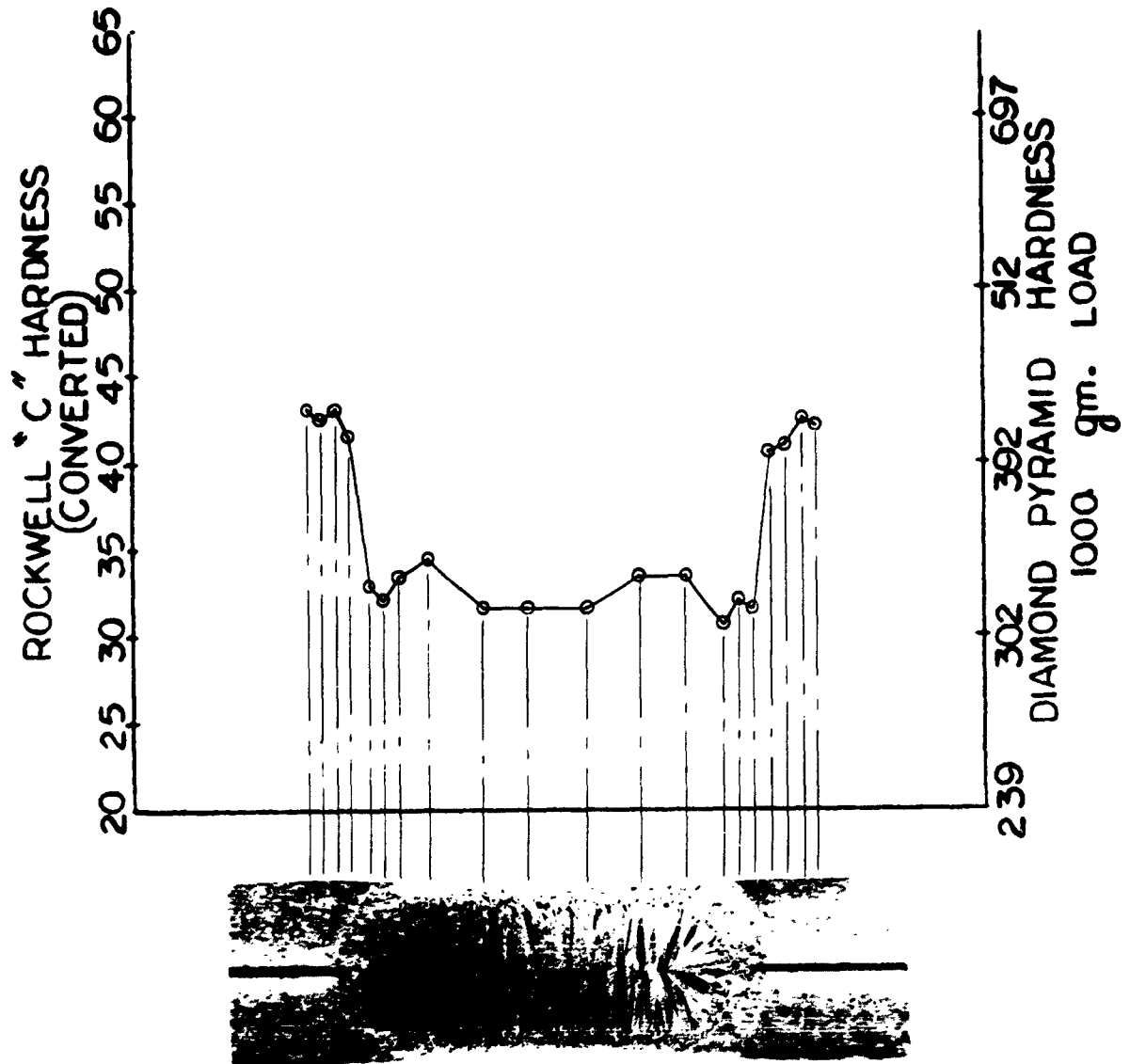
The electrode indentation is typical of titanium base alloys. The sheet separation is more pronounced than with other materials, being approximately 8% of the sheet thickness.

The results of the testing of the tensile-shear and the cross-tension specimens are shown in Table 13. There is a slight increase in the tensile-shear values as compared to the annealed specimens. However, a substantial decrease is realized in the cross tension strength. The cross tension specimens failed by fracturing in bending across the area of the weld nugget. See Report No. 10 for a complete description of these tests and photographs of specimens and test fixtures. As a result of the low cross-tension values the ratio of tensile to tensile-shear is lower than would be expected from a cold rolled austenitic stainless steel. However, this is usually the case with titanium base alloys.

Photomicrographs of the base metal, heat affected zone and weld nugget are shown in Figure 17. These

# MICRO HARDNESS TRAVERSE

WELD CROSS SECTION  
KENTRON MICRO HARDNESS TESTER  
DIAMOND PYRAMID PENETRATOR



SPEC. NO. EJO-1 WELD TYPE Resistance MAG. 9X  
ETCHANT \_\_\_\_\_

MATERIAL T1 13V-11Cr-3Al GAGE 0.060

CONDITION Cold Rolled and Aged, Heat D575, Sheet #1

WELD DIA. INS. 0.236 HAZ DIA. INS. 0.280

PENETRATION % 68 ELECTRODE INDENTATION % 7

FIG. 16



Base Metal      Heat Affected Zone  
Specimen EJN-1



Weld Nugget  
Specimen EJN-2

Ti 13V-11Cr-3Al, Cold Rolled and Aged  
100X Mag.

Resistance Spot Weld  
Etchant: 2% HF + 10% HNO<sub>3</sub>

Figure 17

photographs at 100X show the extent of recrystallization and grain growth within the heat affected zone. The elongated grain and cold worked structure is found near the base metal (dark area) and heat affected zone boundary. A relatively fine background structure is seen within the equiaxed beta grains. This fine structure may be alpha titanium which is not clearly resolved at this magnification. The weld nugget shows large columnar beta grains and a lesser defined dendritic structure. Again, the precipitate is distributed through the grains. The lower left corner of Specimen EJN-2 shows equiaxed grains of the heat affected zone.

#### Stress Corrosion, Resistance Spot Welds

The description of the test used to measure the susceptibility of resistance spot welds to stress corrosion cracking may be found in Report No. 11.

As with all materials in this program a limited stress corrosion study has been made. We have exposed the Ti 13V-11Cr-3Al to two concentrations of magnesium chloride (5% and 20%) in a boiling aqueous solution for periods of time up to 126 hours.

One heat of annealed stock and one heat in the cold rolled and aged condition were used for the test specimens. Two resistance spot welds were made in each specimen using the welding schedule shown in Figure 12. The edges of the specimen were sealed with a synthetic rubber substance to prevent penetration of the solution

between the two pieces joined by the weld. The results of these tests are shown in Table 14.

The annealed specimens withstood the corrosive medium in both the 5% and 20% concentrations of  $MgCl_2$  for the maximum test time. The cold rolled and aged material showed no cracking in the 5%  $MgCl_2$  but did develop typical stress corrosion cracks at 8 1/2, 74, 103 and 126 hours for the four specimens in the 20% concentration. This spread of results is to be expected with a test of this type.

To evaluate the effect of preventing the solution from penetrating between the specimen halves a run was made in 20%  $MgCl_2$  with the specimens unsealed. The results of these tests, which were run 78 1/2 hours, are shown in Table 15.

The tests made with unsealed specimens did not indicate any increase in the severity of the exposure. Only one very small crack developed in the 78 1/2 hour cycle.

#### TIG Welding, Ti 13V-11Cr-3Al Alloy Sheet

Solution annealed and cold rolled Ti 13V-11Cr-3Al sheet was Tungsten Inert Gas welded using beta titanium filler wire. Radiographic examination showed that all weldments contained scattered porosity of 0.008" to 0.020" diameter along the fusion line. Tensile tests of specimens machined from areas with 0.012" diameter and smaller porosity indicated the yield and tensile strengths of the weldments were normal; that is, the same as solution

STRESS-CORROSION DATA OF Ti 13V-11Cr-3Al  
0.060"-0.064" GAGE Resistance Spot Welded Specimens, Type K SEALED EDGES

| Condition<br>and Heat Number                       | Spec.<br>No. | Type of<br>Solution                 | Specific Gravity<br>Start | Specific Gravity<br>Finish | Total<br>Hours | Results          |
|----------------------------------------------------|--------------|-------------------------------------|---------------------------|----------------------------|----------------|------------------|
| Solution Annealed<br>Ht.No.M-9853                  | EAK-1        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
|                                                    | EAK-2        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
|                                                    | EAK-3        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
|                                                    | EAK-4        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
| Cold Rolled and<br>Aged@900°F, 8Hrs.<br>Ht.No.D575 | ENK-1        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
|                                                    | ENK-2        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
|                                                    | ENK-3        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
|                                                    | ENK-4        | 5%M <sub>g</sub> Cl <sub>2</sub> *  | 1.020@83°F                | 1.023@73°F                 | 116            | OK               |
| Solution Annealed<br>Ht.No.M-9853                  | EAK-5        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | OK               |
|                                                    | EAK-6        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | OK               |
|                                                    | EAK-7        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | OK               |
|                                                    | EAK-8        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | OK               |
| Cold Rolled and<br>Aged@900°F, 8Hrs.<br>Ht.No.D575 | ENK-5        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | Cracked 74 Hrs.  |
|                                                    | ENK-6        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | Cracked 126 Hrs. |
|                                                    | ENK-7        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | Cracked 103 Hrs. |
|                                                    | ENK-8        | 20%M <sub>g</sub> Cl <sub>2</sub> * | 1.075@89°F                | 1.078@90°F                 | 126            | Cracked 8½ Hrs.  |

\* Boiling aqueous solutions. See Page 101 of Report No. 9 for complete test procedure.

TABLE 14

| Condition and Heat Number         | Spec. No. | Type of Solution                   | Specific Gravity Start | Specific Gravity Finish | Total Hours | Results              |
|-----------------------------------|-----------|------------------------------------|------------------------|-------------------------|-------------|----------------------|
| Cold Rolled and Aged@900°F, 8Hrs. | ENK-9     | 20% <sub>g</sub> Cl <sub>2</sub> * | 1.076@89°F             | 1.082@89°F              | 78½         | OK                   |
|                                   | ENK-10    | 20% <sub>g</sub> Cl <sub>2</sub> * | 1.076@89°F             | 1.082@89°F              | 78½         | OK                   |
| Ht.No. D575                       | ENK-11    | 20% <sub>g</sub> Cl <sub>2</sub> * | 1.076@89°F             | 1.082@89°F              | 78½         | OK                   |
|                                   | ENK-12    | 20% <sub>g</sub> Cl <sub>2</sub> * | 1.076@89°F             | 1.082@89°F              | 78½         | One very small crack |

\* Boiling aqueous solution. See Page 101 of Report No. 9 for complete test procedure.

annealed stock. Welding schedules to obtain full penetration and adequate weld metal reinforcement were readily established and were reproducible.

#### Materials.

The 0.060" thick beta titanium sheet was procured from the Titanium Metals Corporation in the annealed condition and in the cold rolled and aged condition. The 0.030" annealed beta titanium filler wire was procured from ARMETCO, Wooster, Ohio. The chemical compositions of the sheet and filler wire are shown in Table 3. The mechanical properties of the materials are listed in Tables 4 through 7.

#### Preparation of Samples for Welding.

Coupons for welding were cold sheared from the sheet stock and dye penetrant inspected to insure freedom from shear cracks. The edge to be welded was ground to a 63 microinch finish. The ground edge was dye penetrant inspected for grinding cracks and shear cracks that may have been missed during the first inspection. No cracks were found. The coupons were cleaned by immersing for one minute in a water solution of 40% by volume of concentrated  $H_2SO_4$ , followed by water rinsing and air drying. Just prior to welding, the ground edge and an area back about one inch from the edge on both surfaces, was mechanically cleaned with 400 grit emery paper and thoroughly washed with acetone. The filler wire was mechanically cleaned in a similar manner just prior to welding the coupons.

### Joint Design.

A single pass butt joint was used. The welding edges were prepared such that a 0.001" feeler gage could not be placed in the joint when the edges were butted under slight pressure. The weld metal deposit was parallel to the longitudinal direction of the sheet (direction of rolling), and the weld metal reinforcement aim was 40 to 50 percent total, equally distributed top and bottom. The size of the finished weldment was approximately 10" wide by 12" long. The general characteristics of the joint design, except for the amount of reinforcement, are shown in Figure 1 of Progress Report #10, April, 1961.

### Welding

The tungsten inert gas welding equipment consisted of a Vickers 300 ampere rectified power source, an AIRCO MOD. C torch, and an AIRCO high frequency starter. Auxillary equipment consisted of a copper root shield, a 5/8" nozzle, copper chill bars and C-clamps. A follower shield was not used. This equipment, with a ceramic in lieu of a metal nozzle, is illustrated in pages 10 and 11 of Progress Report #10, April, 1961. The welding schedules developed and used for production of the test weldments are shown in Tables 16 and 17. These schedules provided reproducible test weldments without difficulty.

TIG FUSION WELDING SCHEDULE FOR Ti, 13V, 11Cr, 3Al, 0.060"  
SOLUTION ANNEALED SHEET

| <u>Item</u>             | <u>Description</u>                                                   |
|-------------------------|----------------------------------------------------------------------|
| <u>Electrode</u>        |                                                                      |
| Type                    | 2% thoriated tungsten                                                |
| Size                    | 3/32", tapered point.                                                |
| Stickout                | 3/8".                                                                |
| <u>Torch</u>            |                                                                      |
| Type                    | AIRCO Mod. C.                                                        |
| Attack angle            | 90°.                                                                 |
| Lead angle              | Zero.                                                                |
| <u>Root Shield</u>      |                                                                      |
| Type                    | Copper, Budd Co. dwg. E2434-0121, (see<br>prog. report #10, fig. 4). |
| Groove size             | 0.040" deep by 1/4" wide.                                            |
| Gas ports               | 1/16" diameter, spaced 3/4" apart.                                   |
| <u>Nozzle</u>           |                                                                      |
| <u>Chill Bars</u>       | Copper, 3/4" X 3-1/4" with 45° bevel<br>to a 1/8" land.              |
| <u>ARC Voltage</u>      | 12 volts at electrode tip.                                           |
| <u>DSSP Amperage</u>    | 190 to 195 amperes.                                                  |
| <u>Shielding Gas</u>    |                                                                      |
| Nozzle                  | Argon, 25 cubic feet per hour                                        |
| Root                    | Argon, 3 cubic feet per hour                                         |
| Follower                | Follower shield was not used                                         |
| <u>Filler Wire</u>      |                                                                      |
| Type                    | 0.030" diameter, annealed beta titanium.                             |
| Feed                    | 18" per minute.                                                      |
| <u>Welding Speed</u>    | 7 1/2" per minute.                                                   |
| <u>Preheat-Postheat</u> | None used.                                                           |
| <u>Power Source</u>     | Vicker's, 300 ampere, rectified                                      |
| <u>Start. Mech.</u>     | AIRCO HF-1                                                           |

TABLE 16

**TIG FUSION WELDING SCHEDULE FOR Ti, 13V, 11Cr, 3Al 0.060"**  
**SHEET COLD ROLLED AND AGED TO 230 kpsi U. T. S.**

| <u>Item</u>             | <u>Description</u>                                           |
|-------------------------|--------------------------------------------------------------|
| <u>Electrode</u>        |                                                              |
| Type                    | 2% thoriated tungsten                                        |
| Size                    | 3/32", tapered point                                         |
| Stickout                | 3/8".                                                        |
| <u>Torch</u>            |                                                              |
| Type                    | AIRCO Mod. C.                                                |
| Attack angle            | 90°.                                                         |
| Lead angle              | Zero                                                         |
| <u>Root Shield</u>      |                                                              |
| Type                    | Copper, Budd Co. dwg. E2434-0121,<br>(see prog. report #10). |
| Groove size             | 0.040" deep by 3/16" wide.                                   |
| Gas ports               | 1/16" dia. spaced 3/4" apart.                                |
| <u>Chill Bars</u>       |                                                              |
|                         | Copper, 3/4" X 3-1/4" with 45°<br>bevel to a 1/8" land.      |
| <u>Nozzle</u>           |                                                              |
|                         | Metal, 5/8" diameter.                                        |
| <u>ARC Voltage</u>      |                                                              |
|                         | 12 volts at electrode tip.                                   |
| <u>DSCP Amperage</u>    |                                                              |
|                         | 180 to 190 amperes.                                          |
| <u>Shielding Gas</u>    |                                                              |
| Nozzle                  | Argon, 30 cubic feet per hour.                               |
| Root                    | Argon, 3 cubic feet per hour                                 |
| Follower                | Follower shield was not used                                 |
| <u>Filler Wire</u>      |                                                              |
| Type                    | 0.030" diameter, annealed beta<br>titanium                   |
| Feed                    | 18 inches per minute.                                        |
| <u>Welding Speed</u>    |                                                              |
|                         | 7-1/2" per minute.                                           |
| <u>Preheat-Postheat</u> |                                                              |
|                         | None                                                         |
| <u>Power Source</u>     |                                                              |
|                         | Vicker's 300 amp. rectified.                                 |
| <u>Start. Mech.</u>     |                                                              |
|                         | AIRCO HF-1.                                                  |

TABLE 17

### Radiographic Examination of Weldments

Weldments were radiographed using a 200 KV Mitchell source, a 0.005" thick stainless steel penetrometer, and the following technique:

145 KV, 4.5 Ma., Kodak M Film

2 1/2 Min. Exposure, 36" FFD

5 Minutes Development Time

All welds contained scattered fusion line porosity varying from 0.008" to 0.020" diameter. There was no evidence of cracks, craters, inclusions or serious undercutting.

### Tensile and Bend Test Results.

Tensile and bend tests were machined from areas of the weldments containing porosity indications of 0.012" diameter and less. The procedures for preparation of the test specimens, and the testing procedures are described in Progress Report #9, March, 1961. The mechanical properties of the weldments are listed in Table 18. These properties are typical of fusion welded beta titanium. The bending characteristics of the weldments are as follows:

### Solution Annealed Weldments

Controlled bending parallel to the weld axis to an angle of 135 degrees can be accomplished about a radius of 2.4 times the base metal thickness. Free bending through 180 degrees results in cracking along the fusion line.

MECHANICAL PROPERTIES-TIG WELDMENTS, Ti 13V-11Cr-3Al  
0.060" GAGE SHEET

| Condition         | Spec.<br>No.(1) | Stress Area<br>T x W,<br>Inches(2) | Yield Strength<br>0.2% Offset<br>KSI | Ult.Tensile<br>Strength<br>KSI | %Elong.<br>2" 1/2" | Fracture<br>Location<br>(7) |
|-------------------|-----------------|------------------------------------|--------------------------------------|--------------------------------|--------------------|-----------------------------|
| (3)<br>Ht.No.9853 | EACT-1          | .066 X .505                        | 134                                  | 136                            | 17                 | BM                          |
|                   | EACT-2          | .066 X .502                        | 132                                  | 135                            | 18                 | BM                          |
|                   | EACT-3          | .066 X .502                        | 134                                  | 137                            | 20                 | BM                          |
|                   | EACT-4          | .066 X .506                        | 134                                  | 135                            | 16                 | BM                          |
| (4)<br>Ht.No.9853 | EADT-1          | .067 X .503                        | 134                                  | 136                            | 21                 | BM                          |
|                   | EADT-2          | .065 X .505                        | 134                                  | 137                            | 21                 | HAZ                         |
|                   | EADT-3          | .065 X .505                        | 134                                  | 138                            | 21                 | HAZ                         |
|                   | EADT-4          | .064 X .506                        | 135                                  | 138                            | 18                 | HAZ                         |
| (5)<br>Ht.No.D575 | EJCT-1          | .060 X .484                        | 163                                  | 168                            | 2.5                | HAZ                         |
|                   | EJCT-2          | .061 X .482                        | 160                                  | 162                            | 3                  | HAZ                         |
|                   | EJCT-3          | .062 X .483                        | 160                                  | 163                            | 2                  | HAZ                         |
|                   | EJCT-4          | .062 X .504                        | 161                                  | 165                            | 3                  | HAZ                         |
| (6)<br>Ht.No.D575 | EJDT-1          | .074 X .484                        | 134                                  | 134                            | 3.5                | WD                          |
|                   | EJDT-2          | .072 X .503                        | 130                                  | 130                            | 3                  | WD                          |
|                   | EJDT-3          | .075 X .483                        | 124                                  | 124                            | 4                  | WD                          |
|                   | EJDT-4          | .073 X .484                        | 143                                  | 144                            | 3.5                | WD                          |

- (1) Base metal transverse to rolling direction (4) Same as (3), weld reinforcement removed  
Weld parallel to rolling direction and before testing
- (2) Transverse to tensile stress. (5) Cold Rolled 25%, Aged to 230 KSI U.T.S.,  
Original dimensions at area of fracture welded, tested
- (3) Solution annealed, welded, tested. (6) Same as (5), reinforcement removed before  
testing
- (7) BM=base metal; HAZ=heat affected zone;  
WD=weld deposit

### Cold Rolled and Aged, as Welded

At a radius of 3.9 times the base metal thickness, bending parallel to the weld axis through an angle of 135 degrees results in cracking of the base metal. At a radius of 2.9 times the thickness of the base metal cracking occurs in the weld metal.

The 135 degree bend test is described in Progress Report #9, March, 1961.

### Macrostructures and Hardness Gradients.

Typical macrostructures and hardness traverses of weld bead cross sections for the solution annealed condition and the cold rolled and aged condition are shown in Figures 18 and 19 respectively. The hardness gradient of the weld metal and heat affected zone are essentially the same for both conditions. That is, there is insufficient difference to account for the difference in the bend radius between weldments of solution annealed and cold rolled and aged sheet. Typical weld dimensions, applicable to both base metal conditions, are as follows:

Weld width top - 0.200" to 0.208"

Weld width bottom - 0.125" to 0.133"

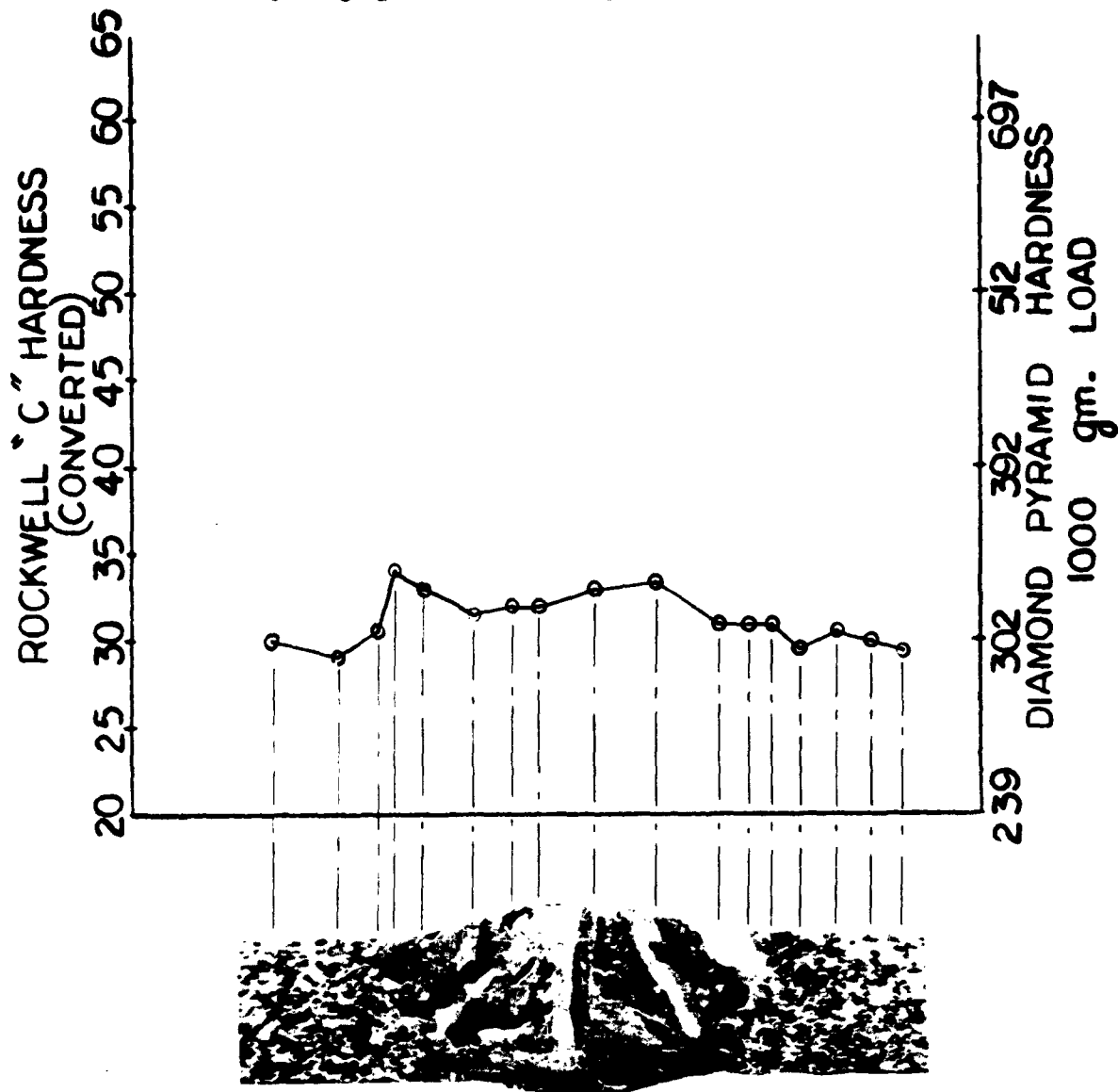
Weld thickness - 0.085" to 0.091"

### Microstructure of Weldments

Typical microstructures of the weldments are shown in Figures 20 and 21. The microstructure of the as-welded solution annealed sheet is typical of fusion welded beta titanium. The deposited weld metal is

# MICRO HARDNESS TRAVERSE

WELD CROSS SECTION  
KENTRON MICRO HARDNESS TESTER  
DIAMOND PYRAMID PENETRATOR



SPEC. NO. EA0-2 WELD TYPE ARC (TIG) MAG. 12X  
ETCHANT 2% HF + 10% HNO<sub>3</sub> + H<sub>2</sub>O

MATERIAL Ti 13V-11Cr-3Al GAGE 0.060

CONDITION Solution Annealed

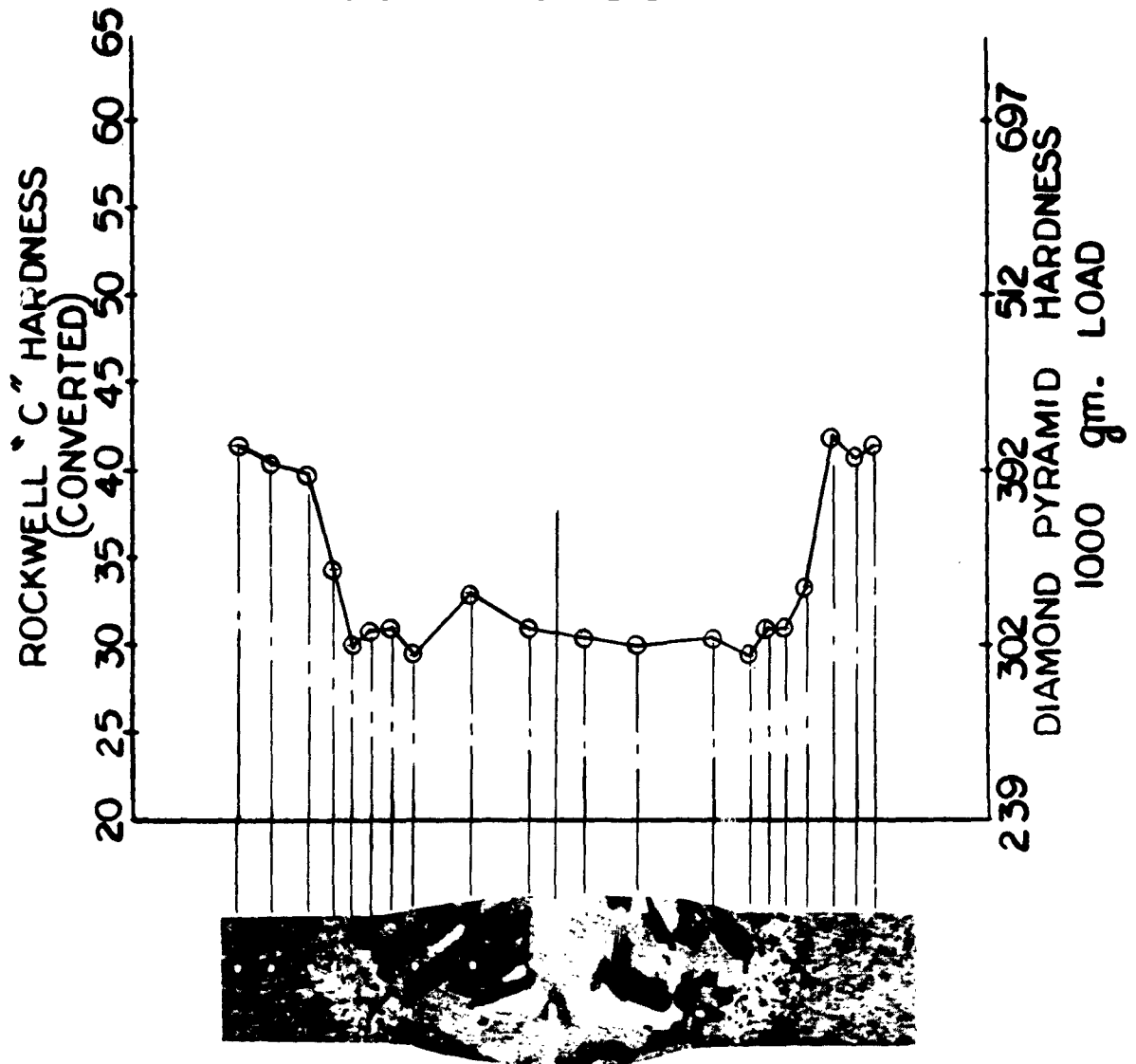
Heat No. 9858, Sheet No. 13

WELD SIZE Top - 0.200", Bottom - 0.125"

FIG. 18

# MICRO HARDNESS TRAVERSE

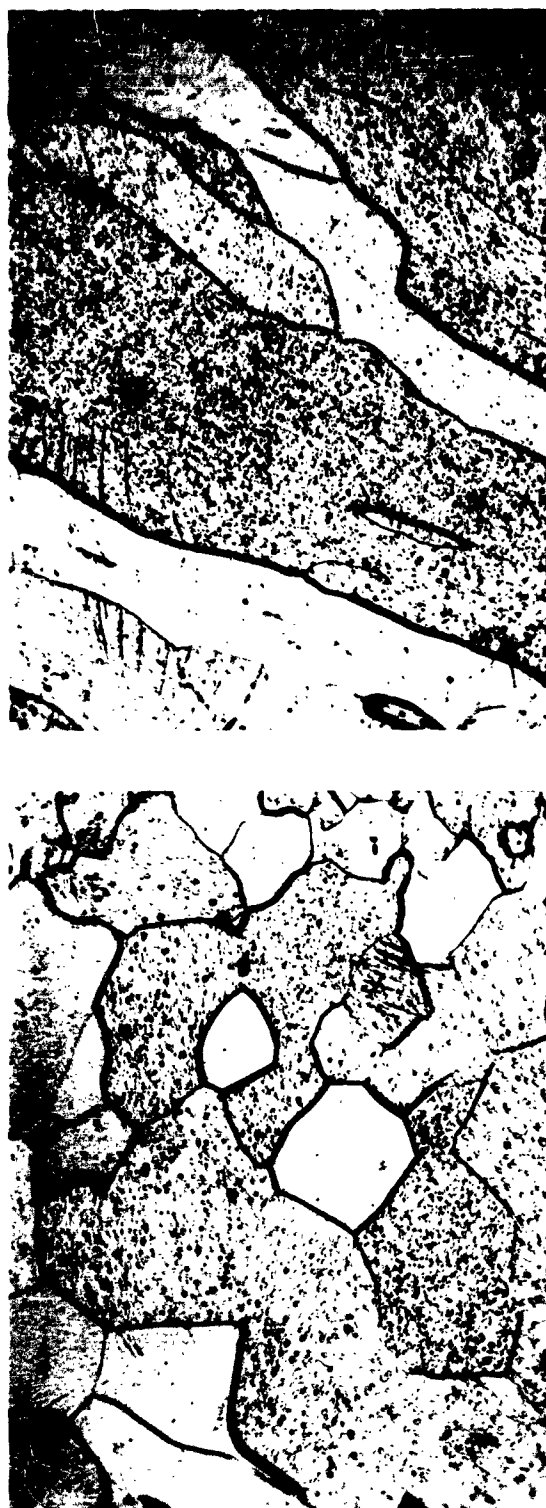
WELD CROSS SECTION  
KENTRON MICRO HARDNESS TESTER  
DIAMOND PYRAMID PENETRATOR



SPEC. NO. EJO-2 WELD TYPE TIG MAG. 12X  
ETCHANT 2% HF + 10% HNO<sub>3</sub> + H<sub>2</sub>O

MATERIAL Ti 13V-11Cr-3Al GAGE 0.060  
CONDITION As welded (cold rolled and aged sheet welded with beta titanium filler wire ). HT D575, Sht. #1  
WELD SIZE Top 0.208 in., Bottom 0.133

FIG. 19



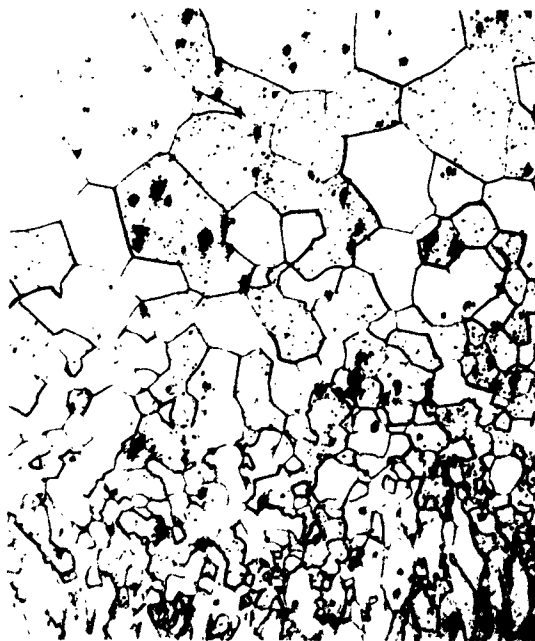
Base Metal

HAZ

Weld Metal

Ti 13V, 11Cr, 3Al, TIG Weldment. 060" Sheet Sol. Ann. .030" dia. Filler Wire.  
As Welded. Etch-2% HF + 10% HNO<sub>3</sub>. 100X

FIG. 20



Base Metal



HAZ

Ti 13V, 11Cr, 3Al. TIG Weldment. 060" Sheet Cold Rolled 25%,  
Aged to 230 ksi U.T.S. .030" dia. filler wire. As Welded  
Etch-2% HF + 10% HNO<sub>3</sub>. 100X

Weld Metal

FIG. 21

composed of large columnar grains containing twin and/or strain indications. The relatively narrow heat affected zone shows large equiaxed grains. The cold rolled and aged as-welded structure (Fig. 21) is very similar to Figure 20. The dark areas in the weld metal are believed to be the result of the metallographic polishing procedure.

### Conclusions

The Ti 13V-11Cr-3Al sheet is readily weldable. The tensile properties of as welded solution annealed sheet are essentially the same as the base metal. The bend ductility of these weldments is very good. The tensile properties of weldments made from cold rolled and aged sheet are essentially the same as those for the solution annealed condition. The bend ductility of these weldments is slightly inferior to that of weldments made in solution annealed sheet. Complete penetration with controlled weld reinforcement was readily obtained. Slight variations from the welding schedule did not lead to significant changes in the characteristics of the weldments.

### Data on AM 359 Steel

AM 359 alloy steel strip was heat treated and tensile tested. The ratio of ultimate tensile strength to density varied from 0.80 to 0.82 million inch. This ratio is too low for further consideration of the alloy in the current program, subject to the producer developing process techniques for increasing the strength level.

AM 359 is a precipitation hardening semiaustenitic steel produced by Allegheny Ludlum Steel Corporation. In the form of bar stock it is heat treatable to approximately 250,000 psi ultimate tensile strength. In the form of sheet and strip the tensile strength potential appeared to be about 280,000 psi. At this tensile strength level, the alloy would be suitable for use in cold forming rocket motor end closures that could be heat treated to a tensile strength-density ratio of approximately  $0.98 \times 10^6$  inch. The chemical composition of the alloy are listed in Table 19. The annealed tensile properties of .060" strip are listed in Table 20. It will be noted that in the annealed condition the ratio of yield strength to tensile strength is very low and that the elongation is very high. This indicates that the alloy can readily be cold formed. Figure 23, is a photomicrograph showing the annealed austenitic structure.

Samples of annealed .060 strip were heat treated in accordance with the producers recommendations and tensile tested. (The tensile test specimen and the testing procedures employed are described in progress reports #6, and #9 respectively). The heat treatment practice and test results are listed in Table 20. Typical stress-strain diagrams are shown in Figure 22. A photomicrograph of the heat treated structure is shown in Figure 23. The voids are areas where a precipitate, probably carbide was removed during polishing of the

# AM 359, ALLOY STEEL - CHEMICAL COMPOSITION

| Element    | Percent by Weight    |                         |
|------------|----------------------|-------------------------|
|            | Specification Limits | Analysis of Mtl. Tested |
| Carbon     | 0.17 to 0.21         | 0.20 to 0.21            |
| Manganese  | 0.50 to 1.10         | 0.66                    |
| Phosphorus | 0.040 Max.           | 0.021                   |
| Sulphur    | 0.030 Max.           | 0.017                   |
| Silicon    | 0.50 Max.            | 0.39                    |
| Chromium   | 13.5 to 14.5         | 14.34                   |
| Nickel     | 6.5 to 75            | 7.13                    |
| Molybdenum | 2.5 to 3.0           | 2.52                    |
| Aluminum   | 0.80 to 1.35         | 1.00                    |

TABLE 19

# HEAT TREATMENT AND MECHANICAL PROPERTIES OF AM 359 STEEL STRIP .060 THICK

| Heat Treatment                                                                                                                                                                     | Specimen Number | (1) | Yield Strength<br>0.2%<br>KSI | Ult. Tensile<br>Strength<br>KSI | Elong.<br>% 2" |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----|-------------------------------|---------------------------------|----------------|
| Annealed 1860° F<br>Air Cooled                                                                                                                                                     | BAAL - 1        | L   | 45                            | 142                             | 56             |
|                                                                                                                                                                                    | BAAL - 2        | L   | 45                            | 134                             | 60             |
|                                                                                                                                                                                    | BAAL - 3        | L   | 45.5                          | 122                             | 55             |
|                                                                                                                                                                                    | BAAL - 4        | L   | 46                            | 130                             | 52             |
|                                                                                                                                                                                    | BAAAT - 1       | T   | 49                            | 139                             | 38             |
|                                                                                                                                                                                    | BAAAT - 2       | T   | 49                            | 142                             | 47             |
|                                                                                                                                                                                    | BAAAT - 3       | T   | 48.5                          | 132                             | 28             |
|                                                                                                                                                                                    | BAAAT - 4       | T   | 50                            | 148                             | 47             |
| Annealed 1860° F,<br>Air Cooled 1750° F,<br>-10 Min. Air Cool,<br>-100° F-6Hr.<br>Air Warm, 1750° F,<br>-10 Min. Air Cool,-<br>100° F-6Hr. Air Warm,<br>935° F-1½Hrs., Air<br>Cool | BEAL - 1        | L   | 202                           | 230                             | 8.5            |
|                                                                                                                                                                                    | BEAL - 2        | L   | 198                           | 228                             | 8              |
|                                                                                                                                                                                    | BEAL - 3        | L   | 195                           | 226                             | 11.5           |
|                                                                                                                                                                                    | BEAL - 4        | L   | 197                           | 227                             | 7.5            |
|                                                                                                                                                                                    | BEAT - 1        | T   | 204                           | 231                             | 7.5            |
|                                                                                                                                                                                    | BEAT - 2        | T   | 201                           | 230                             | 7              |
|                                                                                                                                                                                    | BEAT - 3        | T   | 201                           | 230                             | 6              |
|                                                                                                                                                                                    | BEAT - 4        | T   | 196                           | 225                             | 9              |

(1) L = Longitudinal Tensile  
T = Transverse Tensile

TABLE 20

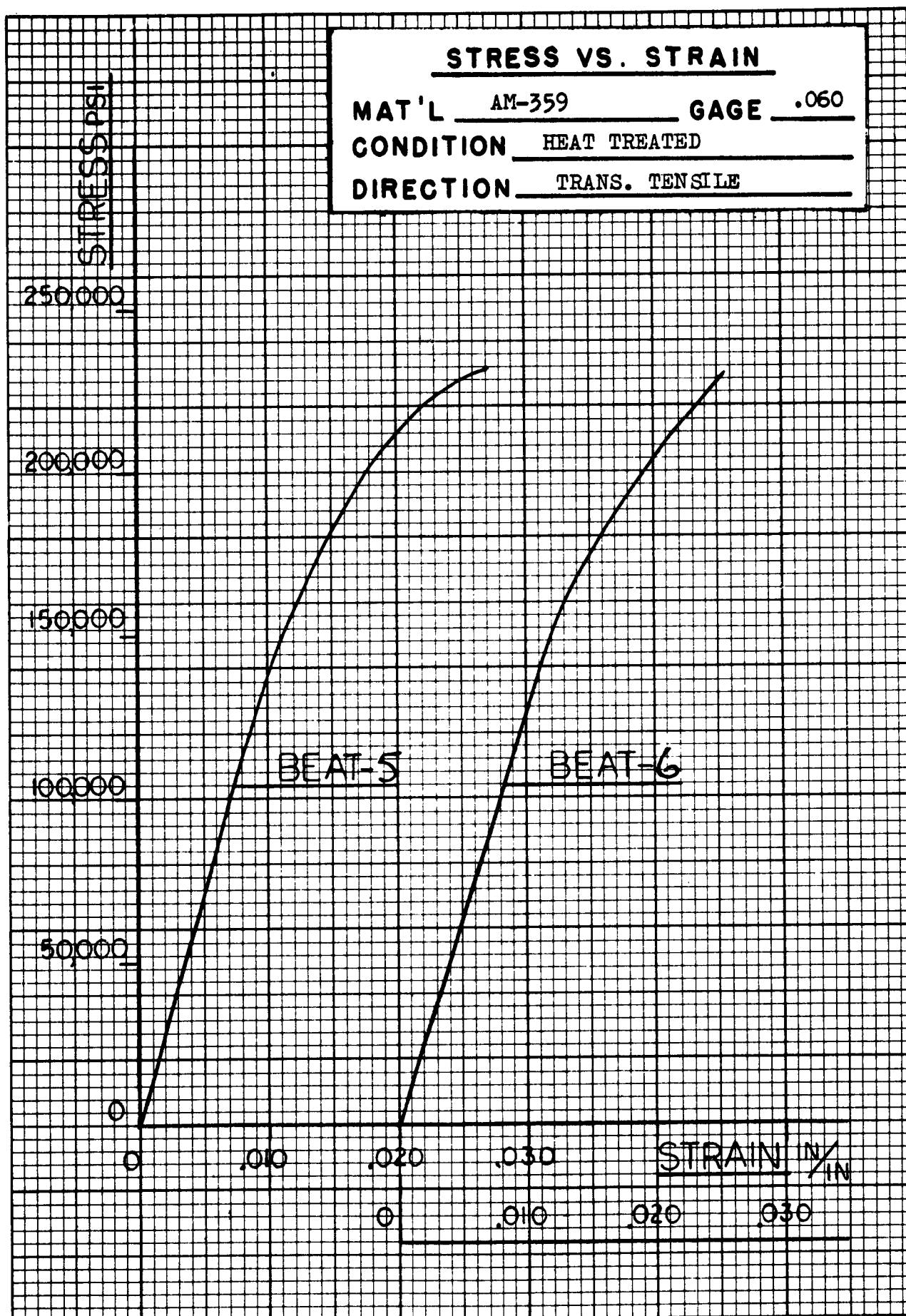
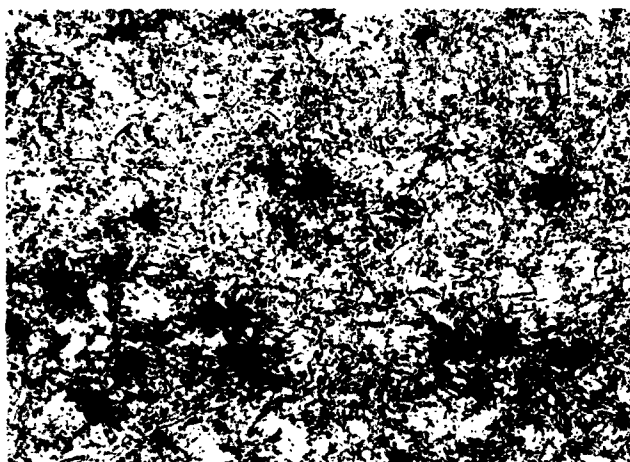


FIG. 22



Annealed 1860°F A.C.



Anneal 1860°F, A.C. 1750°F, A.C.  
-100°F, A.W. 1750°F, A.C. -100°F, A.W.  
Temper 935°F, A.C.

Photomicrographs  
AM 359 Steel Strip .060" Thick 250X  
Ferric Chloride Etch

FIG. 23

specimen. The retained austenite (light areas) is very high, indicating there is a possibility of adjusting the heat treatment to obtain higher strength levels.

#### Conclusions.

It is believed that heat treatment procedures can be developed to obtain higher tensile strengths in AM 359 steel, to approach the ultimate strength to density ratio of  $1 \times 10^6$  inch desired for this program.

#### UNIAXIAL WELD JOINT EVALUATION

##### Data on AM 355 - PH 15-7 Mo Uniaxial Head to Shell and Shell to Shell Joints

Hydrostatic testing of resistance welded wrapped chambers on previous programs, using AM 355 material for shells and PH 15-7 Mo for closure, indicated the need for a closer examination of the weld joint designs. Failure in these tests occurred in the head to shell welded joints. Analysis of these failures revealed that the reinforcing doublers did not carry the membrane loads from the closure to the shell due to the inadequacy of the spot weld pattern in the doublers. A series of 9 uniaxial welded joint specimens were designed and tested to obtain data to develop a more efficient joint design, and verify the analysis reported in Appendix F, report number 6. The results of these tests are reported herein.

The design variables for these joints were in two major areas:

- 1) The relative position and size of the spot resistance welds.

- 2) The relative size and number of seam welds immediately adjacent to the fusion weld.

Seam welds adjacent to the fusion welds were required to: (1) Seal interface areas and prevent contamination during fusion welding, (2) Increase annealed area to provide additional strains to offset discontinuity strains inherent in the particular design concept tested.

The material selected for the cylinder case simulation specimen was AM-355 in condition SCCRT. This alloy is a stainless steel of the transformation - age hardenable type. Condition SCCRT is obtained by solution annealing, exposure at -100°F, cold rolling and tempering. It has a guaranteed ultimate tensile strength of 290,000 psi for thicknesses up to 0.080 inches.

The heat treatable steel for the end closure simulation was PH 15-7 Mo, condition RH 1050. This alloy is a transformation - precipitation hardenable stainless steel. Condition RH 1050 is obtained by solution annealing, exposure at -100°F and aging at 1050°F. This heat treatment gives an ultimate tensile strength of 220,000 psi.

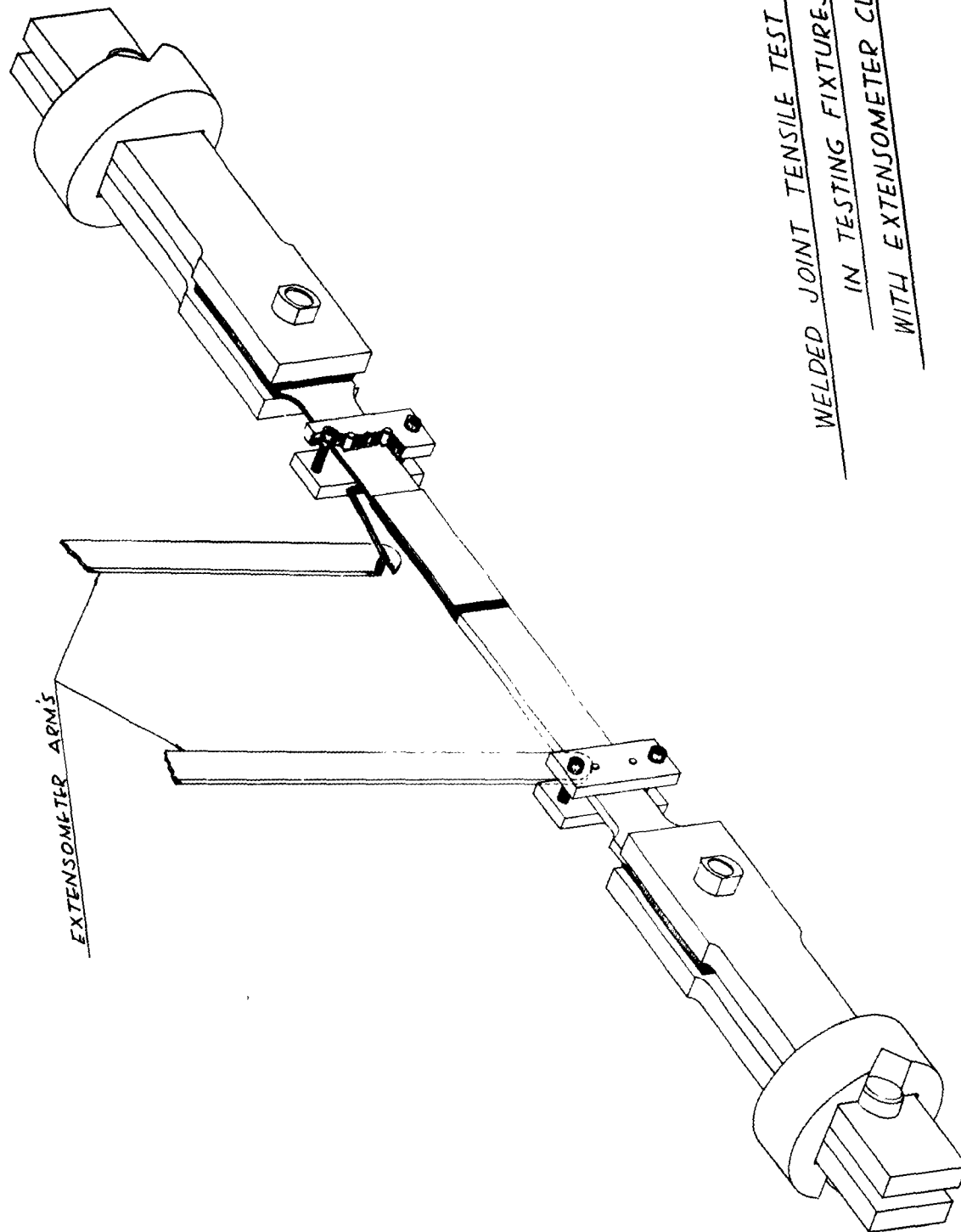
Certifications, tensile tests and chemical analysis were obtained for all the materials, including the welding wire, used in making the specimens. Spot resistance, seam resistance and fusion weld schedules were established prior to assembly operations for maximum weld strength values. This data was included in report Number 6.

The specimens were tested on a 200,000 lb. Baldwin Southwark testing machine. Special grip and adapters were employed in head mountings and special extensometer dampers were used to permit measurement of strains over an 8" gage length. Fig. 24 is a schematic sketch showing the test arrangement.

From the test data and examination of the joints after failure several conclusions on the overall design may be made. They are:

- 1) The doubler spot welds must be designed to take higher loads, by increasing the number of spot welds and/or increasing the doubler length. In every case the doubler spot welds sheared before joint failure. This confirms the conclusions reached from analysis of the results of hydrostatic testing of large chambers.
- 2) The double row of seam welds through the entire pile-up produced the highest overall strains because of the greater overall ductility of the seam welds.
- 3) Joint designs shown on drawings E2434-0009 and E2434-0010 appeared to be the most desirable.

Table 21 shows a summary of actual versus calculated joint strengths and the failure sequence observed for each joint. Table 22 is a correlation of actual strains measured during the test with the number and pileup of spot and seam welds in each joint design tested.



WELDED JOINT TENSILE TEST SPECIMENS  
IN TESTING FIXTURES  
WITH EXTENSOMETER CLAMPS

FIG. 24

71

AM 355, PH 15-7 MO UNIAXIAL WELD JOINT DESIGN  
COMPARISON OF JOINT EFFICIENCIES, FRACTURES  
AND FAILURE LOCATION

| Specimen<br>No. | Unit<br>Failure<br>Load* | Joint<br>Efficiency** | Maximum<br>Strain<br>in/in | Location of<br>Initial Fracture                                                                                                                       | Location of<br>Joint Failure                                               |
|-----------------|--------------------------|-----------------------|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| B480-SK-        |                          |                       |                            |                                                                                                                                                       |                                                                            |
| -0007           | 30,500                   | 92                    | .0256                      | Sheared Spot Welds                                                                                                                                    | Outer Seam Weld HAZ                                                        |
| -0008           | 28,900                   | 87                    | .0125                      | Sheared Spot Welds<br>doubler to PH 15-7<br>Mo Plate                                                                                                  | Fusion Weld                                                                |
| -0009           | 35,600                   | 107                   | .0132                      | Sheared Spot Welds<br>doubler to PH 15-7<br>Mo Plate                                                                                                  | Fusion Weld HAZ<br>in PH 15-7 Mo Plate                                     |
| -0010           | 35,900                   | 108                   | .0212                      | Sheared Spot Welds<br>doubler to PH 15-7<br>Mo Plate                                                                                                  | Fusion Weld HAZ in<br>PH 15-7 Mo Plate                                     |
| -0011           | 23,650                   | 70                    | .0162                      | a) Sheared Spot<br>Welds in Shell<br>Plate Assembly<br><br>b) Sheared one<br>Plate of double<br>thickness shell<br>plate assembly<br>from fusion weld | a) Spot Weld in<br>doubler to shell<br>plate<br><br>b) Outer seam weld HAZ |
| -0012           | 25,200                   | 76                    | .0056                      | Sheared Spot<br>Weld in doubler<br>to shell plate<br>assembly                                                                                         | Seam Weld HAZ                                                              |

TABLE 21

| Specimen No. | Unit Failure Load* | Joint Efficiency** | Maximum strain in/in | Location of Initial Fracture                                       | Location of Joint Failure |
|--------------|--------------------|--------------------|----------------------|--------------------------------------------------------------------|---------------------------|
| B480-SK-     |                    |                    |                      |                                                                    |                           |
| -0013        | 33,700             | 102                | .0194                | Sheared Spot Weld in doubler to shell plate assembly               | Inner Seam Weld HAZ       |
| -0014        | 37,000             | 111                | .0188                | Tensile Failure Outer Spot Weld in doubler to shell plate assembly | At first fracture         |
| -0015        | 26,200             | 79                 | .0100                | Sheared Spot Welds doubler to shell plate assembly                 | Inner Seam Weld HAZ       |

\* pounds per linear inch of fusion weld

\*\* Joint Efficiency based on strength of two sheets with 1.20" field weld spacing. This represents the basic sheet as shown in the joint design stress analysis, Appendix F, Quarterly Report No. 6. Joint efficiencies greater than 100% indicates that the stress analysis is conservative.

NOTE: All specimens had an 8 inch gage length with extensometer mounted beyond the doublers.

TABLE 21

CORRELATION OF MAXIMUM STRAIN WITH NUMBER AND PILE-UP THICKNESS OF SPOT  
AND SEAM WELDS IN JOINT DESIGN

| Specimen<br>Number<br>B48-SK- | Doubler Spot Welds |                      | Seam Welds in Shell |                                        | Calculated<br>Load on Spot<br>Welds at<br>Failure, lbs. | Maximum<br>Strain<br>in/in |
|-------------------------------|--------------------|----------------------|---------------------|----------------------------------------|---------------------------------------------------------|----------------------------|
|                               | No. Weld           | Pile-up<br>Thickness | No. Welds           | Plate Assembly<br>Pile-up<br>Thickness |                                                         |                            |
| -0007                         | 2                  | 3t                   | 2                   | 3t                                     | 11,300                                                  | .0256                      |
| -0008                         | 2                  | 4t                   | 2                   | 4t                                     | 8,250                                                   | .0125                      |
| -0009                         | 2                  | 4t                   | 1                   | 4t                                     | 10,000                                                  | .0132                      |
|                               |                    |                      | 1                   | 2t                                     |                                                         |                            |
| -0010                         | 2                  | 4t                   | 2                   | 4t                                     | 10,500                                                  | .0212                      |
| -0011                         | 1                  | 3t                   | 2                   | 4t                                     | 14,050*                                                 | .0162                      |
| -0012                         | 1                  | 3t                   | 1                   | 4t                                     | 9,670                                                   | .0056                      |
| -0013                         | 1                  | 3t                   | 1                   | 4t                                     | 9,500                                                   | .0194                      |
|                               | 1                  | 4t                   | 1                   | 2t + 2t                                |                                                         |                            |
| -0014                         | 1                  | 3t                   | 2                   | 4t                                     | 10,300                                                  | .0188                      |
|                               | 1                  | 4t                   |                     |                                        |                                                         |                            |
| -0015                         | 1                  | 4t                   | 1                   | 4t                                     | 7,500                                                   | .0100                      |
|                               | 1                  | 3t                   | 1                   | 2t + 2t                                |                                                         |                            |

\*NOTE: Under doubtful assumption load =  $\div$  between sheets

Appendix B includes revised specimen drawings reflecting the addition of bearing plate reinforcements, and drawings of the special test fixtures used in tensile testing the specimens.

Appendix C reports in detail the sequence of failure and load versus strain diagrams for each specimen type.

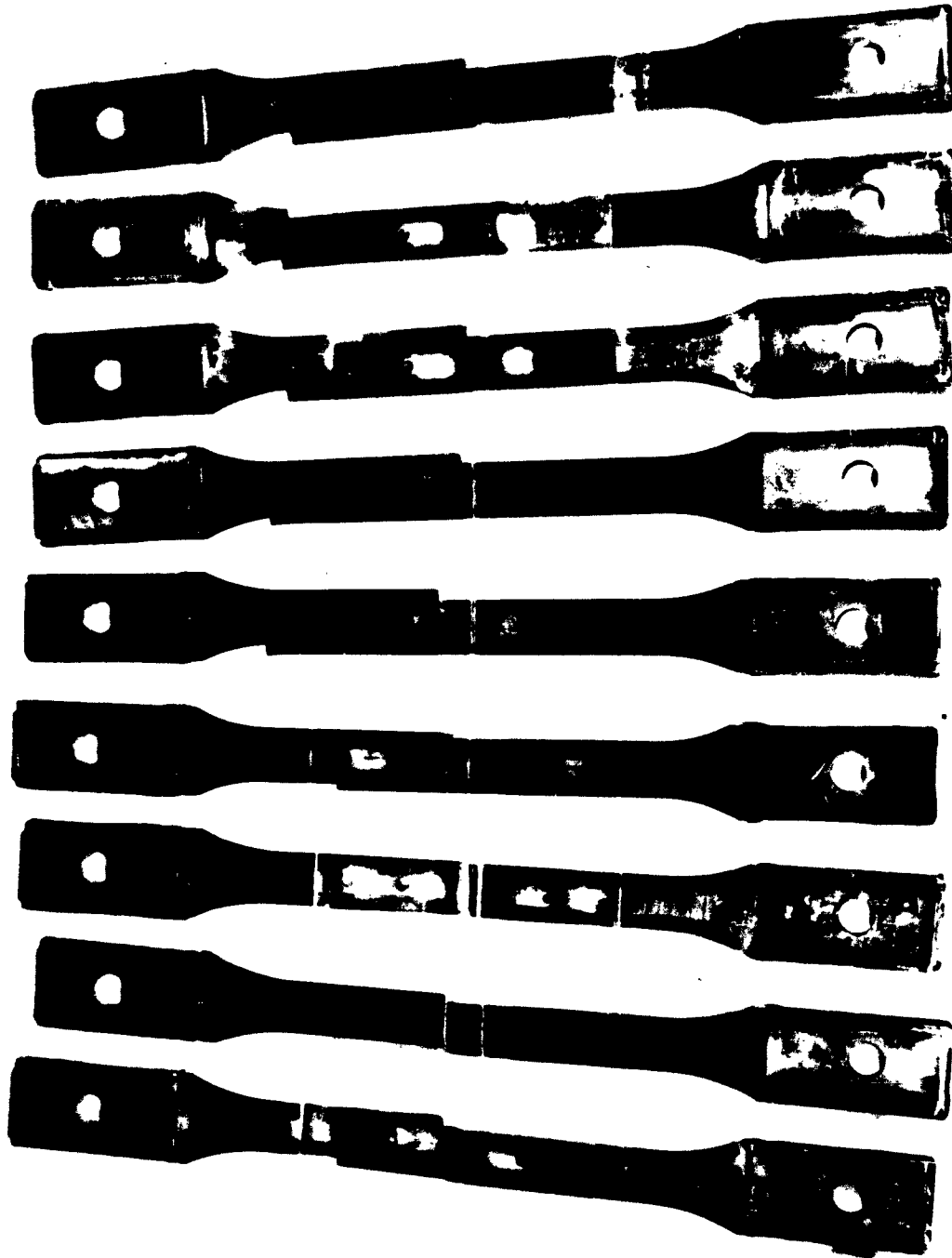
Figure 25 includes photographs of the AM 355-PH 15-7 Mo specimens after fracture. Location of the fracture with respect to weld patterns are illustrated.

#### Electron Beam Welded Joints - JLS 300 Steel

JLS 300, .040 strip, cold rolled and tempered to 340,000 psi yield strength, was electron beam welded. Metallographic examination revealed the presence of shear cracks caused by overdrafting of the strip during rolling. Subsequent work has been delayed because of this defective base metal condition. The results of the work completed to date are presented herein.

The mechanical properties of electron beam welded specimens and comparable T.I.G. specimens are shown in Table 23. Chemical composition of the .040 JLS 300 strip is shown in Table 24. Coupons were cold sheared from the strip, then ground to remove edge cracks, dye penetrant inspected and mechanically cleaned to remove a light oxide scale.

The joint designs are shown in Appendix B, progress report #9, March, 1961, drawings E2434-0116 and E2434-0117. The important characteristics of the joint are



AM-355 SCCRT, PH 15-7 MO WELDED TENSILE TEST SPECIMENS SHOWING  
FRACTURE LOCATIONS

FIGURE 25

AM-355 SCCRT, PH 15-7 MO WELDED  
TENSILE TEST SPECIMENS  
SHOWING FRACTURE LOCATIONS



SPECIMEN B480-SK-0013  
HEAD TO SHELL JOINT



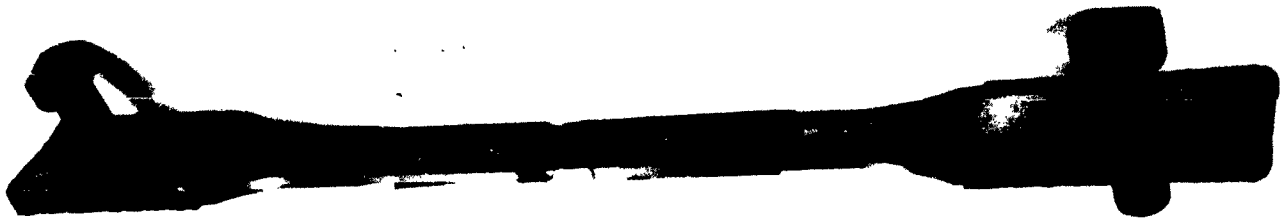
SPECIMEN B480-SK-0014  
HEAD TO SHELL JOINT



SPECIMEN B480-SK-0015  
HEAD TO SHELL JOINT

FIGURE 25

AM-355 SCRT, PH 15-7 MO WELDED  
TENSILE TEST SPECIMEN  
SHOWING FRACTURE LOCATIONS



SPECIMEN B480-SK-0010  
HEAD TO SHELL JOINT



SPECIMEN B480-SK-0011  
HEAD TO SHELL JOINT



SPECIMEN B480-SK-0012  
HEAD TO SHELL JOINT

FIGURE 25

AM-355 SCRT, PH 15-7 MO WELDED  
TENSILE TEST SPECIMENS  
SHOWING FRACTURE LOCATIONS



SPECIMEN B480-SK-0007  
SHELL TO SHELL JOINT



SPECIMEN B480-SK-0008  
HEAD TO SHELL JOINT



SPECIMEN B480-SK-0009  
HEAD TO SHELL JOINT

FIGURE 25

JLS 300 COLD ROLLED AND TEMPERED STRIP - COMPARISON OF MECHANICAL PROPERTIES  
OF TIG AND ELECTRON BEAM WELDMENTS

| Test<br>Number | Condition                                    | L<br>or<br>T | 0.2% Yield<br>Strength<br>KSI | Ultimate<br>Tensile<br>Strength<br>KSI | Elong.<br>%<br>2" | Elong. in 1/2"<br>Across Weld<br>Area |
|----------------|----------------------------------------------|--------------|-------------------------------|----------------------------------------|-------------------|---------------------------------------|
| Base Metal     | Strip-040" X 6 1/2",<br>CR, Tempered         | L<br>T       | 340 to 346<br>330 to 333      | 344 to 347<br>350 to 353               | 1.5 to 2.5        |                                       |
| TIG Welded     | Base Metal as<br>Welded                      | L            | 92 to 94                      | 208 to 210                             | 2.5 to 3.0        | 10 to 12%                             |
| TIG Welded     | Base Metal, Weld<br>Reinforcement<br>Removed | L            | 86 to 90                      | 200 to 206                             | 2.5 to 3.0        | 10 to 12%                             |
| FTC 4-1        | Base Metal as                                | L            | 137                           | 200                                    | 2                 | 12%                                   |
| FTC 4-2        | Electron Beam                                | L            | 117                           | 196                                    | 2                 | 12% (1)                               |
| FTC 4-3        | Welded                                       | L            | 117                           | 202                                    | 2                 | 12%                                   |

(1) Width of weld zone prior to test varied from 0.080" to 0.090". After test the width varied from 0.115" to 0.120". The localized elongation varied between 35 and 38 percent.

TABLE 23

CHEMICAL COMPOSITION JLS 300, 040" STRIP  
ELECTRON BEAM WELDED

| <u>Element</u> | <u>Percent by Weight</u> |
|----------------|--------------------------|
| Carbon         | 0.115                    |
| Manganese      | 1.27                     |
| Phosphorus     | 0.020                    |
| Sulphur        | 0.013                    |
| Silicon        | 0.69                     |
| Chromium       | 17.20                    |
| Nickel         | 5.12                     |
| Nitrogen       | 0.08                     |

TABLE 24

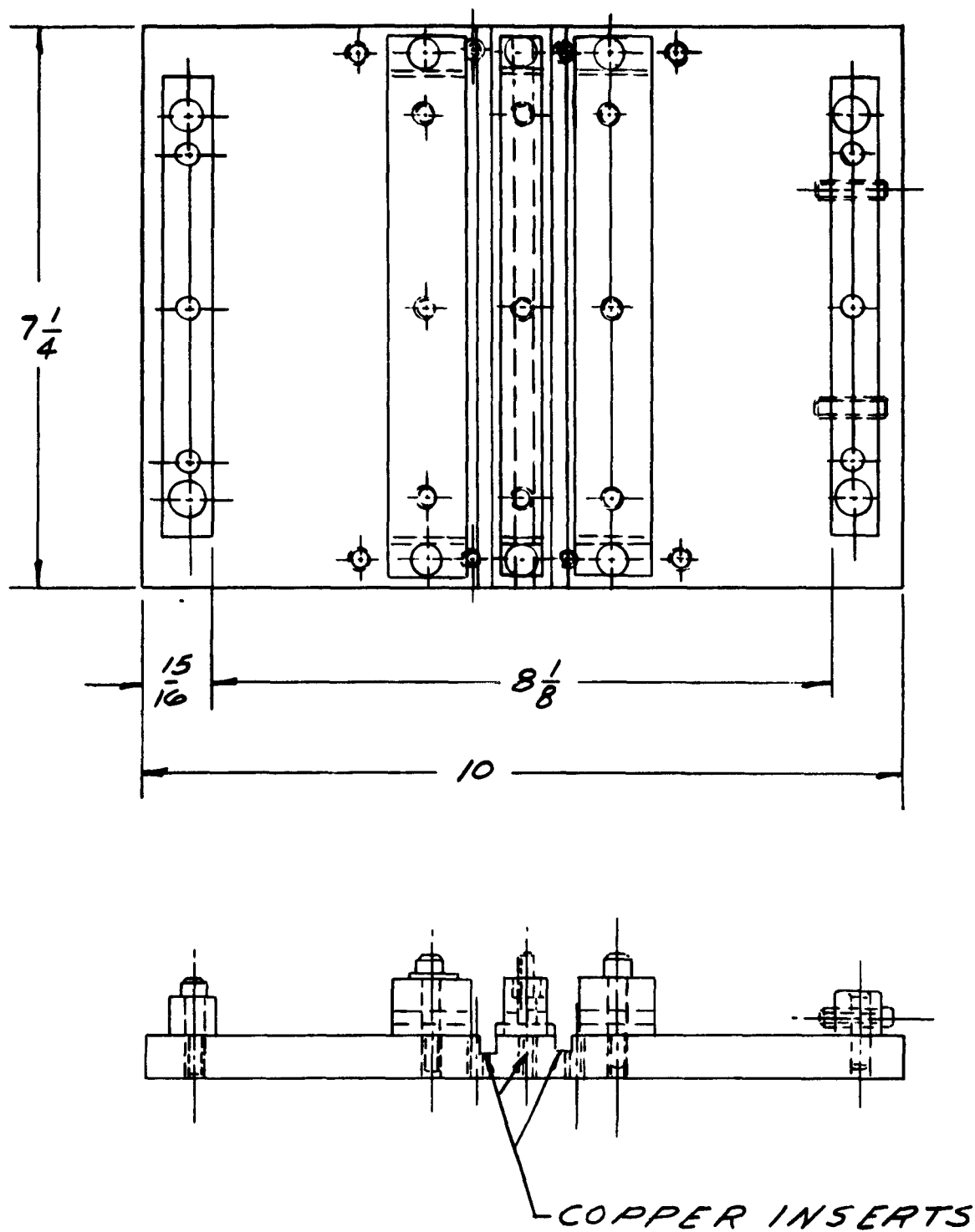
cleanliness, freedom from cracks and a fit up having less than 0.001" gap.

The micro-cracks in the base metal apparently caused excessive porosity and oxides in the weld metal. It was determined that a multi-pass weld considerably reduced these unsatisfactory conditions. Two, 2 pass and one 3 pass electron beam weldments have been made and are currently being evaluated.

The Bristol Machine & Tool Co. Inc., Forestville, Conn. welded all specimens, using Hamilton-Zeiss high voltage electron beam welding equipment. Eight to ten bead on sheet tests were made to establish the welding schedule. The specimens were then loaded in the fixture shown in Fig. 26 (see electron beam welding of beta titanium) and welded under a vacuum of  $10^{-4}$  mm. of Hg. The welding schedule employed is listed in Table 25.

All weldments exhibited excessive porosity and oxide inclusions when single pass welding was used. Two or three weld passes resulted in radiographic clear weldments.

One single pass weldment was mechanically tested; the weld metal being 90° to the direction of tensile loading. The validity of the test results is open to question because of the presence of micro cracks in the heat affected zone. It will be noted, however, that the tensile yield strength of the weldment is 30% to 35% higher than similar weldments made by the tungsten inert



WELDING FIXTURE  
 SCALE: HALF-SIZE  
 (BRISTOL MACHINE & TOOL Co. INC.)

FIGURE 26

ELECTRON BEAM WELDING SCHEDULE  
JLS 300, 040 STRIP COLD ROLLED AND  
TEMPERED TO 340 KSI YIELD STR.

|                                  |                                                            |
|----------------------------------|------------------------------------------------------------|
| Voltage                          | - 110 K. V.                                                |
| Current                          | - 1.8 Mil. amps.                                           |
| Deflection<br>(Parallel to Weld) | - .050 (relative #, approx =<br>to inches beam deflection) |
| Welding Speed                    | - 25 inches per minute                                     |
| Beam Diameter                    | - .006"                                                    |
| Focus of Beam                    | - Surface of Specimen                                      |
| Filament                         | - Tungsten Coil, 40 Mil. amp.<br>current                   |
| Vacuum                           | - $10^{-4}$ mm of Hg.                                      |
| Number of Passes                 | - 1                                                        |

TABLE 25

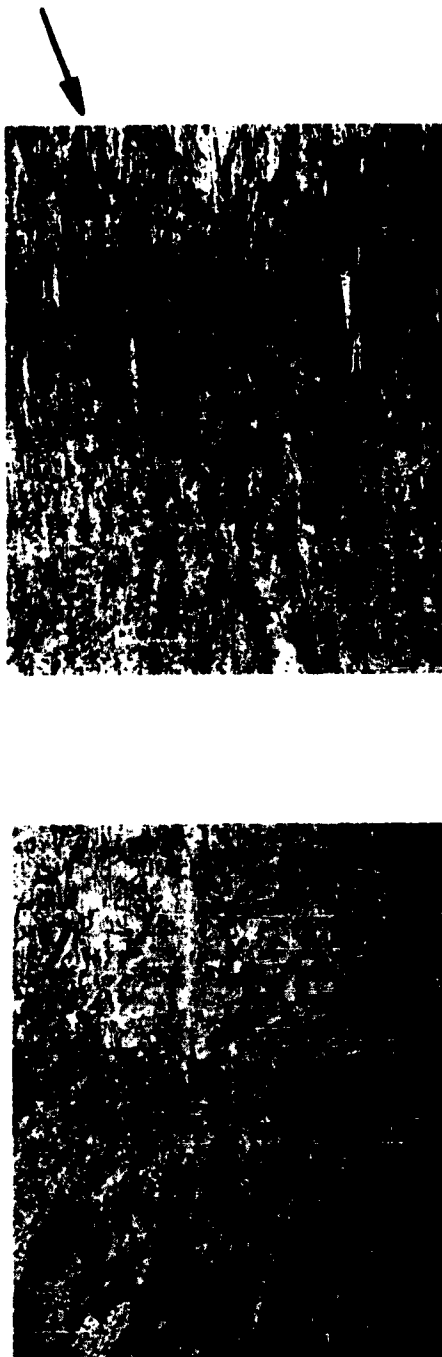
arc process employing AM 355 filler wire. This is attributed to the fine weld metal grain size and the very narrow heat affected zone.

Figure 27 is a photomicrograph across the weld zone. The weld metal is fine grained. The fusion line and HAZ consists of somewhat larger grains of austenite graduating into tempered martensite. There is also a small amount of ferrite (white areas) along the fusion line and throughout the HAZ. A microcrack extending from the HAZ into the base metal is shown in the right hand photomicrograph. Figure 28 is a photomicrograph of the type of shear cracking found in the base metal.

#### Electron Beam Welding of Ti-13V-11Cr-3Al Alloy Sheet

The effects of the angle of inclination of the weld deposit line to the applied tensile load, the prior metallurgical condition of the base metal, and of the type of postweld treatment were measured for Ti, 13V, 11Cr, 3Al, electron beam weldments. Preliminary analysis of the data indicates that 0.060" sheet cold rolled and aged to 225 ksi tensile strength gives weldments having the best combination of strength and ductility when the angle of the weld deposit to the tensile load is about 20° and postweld treatments are not employed. A more thorough analysis of the data is in process and the results will be included in a subsequent progress report.

The scope of the program is listed in Table 26.



|               |                |     |     |               |
|---------------|----------------|-----|-----|---------------|
| Weld<br>Metal | Fusion<br>Line | HAZ | HAZ | Base<br>Metal |
|---------------|----------------|-----|-----|---------------|

Material and Condition

JLS 300 Steel Strip, cold rolled, tempered to 240 Ksi yield strength, 040" thick. Electron beam welded at a vacuum of 10<sup>-4</sup> mm of Hg. Zeiss Equipment. 110 KV, 1.7 milliamperes. Note crack in base metal, extending into heat affected zone.

Etchant - Electrolytic - Oxalic Acid.      MAG. 100X

FIG.27



Material and Condition

JLS 300 Steel Strip 0.40" thick. Cold rolled and tempered to 340 Ksi yield strength. Cracks parallel to direction of rolling and surfaces of strip.

Etchant - Electrolytic, Oxalic Acid

Mag 100X

FIG. 28

ELECTRON BEAM WELDMENTS - JOINT DESIGN STUDY  
SCOPE OF PROGRAM  
Ti-13V-11Cr-3Al ALLOY SHEET

| Condition Prior to Welding                                                              | Postweld Heat Treatment                                       | Identification           |                         |                        |
|-----------------------------------------------------------------------------------------|---------------------------------------------------------------|--------------------------|-------------------------|------------------------|
|                                                                                         |                                                               | 20°Angle<br>.060"X6"X10" | 40°Angle<br>060"X8"X10" | 90°Angle<br>060X10X7   |
| Solution Annealed                                                                       | None                                                          | None                     | None                    | HT-D31<br>Sht 16 (C2)  |
| Cold Rolled 25%<br>Age Hardened 900°F<br>to 225/235 KSI<br>Ultimate Tensile<br>Strength | Age Harden 900°F<br>40 Hr.                                    | None                     | None                    | HT.D31<br>Sht 16 (C-1) |
|                                                                                         | None                                                          | HT-D575<br>(J-6)         | HT-D575<br>(J-5)        | HT.-D575<br>(J-7)      |
|                                                                                         | Age Harden 900°F<br>40 Hrs.Stress<br>Relief 1025°F<br>10 Min. | None                     | None                    | HT-D575<br>(J-8)       |
| Solution Anneal,<br>Age Harden 72Hr.<br>900°F (1)                                       | None                                                          | HT-D31<br>Sht 16 (C-6)   | HT.D31<br>Sht 16 (C-5)  | HT.D31<br>Sht 16 (C-3) |
|                                                                                         | Duplex Heat Treat                                             | None                     | None                    | HT.D31<br>Sht 16 (C-4) |

(1) Preparation of samples and welding delayed because of porosity found in weldments made from solution annealed and cold rolled and aged material.

TABLE 26

Three joint designs, three base material conditions, and two postweld treatments were used. The joint designs of 20°, 40° and 90° were selected on the basis of previous research experience which indicated that for the lower modulus material about 20° is the optimum angle and 90° the least desirable angle for optimum joint strength and ductility, where the deposited weld metal strength is lower than the base metal strength. A literature survey indicated that the tensile ductility, in the presence of discontinuities, of cold rolled and aged sheet may be somewhat better than that of solution annealed and aged sheet; hence both conditions were included. The postweld treatments were included to determine whether electron beam weldments reacted in the same manner as T.I.G. fusion weldments. That is, single aging yields a brittle structure and duplex aging yields a ductile structure, where the base metal has not been cold rolled.

Sheet material 0.060" thick by 36" wide sheet procured from the Titanium Metals Corporation was used. Sheets were procured in the cold rolled and aged condition and in the solution annealed condition. The solution annealed and aged samples were prepared by The Budd Company Research Laboratory. The samples for welding were cold sheared from the sheet and the edges dye penetrant inspected to determine the extent of shear cracks. None were found. The edges of the samples were ground to a 63 microinch finish and reinspected to assure freedom

from cracks. The perpendicularity of the edge to the upper and lower surfaces was within 15 minutes, and the edge camber was negligible. The samples were then cleaned at room temperature in a water solution containing 40% by volume of concentrated  $H_2SO_4$ . Prior to welding the edges were cleaned with acetone to remove dirt and grease that may have accumulated during transit and storage. The metallurgical condition, and the mechanical properties of the samples are listed in Table 27.

The joint designs are shown on drawings in Appendix B, Progress Report #9, March, 1961, drawings E2434-0116 and E2434-0117. The important characteristics of the joints are cleanliness, freedom from cracks, perpendicularity and straightness of the edge so that a 0.001" feeler gage could not be placed in the joint when two pieces are butted together under slight pressure. The length of the welded joint was limited by the amount of jig movement available in the electron beam vacuum chamber.

The Bristol Machine and Tool Co., Inc., Forestville, Conn., welded all specimens, using Hamilton-Zeiss high voltage electron beam welding equipment.

About 10 bead on sheet welds were made to establish the welding schedule for use in welding the samples for test. On determination of a welding schedule, the samples were loaded in the fixture shown in Figure 26

Ti, 13V, 11Cr, 3Al - MECHANICAL PROPERTIES OF SHEET PRIOR TO ELECTRON BEAM WELDING

| Identity and Conditions                                  |   | (1) | 0.2% Yield<br>Strength<br>(KSI) | Ultimate<br>Tensile<br>Strength<br>(KSI) | Elong.<br>%<br>2" | KCl<br>1000 psi in |
|----------------------------------------------------------|---|-----|---------------------------------|------------------------------------------|-------------------|--------------------|
| HT. D31, Solution Annealed<br>+ Age Harden 900°F - 72Hr. | L | L   | 188                             | 210                                      | 6.0               | 71                 |
|                                                          | L | L   | 184                             | 208                                      | 8.0               | 73                 |
|                                                          | L | L   | 183                             | 206                                      | 8.0               | 73                 |
|                                                          | T | T   | 200                             | 215                                      | 2.5               | 46                 |
|                                                          | T | T   | 188                             | 209                                      | 6.5               | 55                 |
| HT.D575, Cold rolled<br>25% Age Hardened 900°F           |   | L   | 208                             | 225                                      | 6.5               | (2)                |
|                                                          |   | T   | 220                             | 235                                      | 5.5               | (2)                |
| (1) Longitudinal - Transverse                            |   |     |                                 |                                          |                   |                    |
| (2) In Process                                           |   |     |                                 |                                          |                   |                    |

TABLE 27

and welded. The welding schedules employed for the test weldments are listed in Table 28.

#### Radiographic Examination of Weldments

The weldments were radiographed by the Magnaflux Corporation, Hartford, Conn. using a Balto, 300 KVP, 5ma machine a thin stainless steel penetrameter and the following technique: 120 KV, 5ma, 36" FFD, Kodak AA film, 6 minutes development time. Examination of the radiographs indicated that some of the weldments were considerably more porous than anticipated. To date, the source of the contamination has not been definitely established. However, it is believed that inadequate cleaning and/or interstitial gas content are the predominating factors. Fig. 29 lists the radiograph indications found in the weldments. As a result of this condition, and of cracking during preparation the number of specimens available for test was reduced by 33%.

#### Tensile Testing of the Weldments

Coupons for tensile test were machined from the weldments as shown in Appendix B, progress report #9, March, 1961. Where possible, the coupons were removed from radiographic clear areas. However, some of the specimens contained porosity as large as 0.20" diameter, which apparently had little or no effect on the resultant tensile properties. The coupons were machined to the form and dimensions shown in Figure 30, Dwg. E2434-0015 (Figure 2 shows a 40° angle weldment. All specimens

ELECTRON BEAM WELDING SCHEDULES  
Ti, 13V, 11Cr, 3Al, 060" SHEET (1)

| Specimen Type | Condition of Material Prior to Welding | Voltage KV | Current MA | Beam Deflection (2) |
|---------------|----------------------------------------|------------|------------|---------------------|
| C-1           | Solution Annealed                      | 120        | 2.5        | 075                 |
| C-2           | Solution Annealed + Age Harden         | 120        | 2.3        | 075                 |
| J-5           | CR 25% + Age Harden                    | 120        | 2.6        | 070                 |
| J-6           | CR 25% + Age Harden                    | 120        | 2.6        | 070                 |
| J-7           | CR 25% + Age Harden                    | 120        | 2.6        | 070                 |
| J-8           | CR 25% + Age Harden                    | 120        | 2.6        | 070                 |

(1) Welding speed - 25 inches per minute all samples.

Focal spot - .006" dia. at metal surface.

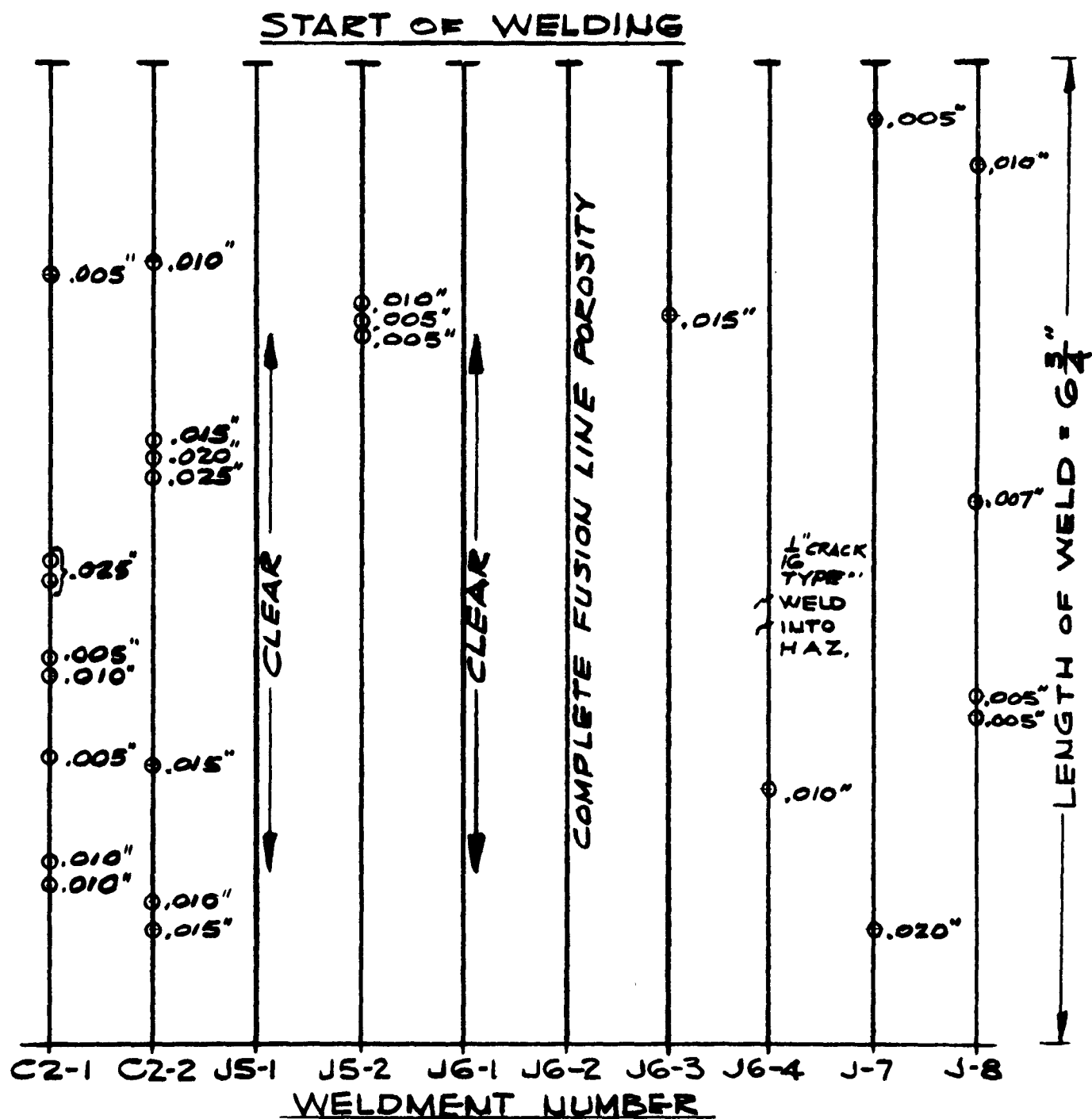
Joint gap less than .001"

Filament - Tungsten coil at 40 Mil. Amperes relative meter reading

Number shown is approx. length in inches.

Deflection was parallel to direction of welding.

TABLE 28



RADIOGRAPH INDICATIONS, ELECTRON  
BEAM WELDMENTS.

Ti, 13V, 11Cr, 3Al, SHEET.

FIG. 29



had the same form and dimensions except for the angle of the weld deposit). Where postweld heat treatment was required, the coupons were rough machined, heat treated and then ground to finished size. Cracks were observed in specimens J7-1 and J7-3 after heat treatment, and they were discarded. The cracking apparently originated during the rough machining operation (blanking die shown in progress report #9, March 1961). The grid noted in Figure 2 was applied to some of the specimens to allow time-sequence pictures of the deformation occurring during test. The grid is a series of 0.1" X 0.1" squares ink stamped over the gage area of the specimen. To provide sharp lines and good contrast, ink having the following formula was used:

31 grams of rosin and 2.3 ounces of Dupont Victoria Green Aniline dye in 100cc of methanol.

The tensile test procedures described in progress report #9, March, 1961, were used, except for the specimens containing the grid. These specimens were tested in a Tatnall Mod. UWR Universal Testing Machine employing hydraulically loaded V-grips. A 35MM Exacto V camera manually operated was used to obtain time sequence shots of the deformation patterns. The mechanical properties are listed in Table 29. The types of fractures obtained are shown in Figure 31.

Metallographic work, and analysis of the deformation patterns is in process, hence no conclusions will be made in this report.

MECHANICAL PROPERTIES ELECTRON BEAM WELDMENTS  
Ti, 13V, 11Cr, 3Al, ALLOY SHEET

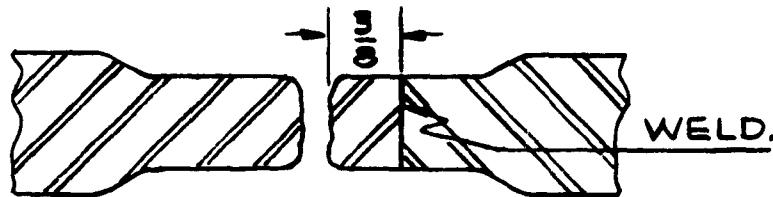
| Sample Number | Condition of Weldment                                   | Yield Strength to KSI                  | Ultimate Tensile Strength KSI | Elongation - % |      |     |       | Fracture      |
|---------------|---------------------------------------------------------|----------------------------------------|-------------------------------|----------------|------|-----|-------|---------------|
|               |                                                         |                                        |                               | 1/4"           | 1/2" | 1"  | 2"    |               |
| C1-1          | Solution Annealed, Weld, Age Harden 900°F, 40 Hr. (90°) | Missed                                 | 162                           | 1/2            | 1/2  | 1/2 | 1/2   | Brittle, Weld |
| C1-2          |                                                         | Excessive Porosity - not heat treated. |                               |                |      |     |       |               |
| C2-1          | Solution Annealed, Weld. (90°)                          | 146                                    | 146                           | 4              | 4    |     | 9     | Base Metal    |
| C2-2          |                                                         | (1)                                    | 139                           | -              | -    | 6   | -     | Base Metal    |
| C2-3          |                                                         | (1)                                    | 144                           | -              | -    | 9   | -     | Base Metal    |
| J5-1-2        | Cold Rolled 25%, Aged 900°F to 225 KSI                  | 141                                    | 147                           | 28             | 14   |     | 3 1/2 | Weld Metal    |
| J5-1-2        | Ultimate Tensile                                        | (1)                                    | 147                           | -              | -    | 5   | -     | Weld Metal    |
| J5-2-1        | Strength Welded (40°)                                   | 140.5                                  | 145                           | 28             | 12   |     | 4     | Weld Metal    |
| J5-2-2        |                                                         | (1)                                    | 145                           | -              | -    | 6   | -     | Weld Metal    |
| J6-1          | Cold Rolled 25% Aged 900°F to 225 KSI                   | 151                                    | 188                           | 8              | 8    |     | 4     | (2)           |
| J6-2          | Ultimate Tensile                                        | Excessive Porosity (1)                 | 187                           | -              | -    | 7   | -     | (2)           |
| J6-3          | Strength Welded (20°)                                   | To be Tested                           |                               |                |      |     |       |               |
| J7-1          | CR 25%, 900°F, Age to 225 KSI U. T. S.                  | Specimen Cracked in Preparation Missed | 185                           | 4              | 2    | -   | 1 1/2 | Weld Metal    |
| J7-2          | Weld, Age 900°F, 40 Hr., S.R. 1025° F 10 Min. (90°)     | Specimen Cracked in Preparation        |                               |                |      |     |       |               |
| J8-1          | CR 25% 900°F Age to 225 KSI UTS. Weld (90°)             | Not Tested (1)                         | 159                           | -              | -    | 3   | -     | Weld Metal    |
| J8-2          |                                                         | (1)                                    | 151                           | -              | -    | 3   | -     | Weld Metal    |
| J8-3          |                                                         |                                        |                               |                |      |     |       |               |

TABLE 29

SKETCHES OF TYPICAL TENSILE  
FRACTURES IN ELECTRON BEAM WELD-  
MENTS OF-T<sub>2</sub>, 13V, 11Cr, 3Al, SHEET.

SPECIMEN-C2-1.

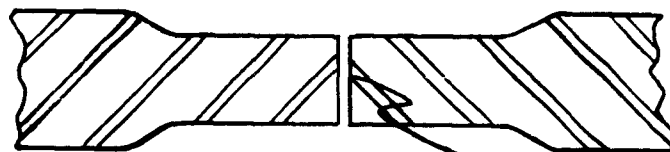
SOLUTION ANNEALED, WELD. BASE METAL FRACTURE.



DUCTILE FRACTURE, NECKING AND GOOD ELONGATION.

SPECIMEN-C1-1.

SOLUTION ANNEALED, WELD, AGE HARDEN.



BRITTLE FRACTURE WELD METAL.

SPECIMEN-J5-2-1.

COLD ROLLED 25%, AGE HARDEN, WELD



DUCTILE FAILURE IN  
WELD METAL.

FAILED BY SHEARING ALONG WELD. GOOD DUCTILITY  
AND SLIDING.

SPECIMEN-J6-1.

COLD ROLLED 25% AGE HARDEN, WELD.



BASE METAL WELD METAL FAILURE.  
CONSIDERABLE DEFORMATION ALONG ENTIRE  
GAGE LENGTH, BENDING AND NECKING OCCURED.

It is anticipated that the metallographic studies and interpretation of the mechanical test results will be completed in the next period. The investigation of the effects of joint design and treatment on the properties of solution annealed and aged titanium sheet electron beam weld will also be initiated in the next period.

## HELICAL WELDED CYLINDERS

In report number 11 we discussed generally, designs of cylindrical sections using strip materials in high strength conditions. A helical fusion butt welded cylinder having the weld line preferentially oriented to reduce the normal stress sustained across the weld line is being considered.

Geometric elements which control this design of cylinder are: Material coil width, helix angle, and cylinder diameter. Figure 32 shows the relationship of these elements. A weld line helix angle of approximately  $18^{\circ}$  to  $25^{\circ}$  appears to be optimum, based on previous tests of small cylinders. This would apply where the weld strength is in the area of 60% to 80% of the yield strength of the base metal. We expect to develop data on this using uniaxial tensile joint specimens and sub-scale cylinder tests.

Figure 33 shows a qualitative relationship between helix angle and the ratio of membrane hoop stress to yield strength of the base material. It can be seen that as the helix angle decreases there is a corresponding increase in this stress ratio. We are currently obtaining actual data from uniaxial weld joint specimens with welds oriented at  $90^{\circ}$  -  $40^{\circ}$  and  $20^{\circ}$  to the line of load application. A yield criteria for various materials in different heat treat conditions will be determined. From this data, actual values for each

|              |                                                                            |             |
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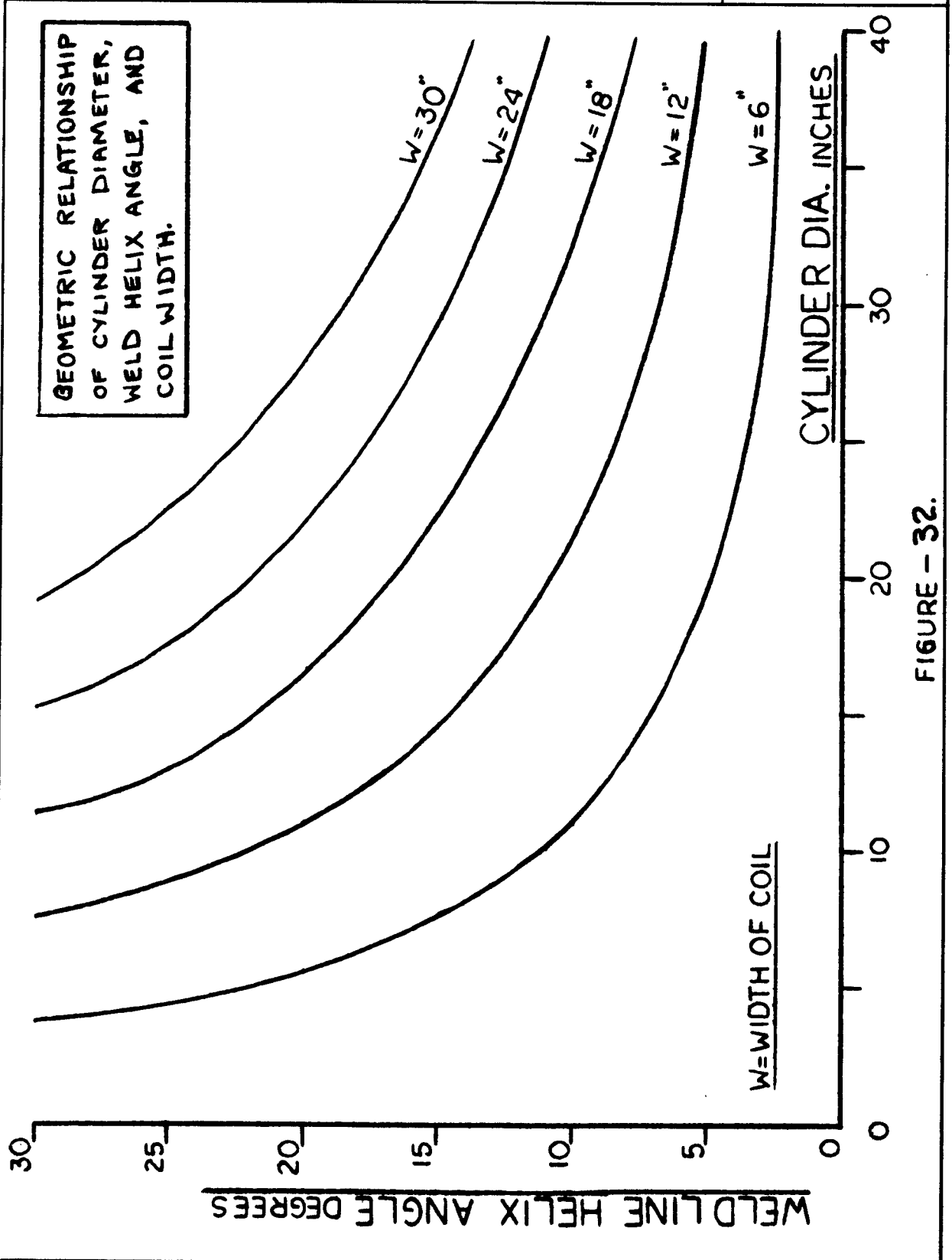


FIGURE - 32.

|              |                                                                            |             |
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## EFFECT OF HELIX ANGLE ON THE YIELD STRENGTH OF A CYLINDER

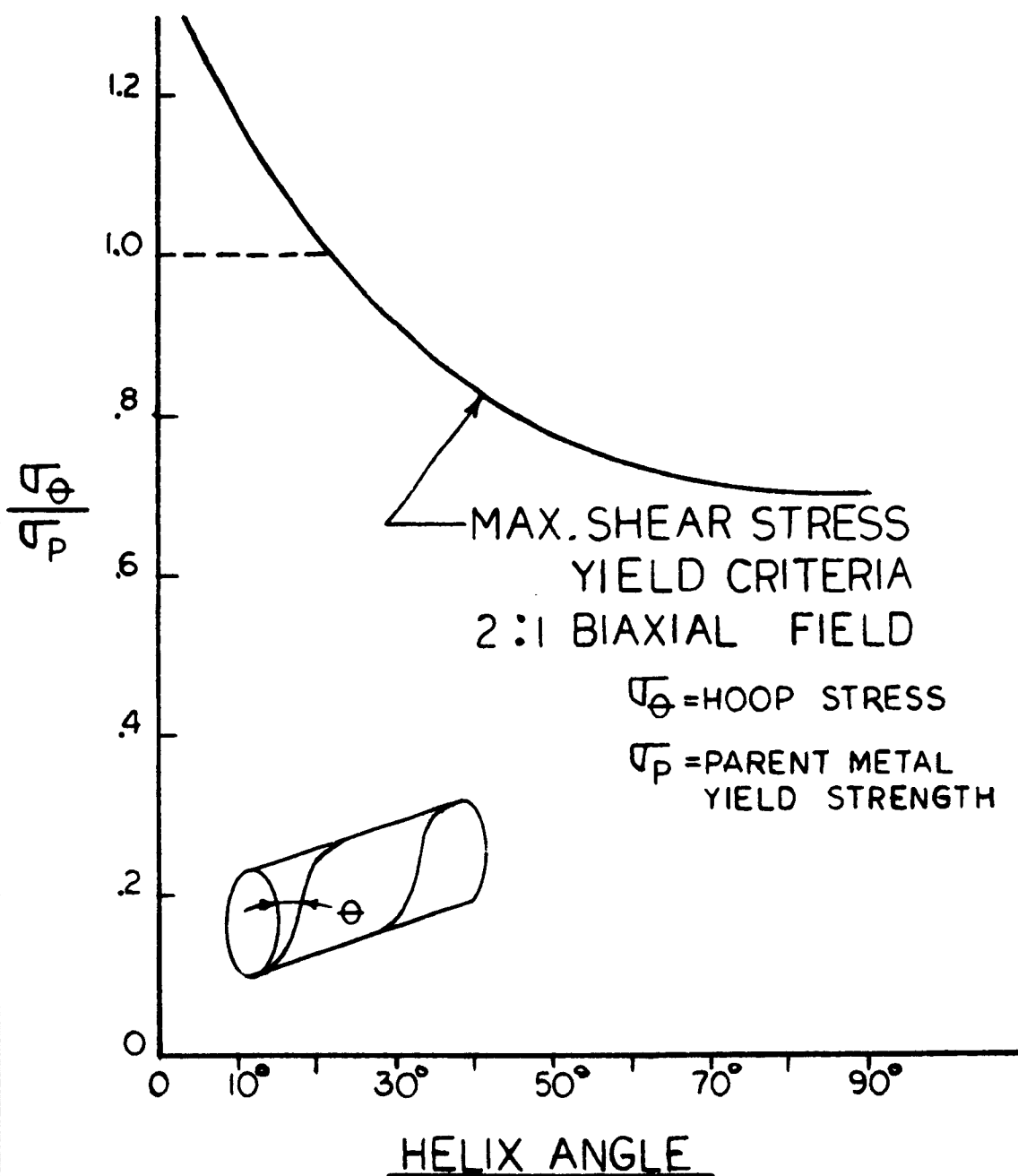


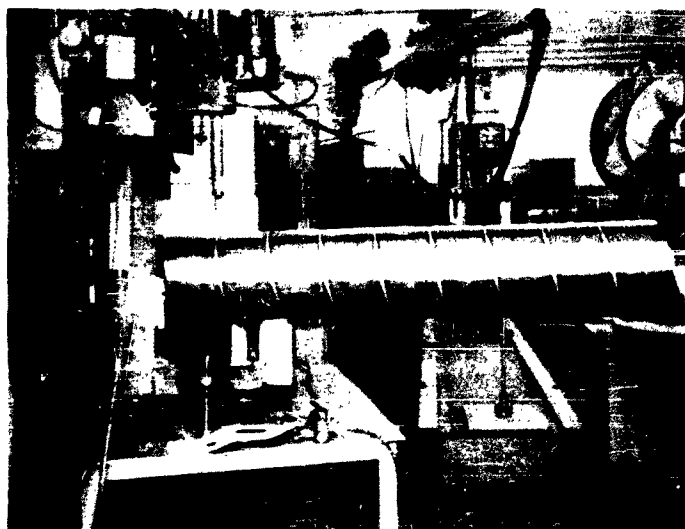
FIGURE-33

material considered can be plotted and optimum helix angles can be established. From tests of sub-scale 20° cylinders we expect to obtain actual data to confirm the validity of the design and the cumulative effect bending stresses, etc. on the performance of the cylinder.

A parallel program to the development of analytical data is being conducted on the method of welding helical butt welded cylinders. A fixture was rigged up using a stationary shoe, and roller drive to feed coil strip, under the welding head. This was done using 6" wide strip and a 10" diameter cylinder. The material welded was .020" thick Type 301 stainless steel. Figure 34 is a photograph showing the welding operation on a 36" long cylinder. A total of six cylinders have been welded using the rigged up fixture, which we feel amply demonstrates the feasibility of the method.

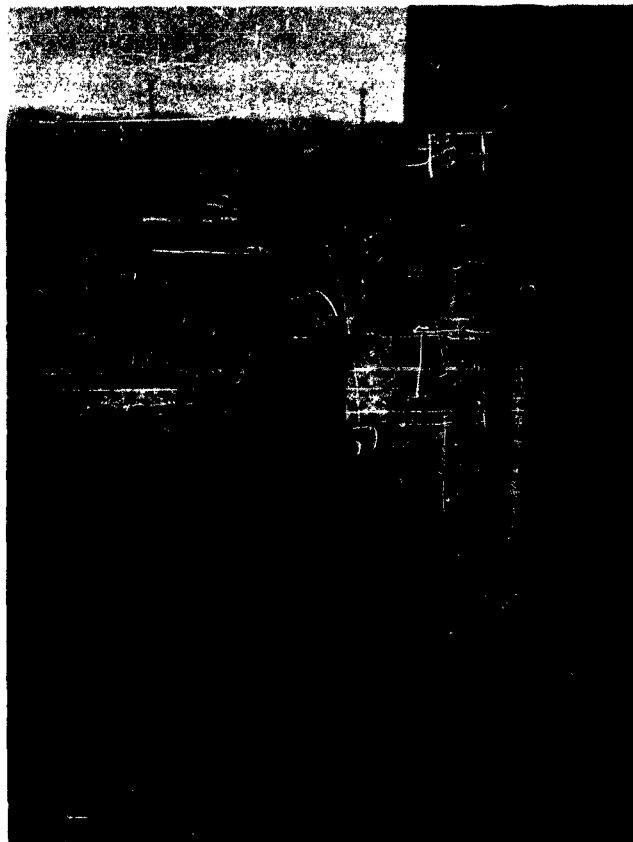
We are currently designing a fixture capable of welding 20" Dia. cylinders for the sub-scale program. This fixture will have sufficient power in the drive, and accuracy to enable us to weld cylinders in various alloys with reliable repeatability.

In addition to the welding development of 10" cylinders noted above, we are working on an explosive sizing technique. Figure 35 shows a photograph and schematic design of an experimental setup used to size a 10" cylinder. The .020" thick cylinder was sized to between 1% and 2% of its diameter explosively in a steel



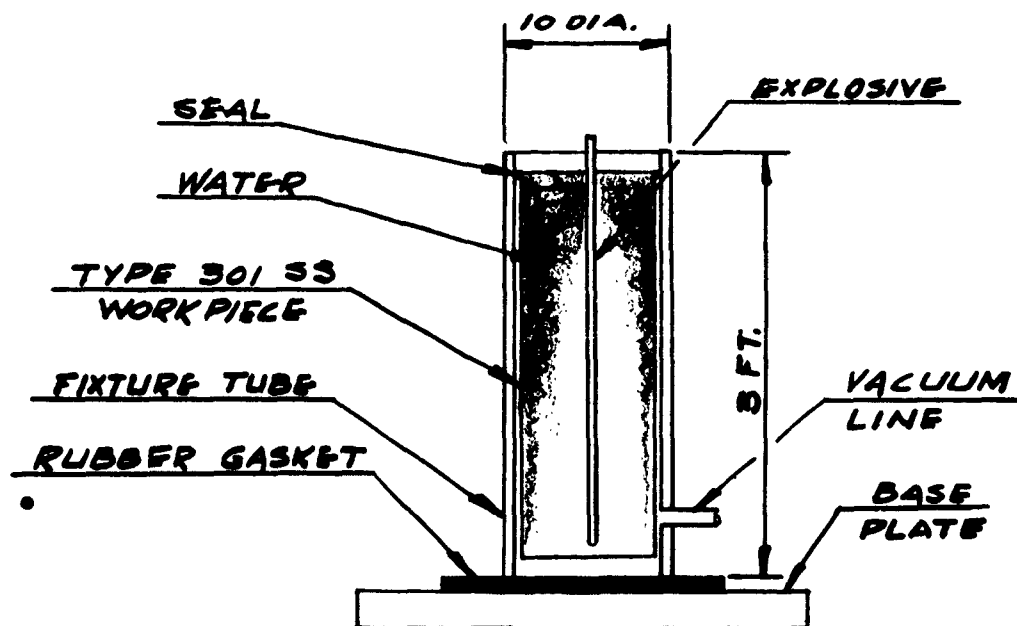
HELICAL WELDING FIXTURE AND  
ARRANGEMENT - 10" CYLINDER

FIGURE 34



EXPLOSIVE SIZING ARRANGEMENT

10" DIA. TYPE 301 STAINLESS  
SHELL



SCHEMATIC DIAGRAM OF EXPLOSIVE SIZING  
ARRANGEMENT

FIG.-35

tube having a 3/8" thick wall. An explosive charge, calculated to yield the Type 301 stainless steel shell was used. Variations in wall shape of the stainless tube caused by weld shrinkage were removed and we expect that a good stress relief of the wall was obtained. We expect to make a metallurgical examination of the cylinder to determine the effect on properties of the weld and parent metal as a result of explosive sizing.

#### WORK CONTEMPLATED FOR NEXT PERIOD

Evaluation of the Ti-8Al-10V alloy recently received will be made during the period. Tensile and fracture energy tests of preliminary samples of ausrolled low alloy steel will be made. We will determine from the preliminary tests, the heat from which additional evaluation will be made.

Problems at the mills have delayed deliveries of the PH 12-8-6 alloy and the 20% - 25° nickel alloys. Recent status indicates deliveries of these alloys during the next period.

Design of a welding fixture for 20" dia. helical weld cylinders will continue during the next period.

The contract for research on controlled ingot solidification to be conducted at Massachusetts Institute of Technology is at the Philadelphia Ordnance District for approval by the Contracting Officer. We expect to release this to M.I.T. within the next period.

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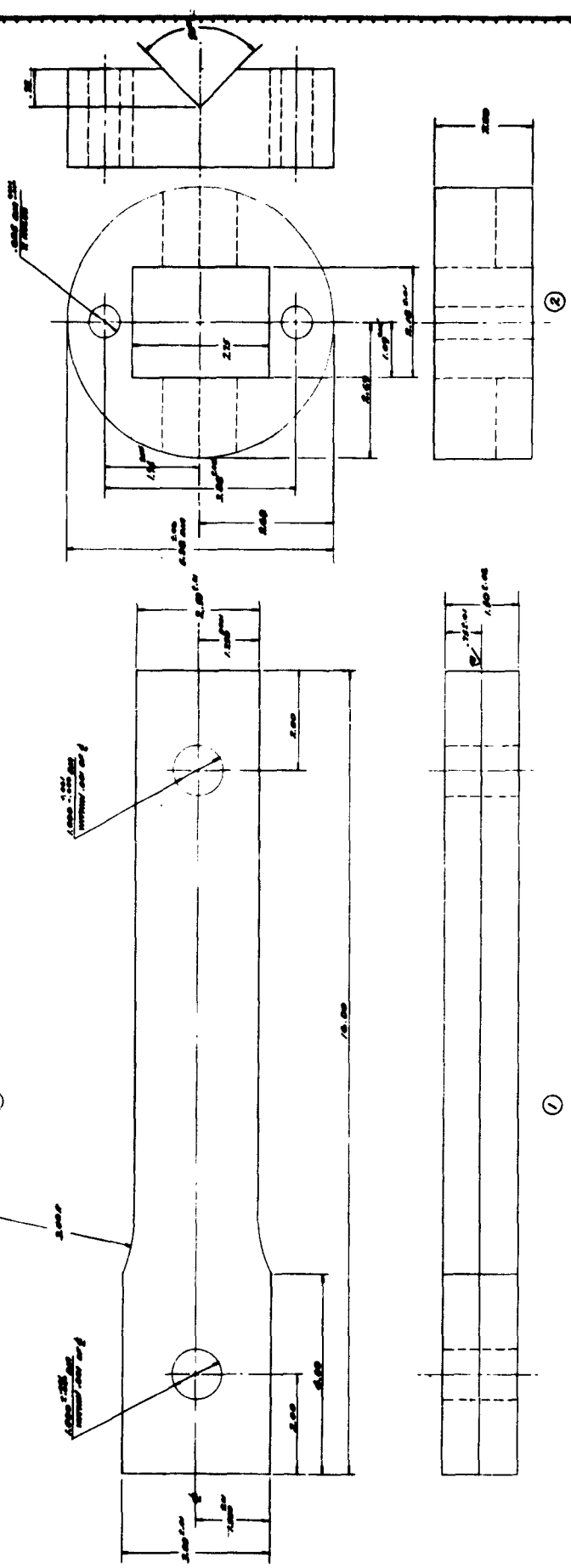
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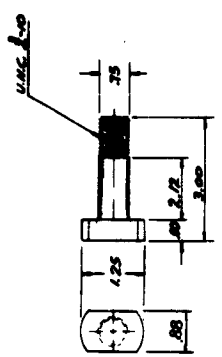
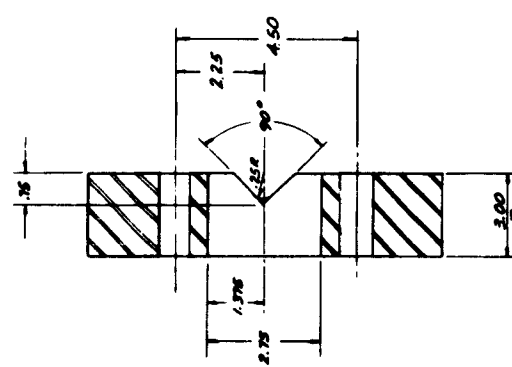
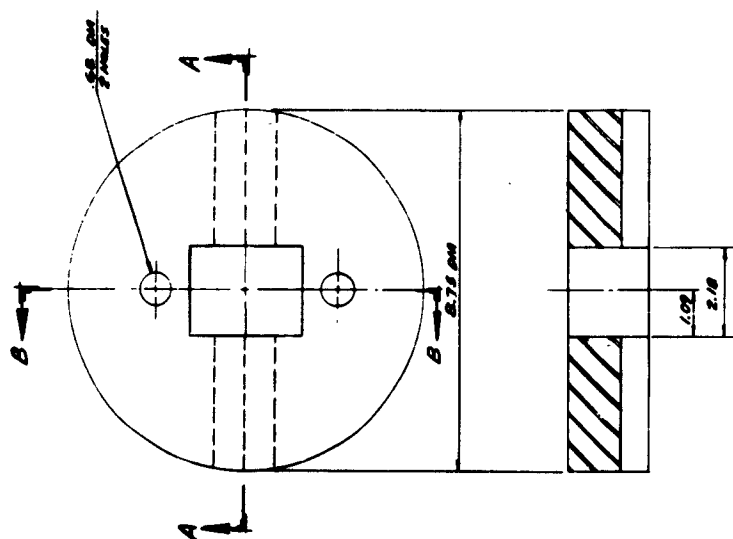
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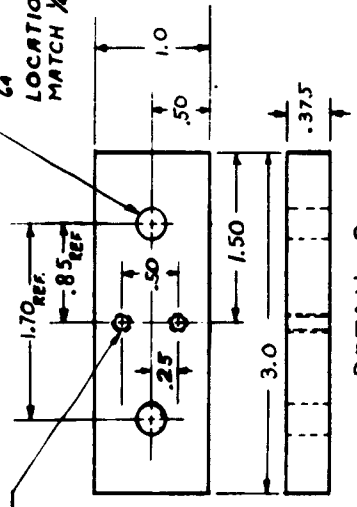
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| 11       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 12       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 13       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 14       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 15       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 16       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 17       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 18       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 19       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 20       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 21       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 22       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 23       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 24       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 25       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 26       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 27       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 28       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 29       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 30       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 31       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 32       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 33       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 34       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 48       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 55       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 56       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 66       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 73       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 78       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 85       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 86       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 92       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
| 93       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 98       | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |
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| 100      | 2 | 2        | 2           | 2    | 2         | 2     | 2    | 2        | 2  | 2    |

DO NOT SCALE DRAWINGS. REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT.

E2434-0109  
DRAWING NO. REV

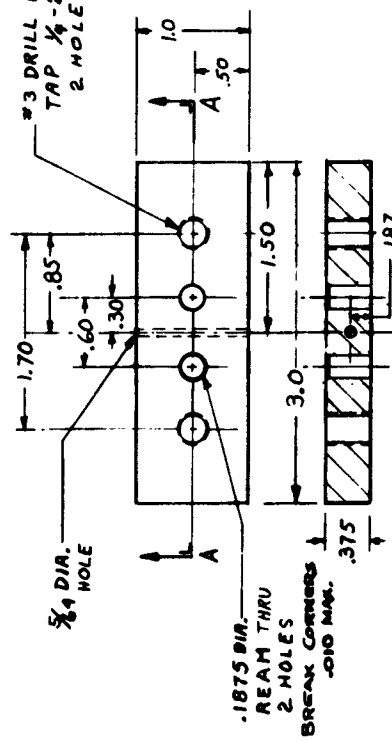
#21 DRILL (.1590 DIA)  
TAP #10-32 THRU  
2 PLACES

17 DIA. 2 HOLES  
THRU  
LOCATION MUST  
MATCH 1/4-28 HOLES IN -3



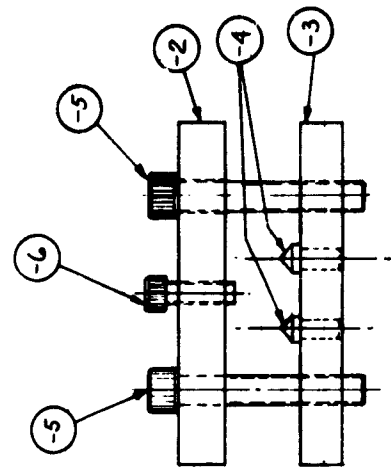
DETAIL -2

#3 DRILL (.2130 DIA)  
TAP 1/4-20 NC  
2 HOLE THRU



SECTION AA  
DETAIL -3

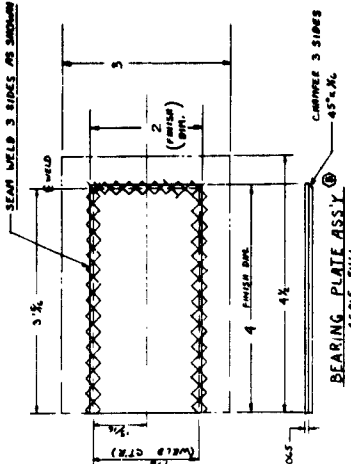
DIMENSIONS ARE IN INCHES  
UNLESS OTHERWISE SPECIFIED  
TOLERANCES ARE AS FOLLOWS  
DECIMAL  $\pm .015$   
FRACTION  $\pm .01$   
ANGLES  $\pm 2^\circ$   
SURF FIN.



-1 ASSEMBLY

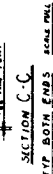
DETAIL -4 HARDENED TO 60-64 Rc  
2x SIZE & GROUND

| ITEM NO.             |                         | DESCRIPTION          |  | MATERIAL    |  | MTL'S SPECS. |  | REV.         |  |
|----------------------|-------------------------|----------------------|--|-------------|--|--------------|--|--------------|--|
| 2                    | SOCKET HD. CAP SCREWS   | #10-32 x 5/8" LONG   |  |             |  |              |  | -6           |  |
| 2                    | SOCKET HD. CAP SCREWS   | 1/4-20 x 1 1/4" LONG |  |             |  |              |  | -5           |  |
| 2                    | HOLDING PIN             | 1/4" DIA x 1/2" LONG |  |             |  |              |  | -4           |  |
| 1                    | HOLDING BAR             | 3/4" x 1" x 3        |  |             |  |              |  | -3           |  |
| 1                    | PRESSURE BAR            | 3/4" x 1" x 3        |  |             |  |              |  | -2           |  |
| 2                    | EXTENSOMETER CLAMP ASSY |                      |  |             |  |              |  | -1           |  |
| QTY.                 |                         | DESCRIPTION          |  | MATERIAL    |  | MTL'S SPECS. |  | REV.         |  |
| PIECE NO.            |                         | NO.                  |  | JOB         |  | USED ON      |  | TITLE        |  |
| THE BUDD COMPANY     |                         | EXTENSOMETER CLAMP-  |  | E 2434-0109 |  | FULL & NOTED |  | DRAWING NO.  |  |
| PRODUCT DEVELOPMENT  |                         | WELD JOINT SPECIMENS |  |             |  |              |  |              |  |
| PHILADELPHIA 32, PA. |                         | APPROVED             |  | APPROVED    |  | APPROVED     |  | SCALE        |  |
| DRAWN                |                         | CHECKED              |  | APPROVED    |  | APPROVED     |  | FULL & NOTED |  |
| 3/24/61              |                         | 3/24/61              |  | 3/24/61     |  | 3/24/61      |  |              |  |



**NOTES:**

- [illegible]



our focus was with off-road vehicles. The off-road vehicles were categorized as follows: ATVs, UTVs, snowmobiles, and motorcycles. The off-road vehicles were categorized as follows: ATVs, UTVs, snowmobiles, and motorcycles.

|                |       |          |      |
|----------------|-------|----------|------|
| NAME           | OTHER | PRICE NO | DATE |
| 1 TO THIS DATE |       |          |      |

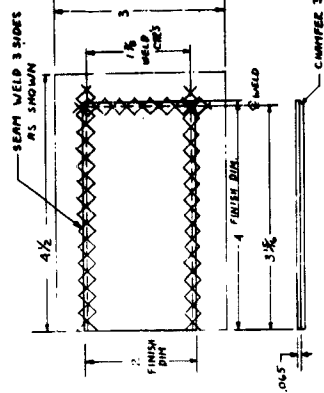
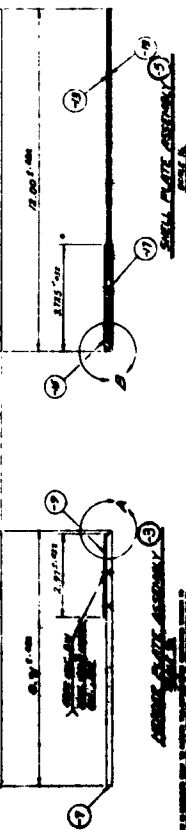
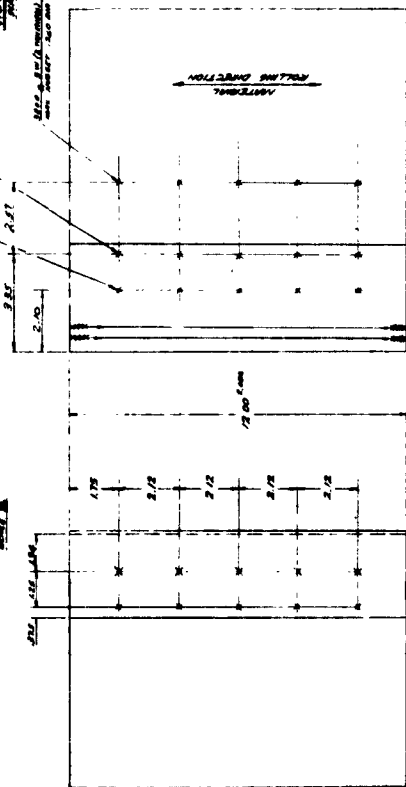
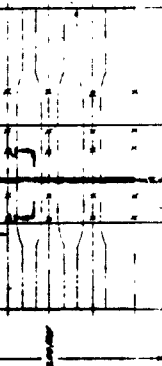
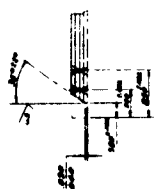
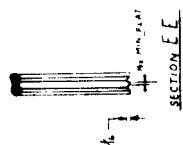
Technical drawing of a Shell Plate Assembly. The drawing shows a side view of a cylindrical component with a central longitudinal slot. Key dimensions and features include:

- Overall Length:** 12.00 ± .002
- Slot Width:** .8712
- Slot Depth:** .250
- Slot Position:** 6.00 ± .002 from the left end.
- Callouts:**
  - ①: Points to the left end of the assembly.
  - ②: Points to the central longitudinal slot.
  - ③: Points to the right end of the assembly.
  - ④: Points to the top surface of the assembly.
  - ⑤: Points to the bottom surface of the assembly.
- Text:** "SHELL PLATE ASSEMBLY" and "FIG. 1A"





**SUPPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT**



⑥ BEARING PLATE ASS'Y - II

**FULL SIZE**

- [illegible]

[illegible][illegible][illegible]











APPENDIX C

|                               |                                                                            |                    |
|-------------------------------|----------------------------------------------------------------------------|--------------------|
| PREPARED BY: <b>FOX, C.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. <b>07</b> |
| CHECKED BY:                   |                                                                            | REPORT NO.         |
| DATE:                         | <b>AM-355 SCORT, PH 15-7 NO UNIAXIAL<br/>WELDED JOINT DESIGNS</b>          | PROJECT NO.        |

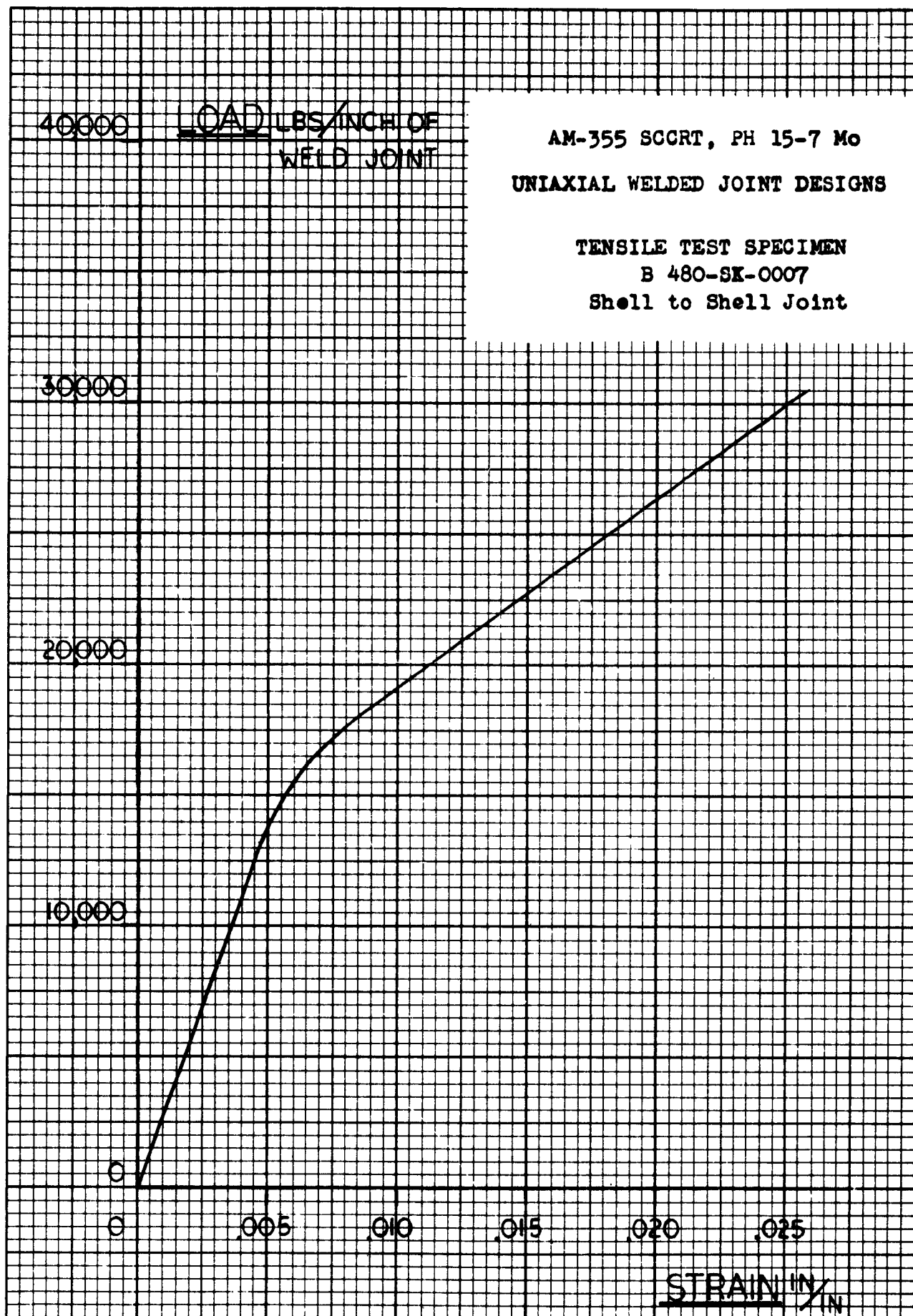
### DISCUSSION OF JOINT FAILURE

#### TENSILE TEST SPECIMEN B 480-SK-0007

#### Shell to Shell Joint



1. Initial failure occurred in the doubler spot welds. These welds sheared from the two thickness shell plate structure.
2. The load was then transferred to the two thickness shell plate structure, producing joint failure in the heat affected zone of the outer seam weld.
3. The maximum load was 30,500 pounds per linear inch of fusion weld with a maximum strain of 0.0256 inches per inch.
4. There was noticeable straining (necking) at the seam weld areas on both sides of the fusion weld.
5. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.



|                               |                                                                            |                    |
|-------------------------------|----------------------------------------------------------------------------|--------------------|
| PREPARED BY: <b>FOX, C.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. <b>97</b> |
| CHECKED BY:                   |                                                                            | REPORT NO.         |
| DATE:                         | <b>AM-355 SCCRT, PH-15-7-MO UNIAXIAL<br/>WELDED JOINT DESIGNS</b>          | PROJECT NO.        |

### DISCUSSION OF JOINT FAILURE

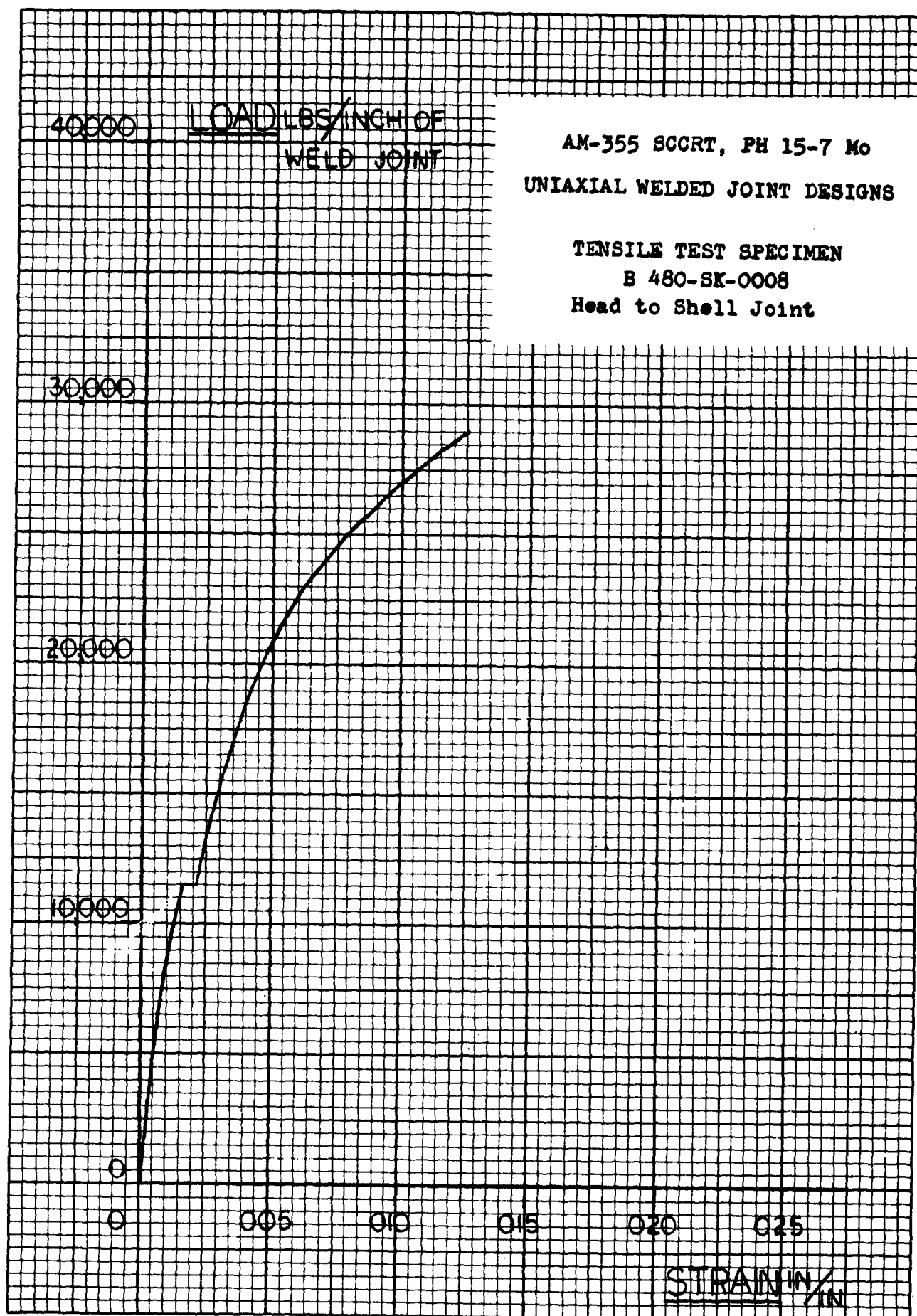
#### TENSILE TEST SPECIMEN B 480-SK-0008 Head to Shell Joint



1. Initial failure occurred in the two spot welds holding the AM-355 doubler to the PH 15-7 Mo plate. These welds sheared at approximately 28,000 pounds per linear inch of fusion weld. At this load the spot welds were carrying a total of 8250 pounds.

It was noted that one of the spot welds which failed had a noticeably smaller weld nugget at the sheared surface. This was a contributory factor to the early spot failure.

2. The joint failed in the fusion weld at a load of 28,850 pounds per linear inch of fusion weld. A maximum strain of 0.0125 inches per inch was recorded.
3. There was a noticeable straining (necking) in the seam weld area.
4. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.



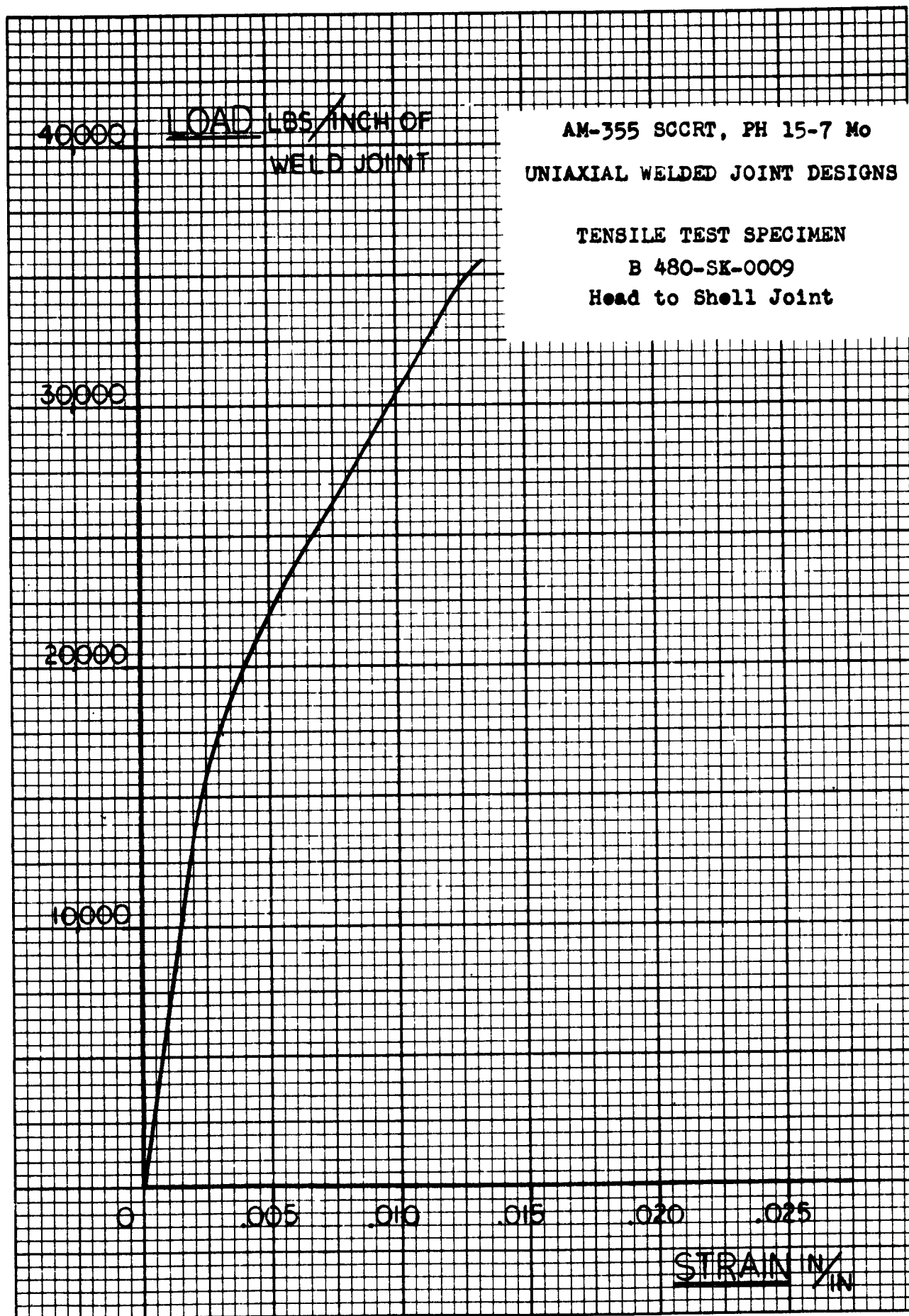
|                               |                                                                            |                    |
|-------------------------------|----------------------------------------------------------------------------|--------------------|
| PREPARED BY: <b>FOX, G.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. <b>97</b> |
| CHECKED BY:                   |                                                                            | REPORT NO.         |
| DATE:                         | <b>AM-355 SCRT, PH 15-7 NO UNIAXIAL<br/>WELDED JOINT DESIGNS</b>           | PROJECT NO.        |

### DISCUSSION OF JOINT FAILURE

#### **TENSILE TEST SPECIMEN B 480-SK-0009** **Head to Shell Joint**



1. Initial failure occurred in the spot welds holding the AM-355 doubler to the PH 15-7 Mo plate. These spot welds failed in shear.
2. There was noticeable straining in the fusion weld area before the spot weld failures. When the doubler on the PH 15-7 Mo plate was no longer transmitting its share of the load to the plate, due to the doubler spot welds failure, severe straining began in the PH 15-7 Mo plate fusion weld heat affected zone. This caused the joint to fail in this area.
3. The joint failed at 35,500 pounds per linear inch of fusion weld with a maximum strain of 0.01325 inches per inch.
4. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.



|                               |                                                                            |                    |
|-------------------------------|----------------------------------------------------------------------------|--------------------|
| PREPARED BY: <b>Fox, G.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. <b>07</b> |
| CHECKED BY:                   |                                                                            | REPORT NO.         |
| DATE:                         | <b>AM-355 SCORT, PH 15-7 MO UNIAXIAL<br/>WELDED JOINT DESIGNS</b>          | PROJECT NO.        |

### DISCUSSION OF JOINT FAILURE

**TENSILE TEST SPECIMEN B 480-SK-0010**

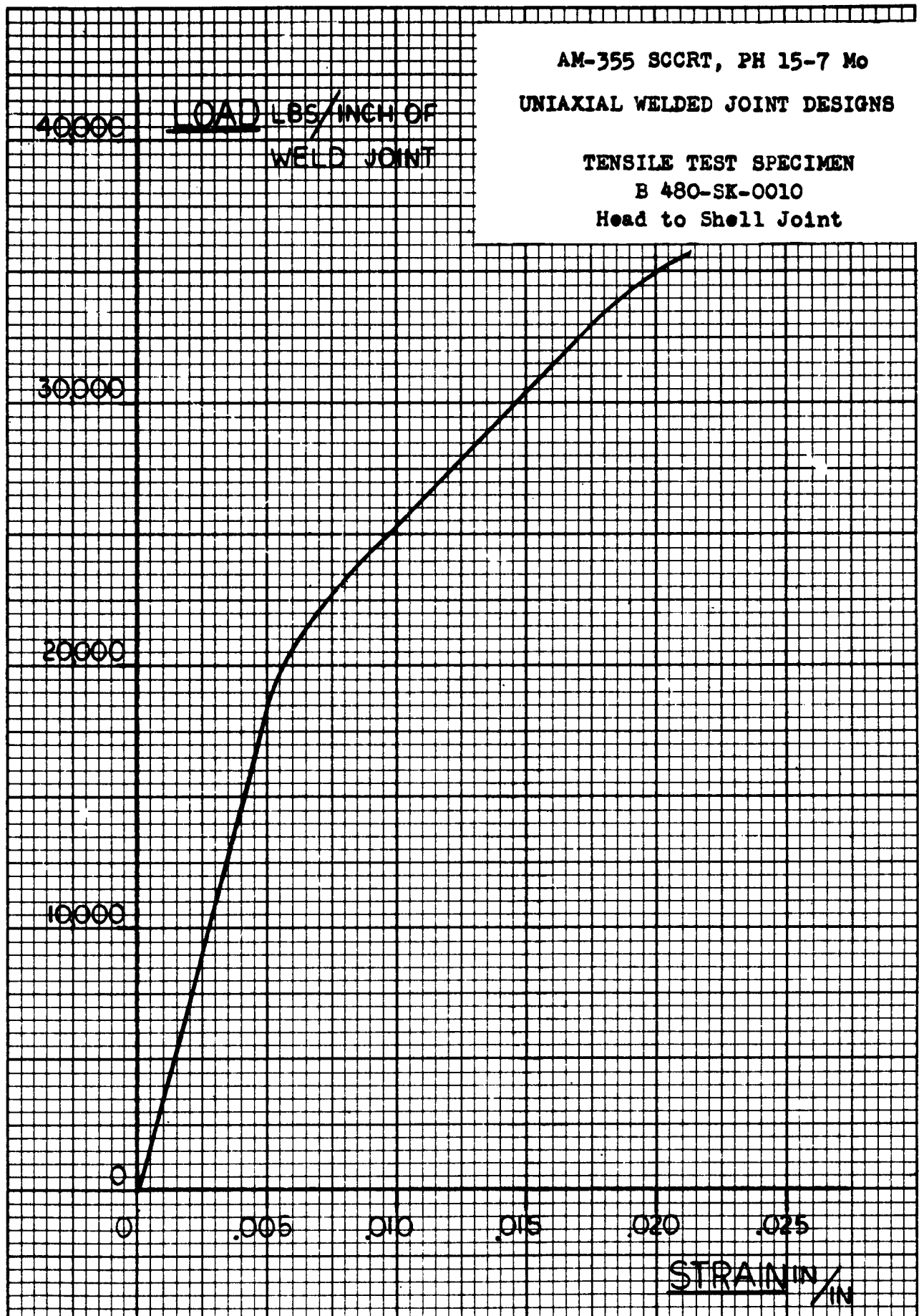
**Head to Shell Joint**



1. Initial failure occurred in the spot welds holding the AM-355 doubler to the PH 15-7 Mo plate. These spot welds failed in shear.
2. There was noticeable straining in the fusion and seam weld areas prior to the spot weld failure. When the doubler on the PH 15-7 Mo plate was no longer transmitting a load, severe straining began in the PH 15-7 Mo plate fusion weld heat affected zone, resulting in joint failure.
3. The joint failed at 35,810 pounds per linear inch of fusion weld with a maximum strain of 0.0212 inches per inch.
4. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.

AM-355 SCCRT, PH 15-7 Mo  
UNIAXIAL WELDED JOINT DESIGNS

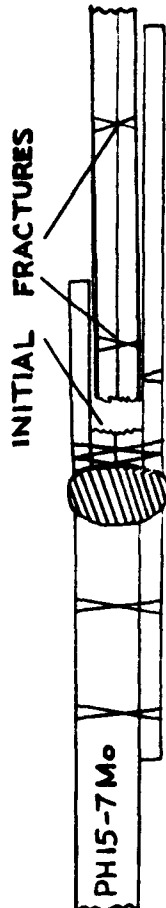
TENSILE TEST SPECIMEN  
B 480-SK-0010  
Head to Shell Joint



|                               |                                                                            |                    |
|-------------------------------|----------------------------------------------------------------------------|--------------------|
| PREPARED BY: <b>FOX, G.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. <b>OF</b> |
| CHECKED BY:                   |                                                                            | REPORT NO.         |
| DATE:                         | <b>AM-355 SCORT, PH 15-7 NO UNIAXIAL<br/>WELDED JOINT DESIGNS</b>          | PROJECT NO.        |

DISCUSSION OF JOINT FAILURE

**TENSILE TEST SPECIMEN B 480-SK-0011**  
**Head to Shell Joint**

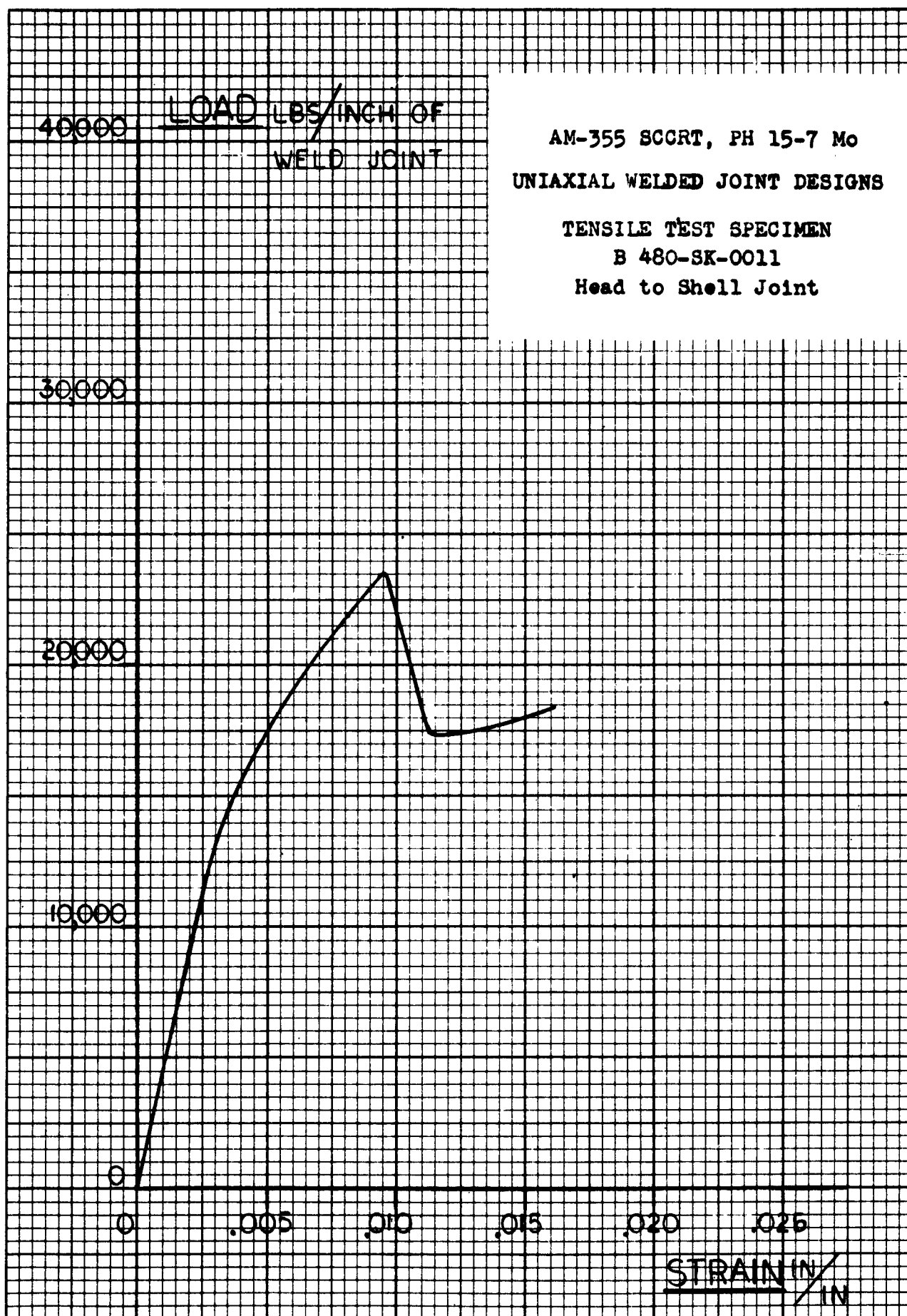


**1. The initial fractures occurred at:**

- a) The outer seam weld heat affected zone in one thickness of the basic two thickness shell plate structure.
- b) The spot weld interfaces between the sheets of the basic two thickness shell plate structure.

After the initial fractures, the long doubler attached to one thickness of the basic two thickness shell plate structure were the only load carrying members on the shell plate assembly side of the fusion weld.

- 2. The initial fractures were at a load of 23,460 pounds per linear inch of fusion weld. After the initial fractures the load fell to 17,150 pounds per linear inch of fusion weld. Joint failure was at 18,430 pounds per linear inch of fusion weld. There was a small amount of straining (necking) in the fusion weld and a maximum recorded strain of 0.01625 inches/inch.**
- 3. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.**



|                               |                                                                            |                         |
|-------------------------------|----------------------------------------------------------------------------|-------------------------|
| PREPARED BY: <b>FOX, C.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. _____ OF _____ |
| CHECKED BY:                   |                                                                            | REPORT NO. _____        |
| DATE:                         | <b>AM-355 SCRT, PH 15-7 NO UNIAXIAL</b><br><b>WELDED JOINT DESIGNS</b>     | PROJECT NO. _____       |

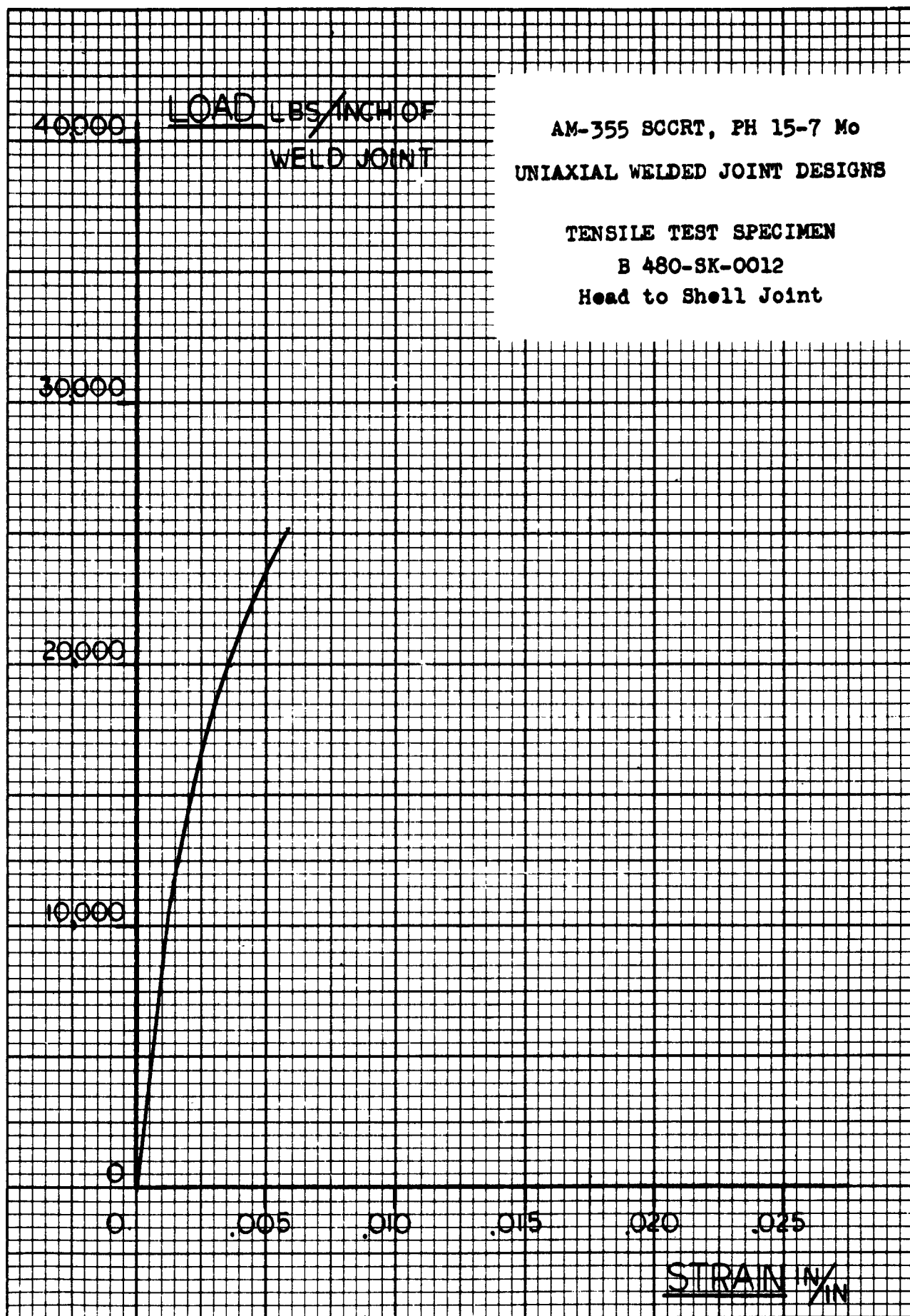


DISCUSSION OF JOINT FAILURE

TENSILE TEST SPECIMEN B 480-SK-0012

Head to Shell Joint

1. Initial failure occurred in the spot weld holding the doubler to the two thickness shell plate structure. This spot weld failed in shear.
2. There was a small amount of straining (necking) in the fusion weld. The most noticeable straining occurred in the shell plate assembly seam weld heat affected zone. This was the failure area.
3. The joint failed at a load of 25,180 pounds per linear inch of fusion weld with a maximum strain of 0.00563 inches per inch.
4. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.



|                               |                                                                            |                         |
|-------------------------------|----------------------------------------------------------------------------|-------------------------|
| PREPARED BY: <b>FOX, G.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. _____ OF _____ |
| CHECKED BY:                   |                                                                            | REPORT NO. _____        |
| DATE:                         | <b>AM-355, SCORT, PH 15-7 MO UNIAXIAL WELDED JOINT DESIGNS</b>             | PROJECT NO. _____       |

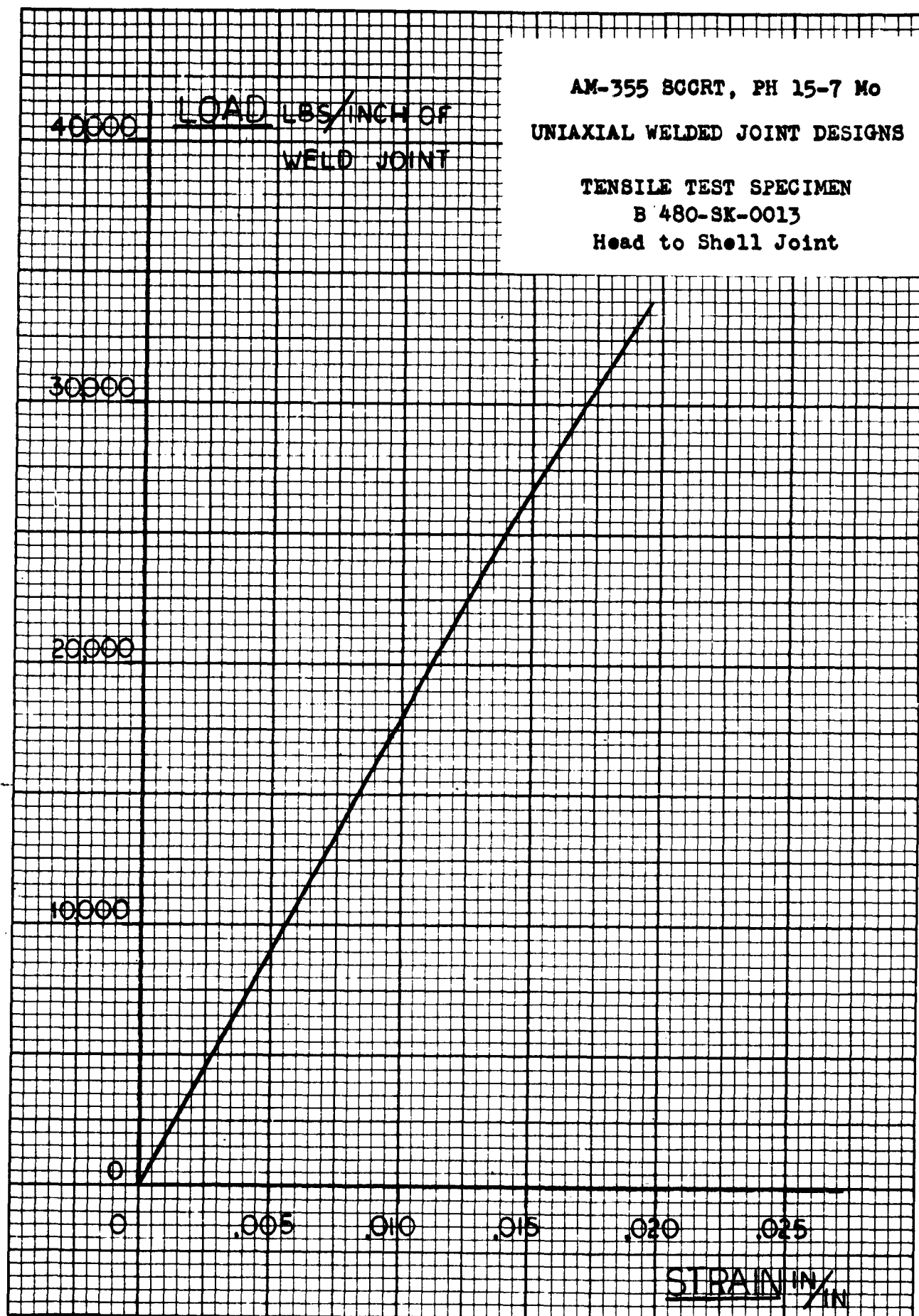
### DISCUSSION OF JOINT FAILURE

#### TENSILE TEST SPECIMEN B 480-SK-0013

#### Head to Shell Joint



1. Initial failure occurred in the spot welds holding the doublers to the basic two thickness shell plate structure. These spot welds failed in shear.
2. There was a small amount of straining (necking) in the fusion weld with very nearly uniform yielding up to joint failure. Failure was in the four pile-up seam weld heat affected zone between the inner and outer seam welds.
3. The joint failed at a load of 33,710 pounds per linear inch of fusion weld with a maximum strain of 0.01938 inches per inch.
4. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.



|                               |                                                                            |                         |
|-------------------------------|----------------------------------------------------------------------------|-------------------------|
| PREPARED BY: <b>FOX, C.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. _____ OF _____ |
| CHECKED BY:                   |                                                                            | REPORT NO. _____        |
| DATE:                         | <b>AM-355 SCRT, PH 15-7 NO UNIAXIAL</b><br><b>WELDED JOINT DESIGNS</b>     | PROJECT NO. _____       |

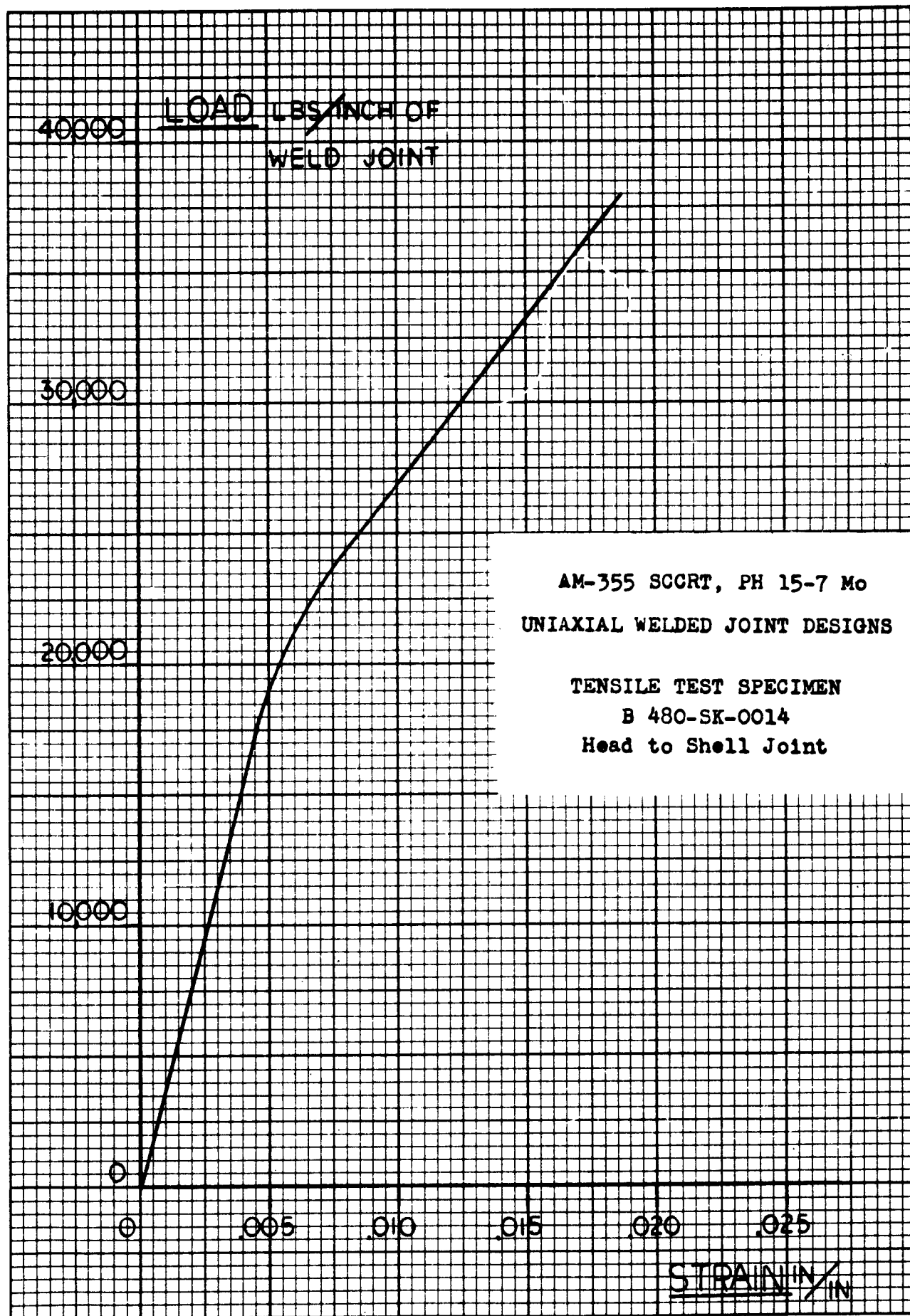


### DISCUSSION OF JOINT FAILURE

#### TENSILE TEST SPECIMEN B 480-SK-0014

##### Head to Shell Joint

1. The joint failed in tension through the outer spot weld on the long doubler of the shell plate assembly.
2. Analysis of the failure indicated that this was the weakest point in the design and failure could be expected around 35,800 pounds per linear inch of fusion weld. The load at failure was 37,960 pounds per linear inch of fusion weld.
3. There was a very definite amount of straining (necking) in the fusion weld with a maximum recorded strain of 0.01875 inches per inch.
4. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.



|                               |                                                                            |                    |
|-------------------------------|----------------------------------------------------------------------------|--------------------|
| PREPARED BY: <b>FOX, C.R.</b> | <b>THE BUDD COMPANY</b><br><b>PRODUCT DEVELOPMENT</b><br>PHILADELPHIA, PA. | PAGE NO. <b>97</b> |
| CHECKED BY:                   |                                                                            | REPORT NO.         |
| DATE:                         | <b>AM-355 SCURT. PH 15-7 NO UNIAXIAL</b>                                   | PROJECT NO.        |
|                               | <b>WELDED JOINT DESIGNS</b>                                                |                    |



### DISCUSSION OF JOINT FAILURE

#### TENSILE TEST SPECIMEN B 480-SK-0015

##### Head to Shell Joint

1. Initial failure occurred in the spot welds holding the doublers to the basic two thickness shell plate structure. These spot welds failed in shear.
2. There was very little straining (necking) in the fusion weld area. The maximum apparent strain was in the shell plate assembly at the point of failure. Failure was in the four pile-up seam weld heat affected zone between the inner and outer seam welds.
3. The joint failed at a load of 26,200 pounds per linear inch of fusion weld with a maximum recorded strain of 0.010 inches per inch.
4. A graph of the Load in pounds per linear inch of fusion weld versus the Total Strain in inches per inch is shown on the following page.

