Budd

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

THE Budd COMPANY

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

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ROCKET MOTOR CASE DEVELOPMENT

Control Number A-5180

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TABLE OF CONTENTS

Page Number

INTRODUCTION - 1

MATERIALS EVALUATION - - - - - - - - - - - - - - - - 2

Discussion of Fracture Energy Testing- - - - - - - 2

Specimen Identification- - - - - - - - - - - - - - 11

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

Data on AM 359 Steel - - - - - - - - - - - - - - - 62

UNIAXIAL WELD JOINT EVALUATION - - - - - - - - - - - 68

Data on AM 355 - PH 15-7 Mo Uniaxial Head to Shell and Shell to Shell Joints - - - - - - - 68

Electron Beam Welded Joints - JLS - 300 Alloy- - [illegible]

HELICAL WELDED CYLINDERS - - - - - - - - - - - - - - 100

WORK CONTEMPLATED FOR NEXT PERIOD- - - - - - - - - - 106

Table 1. Fracture Energy Tests- Fatigue Crack Observations - - - - 10

Table 2. Specimen Identification Chart- - - 13

Table 3. Chemical Composition of Seven Heats of Ti 13V-11Cr-3Al and Arc Welding Filler Wire- - - - 15

Table 4. Tensile Properties, Annealed Ti 13V-11Cr-3Al- - - - - - - - - - - 19

Table 5. Tensile Properties, Cold Rolled and Aged Ti 13V-11Cr-3Al - - - - - - 21

Table 6. Tensile Properties, Solution Annealed and Aged at 900°F for 48 Hours, Ti 13V-11Cr-3Al- - - 22

Table 7. Tensile Properties, Solution Annealed and Aged at 900°F for 72 Hours, Ti 13V-11Cr-3Al- - - 23

		Page Number
Table 8.	Fracture Energy Properties, Ti 13V-11Cr-3Al Solution Annealed and Aged @900°F, 72 Hours - - - - - - - - - - - - - -	31
Table 9.	Fracture Energy Properties, Ti-13V-11Cr-3Al Solution Annealed and Aged @900°F, 72 Hours - - - - - - - - - - - - - -	32
Table 10.	Fracture Energy Properties, Ti-13V-11Cr-3Al Cold Rolled and Aged @ 900°F - - - - - - - - - -	33
Table 11.	Bend Properties, Solution Annealed, and Solution Annealed and Aged at 900°F for 72 Hours, Ti 13V-11Cr-3Al- - -	35
Table 12.	Bend Properties, Cold Rolled and Aged Ti 13V-11Cr-3Al - - - - -	36
Table 13.	Tensile and Tensile Shear Data of Resistance Spot Welds in Ti 13V-11Cr-3Al - - - - - - - -	39
Table 14.	Stress Corrosion Data, Resistance Spot Welds in Ti 13V-11Cr-3Al - - - - - - - -	49
Table 15.	Stress-Corrosion Data, Resistance Spot Welds in Ti 13V-11Cr-3Al - - - - - - - -	50
Table 16.	TIG Welding Schedule, Ti 13V-11Cr-3Al, Annealed- - - - -	53
Table 17.	TIG Welding Schedule, Ti 13V-11Cr-3Al, Cold Rolled and Aged - - - - - - - - - - - - - -	54
Table 18.	Mechanical Properties, Arc Welded Specimens, Ti 13V-11Cr-3Al- - - - - - - - - - -	56
Table 19.	AM 359 Alloy - Chemical Composition - - - - - - - -	64
Table 20.	Heat Treatment and Mechanical Properties of AM 359 Steel Strip - - - - - - - - -	65

Page Number

Table 21. AM 355-PH 15-7 Mo Welded Joint Specimens, Joint Efficiencies - - - - - - - - 72,73

Table 22. AM 355 PH 15-7 Mo Welded Joint Specimens Correlation of Strain with Resistance Weld Design- - - 74

Table 23. Comparison of Mechanical Properties - TIG Welding and Electron Beam on JLS 300 Alloy- - - - - - - - - - 80

Table 24. Chemical Composition JLS 300 Alloy- - - - - - - - - - 81

Table 25. Electron Beam Welding Schedule - JLS 300 Alloy - - - - 84

Table 26. Electron Beam Welding Summary Ti-13V-11Cr-3Al Alloy- - - - - - - - - - - - - 88

Table 27. Condition and Properties of Ti-13V-11Cr-3Al Alloy Prior to Electron Beam Welding - - - - - - - - - - 91

Table 28. Welding Schedule Ti 13V-11Cr-3Al Electron Beam Welding - - - - - - - - - - 93

Table 29. Mechanical Properties - Electron Beam Welding Ti-13V-11Cr-3Al- - - - - - - - - 97

Figure 1. Fracture Energy Specimen Dwg. E 2434-0014 - - - - - - - - - 4

Figure 2. Drill and Ream Fixture Type 'B' Specimen- - - - - - - - - 6

Figure 3. Electrode Discharge Machining Fixture - Center Notch Fracture Energy Testing - - - - - - - - - - 7

Figure 4. Fixture for Fatigue Crack Initiation - Center Notch Fracture Energy Testing- - - - - - 8

		Page Number
Figure 5.	Pin Loading Fixture Center Notch Fracture Energy Testing - - - - - - - - - - -	12
Figure 6.	Tensile Properties vs. Aging Time at 900°F for Ti 13V-11Cr-3Al- - - - - - - - - - -	18
Figure 7.	Photomicrographs. Ti 13V-11Cr-3Al, Solution Annealed- - - - - - - - - -	25
Figure 8.	Photomicrographs, Ti 13V-11Cr-3Al, Solution Annealed- - - - - - - - - -	26
Figure 9.	Photomicrographs, Ti 13V-11Cr-3Al, Cold Rolled 25% - - - - - - - - - -	27
Figure 10.	Photomicrographs, Ti 13V-11Cr-3Al, Cold Rolled and Aged - - - - - - - -	28
Figure 11.	Photomicrographs, Ti 13V-11Cr-3Al, Cold Rolled and Aged - - - - - - - -	29
Figure 12.	Resistance Spot Welding Schedule and Data Sheet Ti 13V-11Cr-3Al- - - - - - - - - - -	38
Figure 13.	Photomacrograph and Hardness Traverse of Resistance Spot Weld in Annealed Ti 13V-11Cr-3Al- - - -	41
Figure 14.	Photomicrograph of Weld Nugget and Heat Affected Zone Structure in Resistance Spot Weld in Annealed Ti 13V-11Cr-3Al - - - - - -	42
Figure 15.	Resistance Spot Welding Schedule and Data Sheet Ti 13V-11Cr-3Al - - - - - - - - - - -	43
Figure 16.	Photomacrograph and Hardness Traverse of Resistance Spot Weld in Cold Rolled and Aged Ti 13V-11Cr-3Al- - - - - - - - - - -	45

Page Number

Figure 17. Photomicrograph of Weld Region in Resistance Spot Welded Ti 13V-11Cr-3Al, Cold Rolled and Aged - - - - - - - 46

Figure 18. Photomacrograph and Hardness Traverse of TIG Weld, Solution Annealed Ti 13V-11Cr-3Al - - - - 58

Figure 19. Photomacrograph and Hardness Traverse of TIG Weld, Cold Rolled and Aged Ti 13V-11Cr-3Al - - - - 59

Figure 20. Photomicrographs of Welded Region in TIG Welded Ti 13V-11Cr-3Al, Solution Annealed- - - - - - - - 60

Figure 21. Photomicrographs of Welded Regions in TIG Welded Ti 13V-11Cr-3Al, Cold Rolled and Aged - - - - - - - 61

Figure 22. Stress Strain Diagrams AM 359 Alloy - - - - - - - - - - - 66

Figure 23. Photomicrograph AM 359 Alloy - - - - - - - - - - - 67

Figure 24. AM 355 - PH 15-7 Mo Welded Joint Specimens Testing Arrangement- - - - - - - - 71

Figure 25. Photographs - AM 355 PH 15-7 Mo Welded Joint Specimens After Fracture - - - - 76,77,78,79

Figure 26. Electron Beam Welding Fixture- - - - - - - - - - - - - - 83

Figure 27. Photomicrograph, Electron Beam Weld, JLS 300 Alloy- - - - - - - - - - 86

Figure 28. Photomicrograph - Shear Crack JLS 300 Alloy- - - - - - - - - - 87

		Page Number
Figure 29.	Radiograph Indications Ti 13V-11Cr-3Al Alloy	94
Figure 30.	Tensile Test Specimen 40° Weld Line Dwg. 2434-0115	95
Figure 31.	Sketch - Type of Fracture on Ti-13V-11Cr-3Al Alloy Electron Beam Weldments	98
Figure 32.	Geometric Relationship of Cylinder Diameter, Weld Helix Angle, Coil Width	101
Figure 33.	Effect of Helix Angle on the Yield Strength of a Cylinder	102
Figure 34.	Photograph of Helical Welding Fixture and Arrangement - 10" Dia. Cylinder	104
Figure 35.	Photograph and Diagram of Explosive Sizing 10" Dia. Cylinder	105
APPENDIX A	Report Distribution	107
APPENDIX B	AM 355-PH 15-7 Mo Weld Joint Specimen Drawings (Revised) and Fixture Drawings	115
APPENDIX C	Test Detail on AM 355-PH 15-7 Mo Weld Joint Specimens	128

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 ausrolled 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.

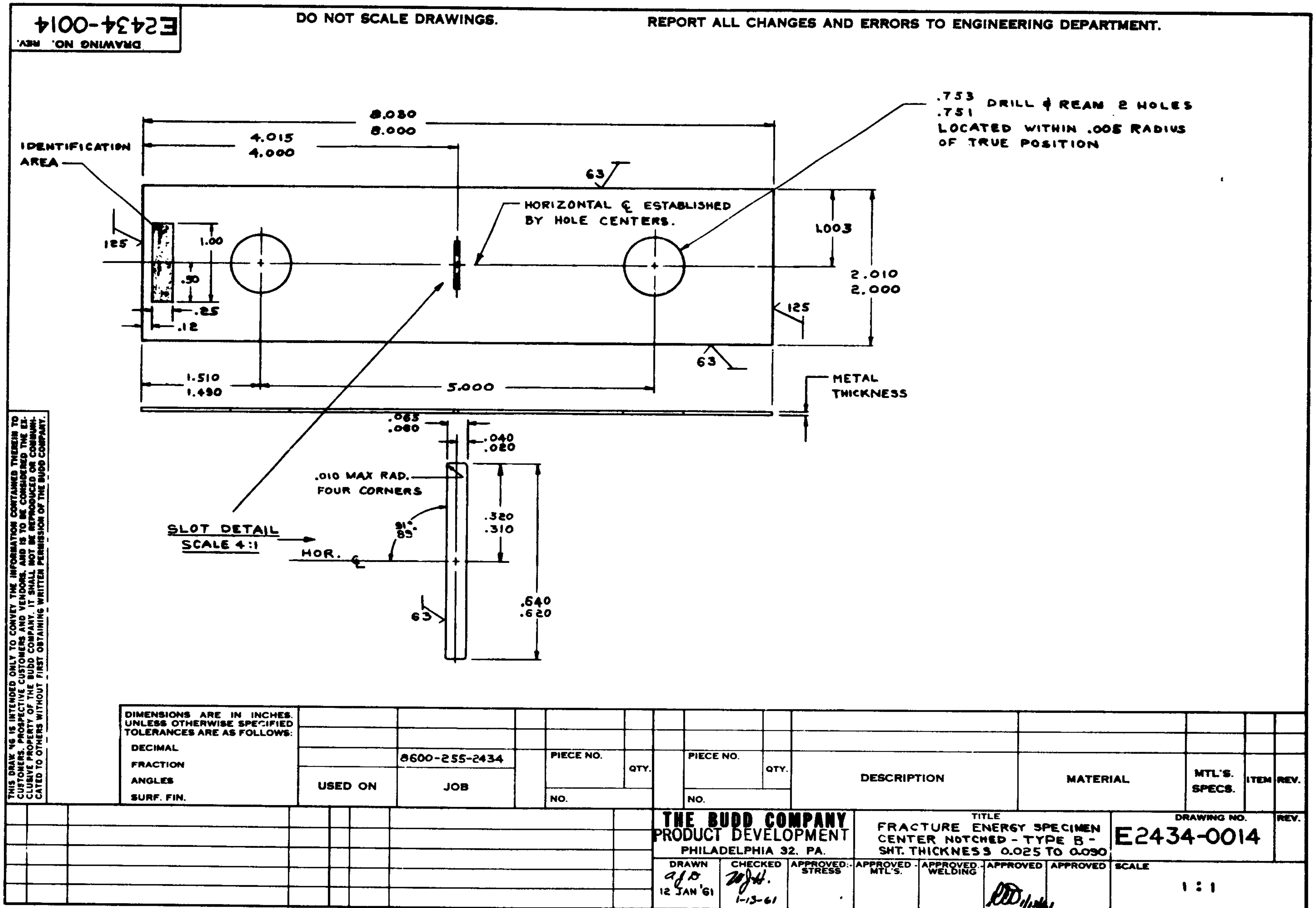
Discussion of Fracture Energy Testing

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



E2434-0014
DRAWING NO. REV.
DO NOT SCALE DRAWINGS.
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT.
.753 .751 DRILL & REAM 2 HOLES LOCATED WITHIN .005 RADIUS OF TRUE POSITION
8.030 8.000
4.015 4.000
IDENTIFICATION AREA
HORIZONTAL ℄ ESTABLISHED BY HOLE CENTERS.
1.003
2.010 2.000
1.00
.50
.25
.12
125
63
1.510 1.490
5.000
METAL THICKNESS
.085 .080
.040 .020
.010 MAX RAD. FOUR CORNERS
.320 .310
91° 89°
.640 .620
SLOT DETAIL SCALE 4:1
HOR. ℄
DIMENSIONS ARE IN INCHES. UNLESS OTHERWISE SPECIFIED TOLERANCES ARE AS FOLLOWS:
DECIMAL
FRACTION
ANGLES
SURF. FIN.
USED ON
JOB
8600-255-2434
PIECE NO.
QTY.
NO.
DESCRIPTION
MATERIAL
MTL'S. SPECS.
ITEM
REV.
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.
TITLE
FRACTURE ENERGY SPECIMEN CENTER NOTCHED - TYPE B - SHT. THICKNESS 0.025 TO 0.090
DRAWING NO.
E2434-0014
DRAWN
12 JAN '61
CHECKED
1-13-61
APPROVED - STRESS
APPROVED - MTL'S.
APPROVED - WELDING
APPROVED
SCALE
1:1
THIS DRAWING IS INTENDED ONLY TO CONVEY THE INFORMATION CONTAINED THEREIN TO CUSTOMERS, PROSPECTIVE CUSTOMERS AND VENDORS, AND IS TO BE CONSIDERED THE EXCLUSIVE PROPERTY OF THE BUDD COMPANY. IT SHALL NOT BE REPRODUCED OR COMMUNICATED TO OTHERS WITHOUT FIRST OBTAINING WRITTEN PERMISSION OF THE BUDD COMPANY.

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

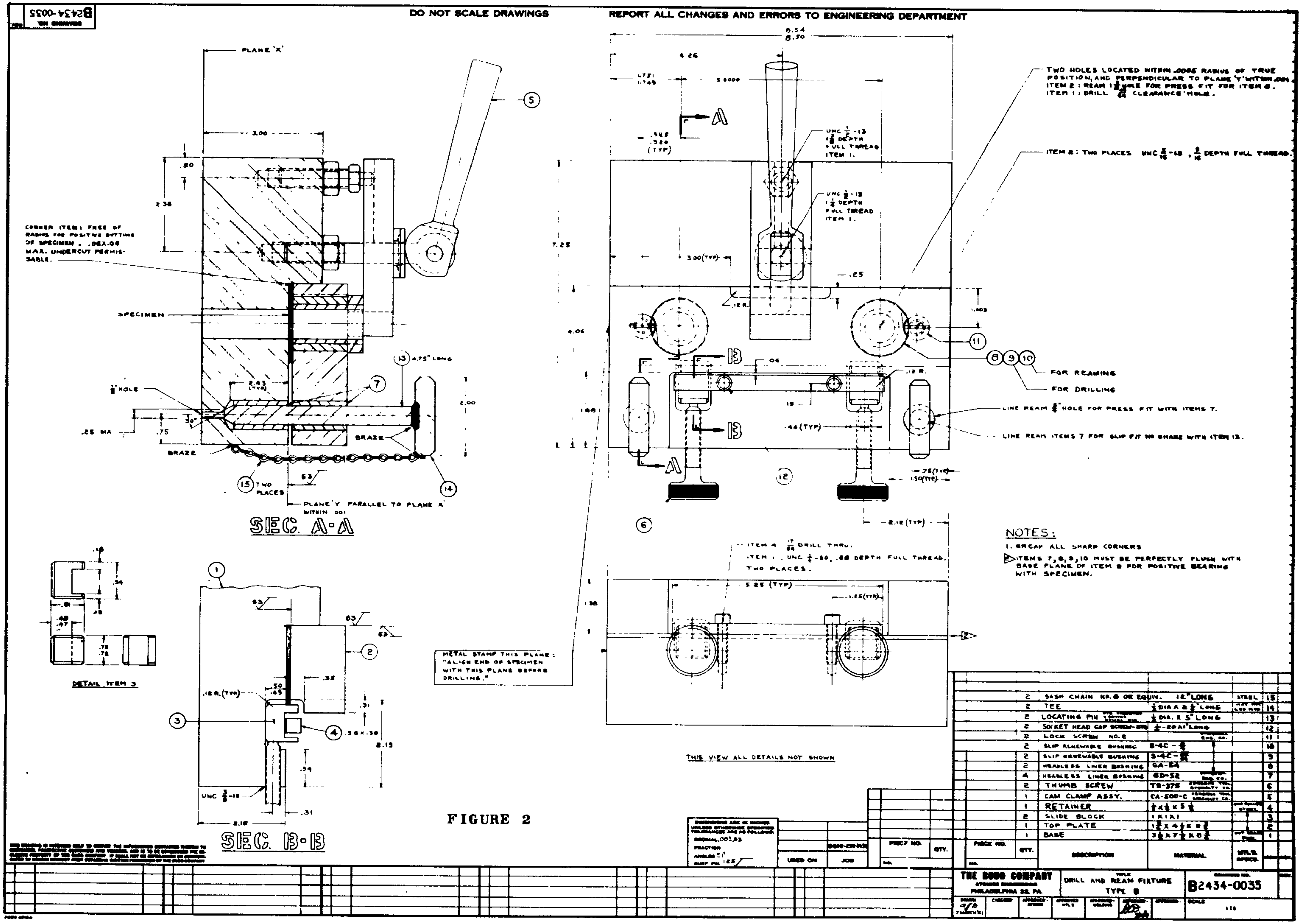
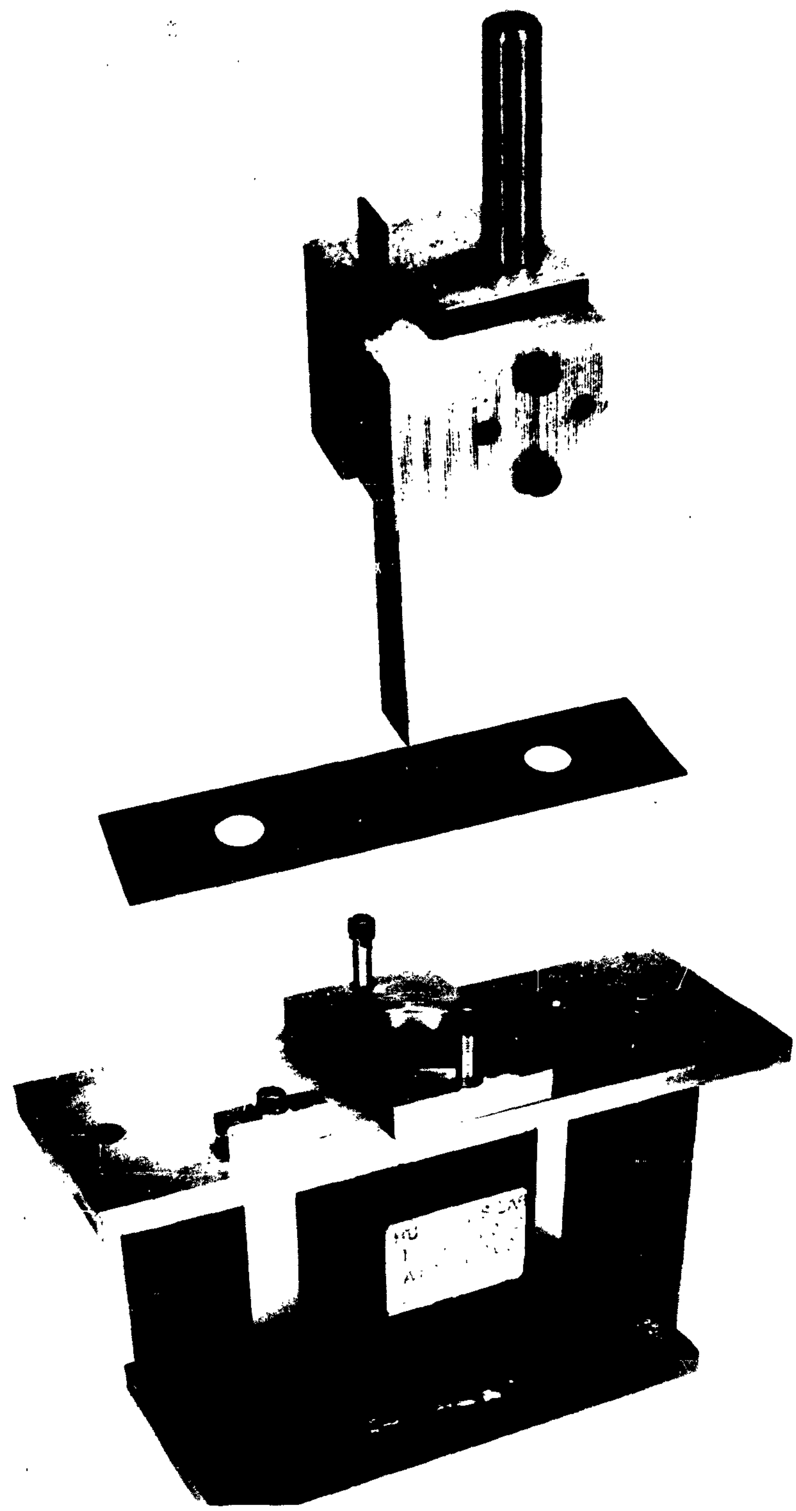
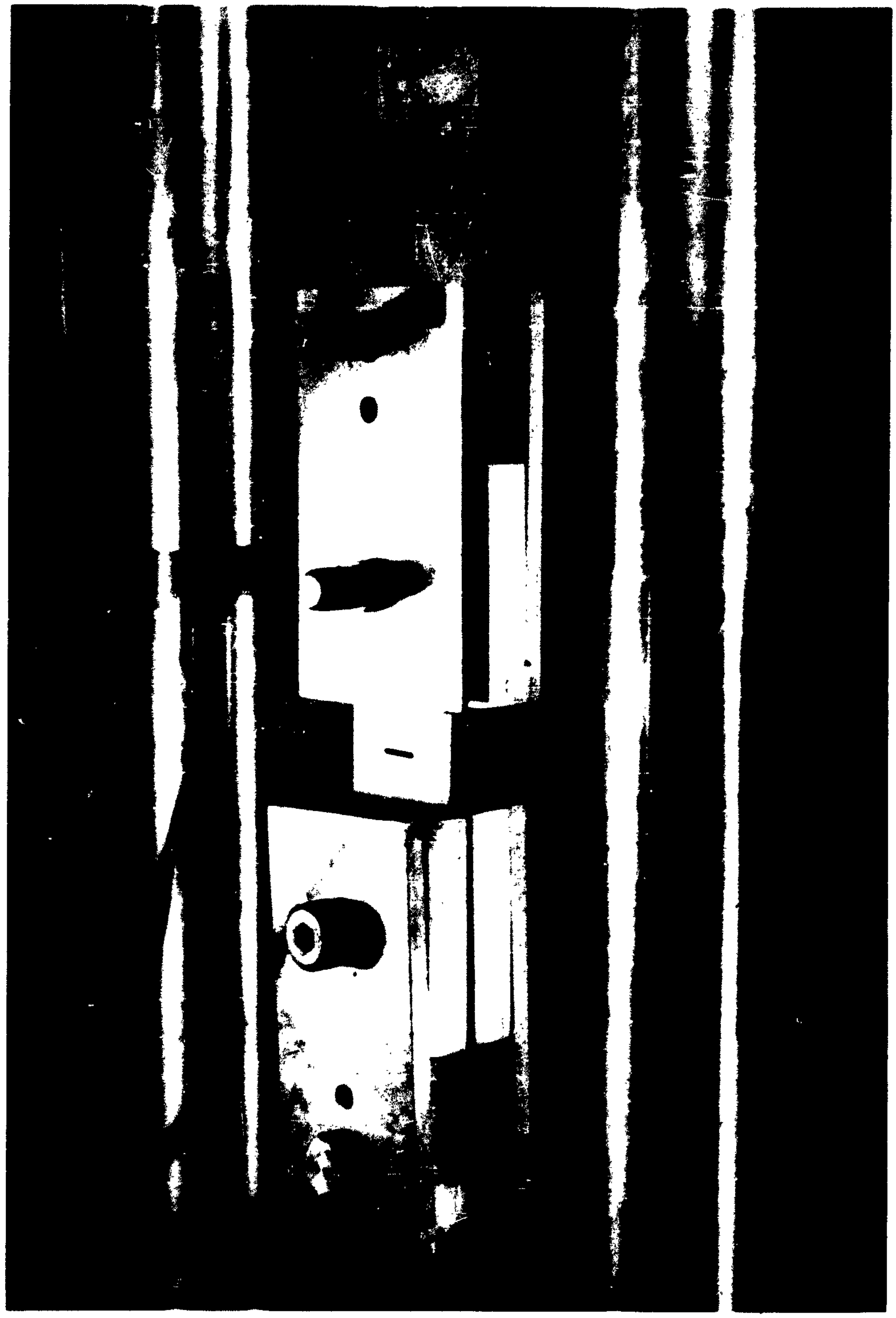

DO NOT SCALE DRAWINGS
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
B2434-0035
PLANE 'X'
SPECIMEN
SEC. A-A
SEC. B-B
DETAIL ITEM 3
CORNER ITEM 1 FREE OF RADIUS FOR POSITIVE SETTING OF SPECIMEN. .06X.06 MAX. UNDERCUT PERMISSABLE.
PLANE 'Y' PARALLEL TO PLANE 'X' WITHIN .001
BRAZE
TWO PLACES
METAL STAMP THIS PLANE: "ALIGN END OF SPECIMEN WITH THIS PLANE BEFORE DRILLING."
TWO HOLES LOCATED WITHIN .0005 RADIUS OF TRUE POSITION, AND PERPENDICULAR TO PLANE 'Y' WITHIN .001 ITEM 2 : REAM 1 HOLE FOR PRESS FIT FOR ITEM 8. ITEM 1 : DRILL CLEARANCE HOLE.
ITEM 2 : TWO PLACES UNC 5/16-18, 5/16 DEPTH FULL THREAD.
FOR REAMING
FOR DRILLING
LINE REAM 3/8 HOLE FOR PRESS FIT WITH ITEMS 7.
LINE REAM ITEMS 7 FOR SLIP FIT NO SHAKE WITH ITEM 13.
ITEM 4 17/64 DRILL THRU. ITEM 1, UNC 1/4-20, .68 DEPTH FULL THREAD. TWO PLACES.
THIS VIEW ALL DETAILS NOT SHOWN
NOTES:
1. BREAK ALL SHARP CORNERS
ITEMS 7, 8, 9, 10 MUST BE PERFECTLY FLUSH WITH BASE PLANE OF ITEM 2 FOR POSITIVE BEARING WITH SPECIMEN.
2 SASH CHAIN NO. 8 OR EQUIV. 12" LONG STEEL 15
2 TEE 1/2 DIA x 2 1/2" LONG 14
2 LOCATING PIN 1/2 DIA. x 5" LONG 13
2 SOCKET HEAD CAP SCREW 1/4-20 x 1" LONG 12
2 LOCK SCREW NO. 2 11
2 SLIP RENEWABLE BUSHING S-4C 10
2 SLIP RENEWABLE BUSHING S-4C 9
2 HEADLESS LINER BUSHING GA-24 8
4 HEADLESS LINER BUSHING GD-52 7
2 THUMB SCREW TS-375 6
1 CAM CLAMP ASSY. CA-500-C 5
1 RETAINER 4
2 SLIDE BLOCK 1 x 1 x 1 3
1 TOP PLATE 2
1 BASE 1
THE BUDD COMPANY
PHILADELPHIA 32, PA.
DRILL AND REAM FIXTURE TYPE B
B2434-0035

FIGURE 2



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.

FIG. 4

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: Load (100 lbs.)	Cycles (1800Cpm)	Crack length (in.) Side 1	Crack length (in.) Side 2	Measurement of Crack length After fracture (in.) Side 1	(in.) Side 2
JLS 300, CRT	FNBL - 1	0 to 23	2500	.03	.03	.025	.03
340,000 psi	FNBL - 2X	0 to 23	6100	.06	.06	.04	.06
Yield Str.							
Ti, 6Al, 6V,	LABL - 2	0 to 26.4	12000	.085	.090	.080	.080
2Sn.Annealed	LABT - 2	0 to 26.4	12000	.075	.080	.080	.080
Ti, 13V, 11Cr, 3Al	DC1	0 to 200	5850	.030	.040	.040	.060
Sol.Ann. + Aged							
72Hrs.	AM1	0 to 20	7100	.020	.030	.040	.040
	FC2	0 to 20	11300	.030	.030	.040	.040

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

TABLE 1

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 Type Direction No.in Group

Materials	Code Letter
AM - 357	A
AM - 359	B
25% Ni	C
20% Ni	D
Ti-13V-11Cr-3Al	E
JLS - 300	F
25% Ni (Mod.)	G
20% Ni (Mod.)	H
Armco 12-8-6	K
Ti-6Al-6V-2Sn	L
Ti-8Al-10V	M
Ausrolled steel A-1	N
Ausrolled steel A-3	O
Ausrolled steel B-2	P

Conditions	Code Letter
Annealed	A
SCCRT	B
CRT	C
SCT	E
Ti, Single Age, 48 Hrs.	F
Ti, Single Age, 72 Hrs.	G
Cold Rolled & Aged, 200,000 psi	J
Cold Rolled & Aged, 230,000 psi	K
25% and 20% Ni, Stand. Heat Treat	L
Cold Rolled and Aged	N
PH 12-8-6, Stand. Heat Treat	P
20% Ni, Isothermal Heat Treat	R
25% Ni, Double Sub-Zero Cool	S
Cold Rolled 25%	T
Quenched + Tempered	U
Quenched, Subzero Cooled + Temper.	W

Specimen Type	Code Letter
Sheet Tensile	A
Fracture Energy, Center Notched	B
Sheet Tensile, "As Welded"	C
Sheet Tensile, Weld Dep. Removed	D
Tensile Shear, Resist Weld	E
Fracture Energy, Center Notched	F
Bend Specimen, Base Metal	G
Bend Specimen, Welded, Weld Dept. Removed	H
Stress Corrosion, Resist Weld	K
Dimensional Change Specimen	L
Arc Welding Plates	M
Photomicrographic Mounts	N
Photomacrographic Mounts	O
Tensile Spec. Cleaning	P
Sheet Tensile, >58 RC	R
Tensile, Resist Weld, Criss-Cross	S
Electron Beam, 90° Butt Weld Tensile	T

DIRECTION

Indicated as L (longitudinal) 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 X 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_2	H_2	O_2
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 TIG Welding	0.01	0.19	13.0	10.3	2.9	0.02	0.0065	0.13
Analysis Range	0.05 Max.	-	12.5 14.5	10.0 12.0	2.5 3.5	0.08 Max.	0.02 Max.	0.20 Max.

TABLE 3

Modulus of Elasticity (room temp.)

Solution Annealed - 14.7 X 10^6 psi.

Aged - 16.0 X 10^6 psi.

Thermal Conductivity

4.0 BTU/hr./ft^2/°F/ft. - @ 70°F

8.2 BTU/hr./ft^2/°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 ± 10°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.

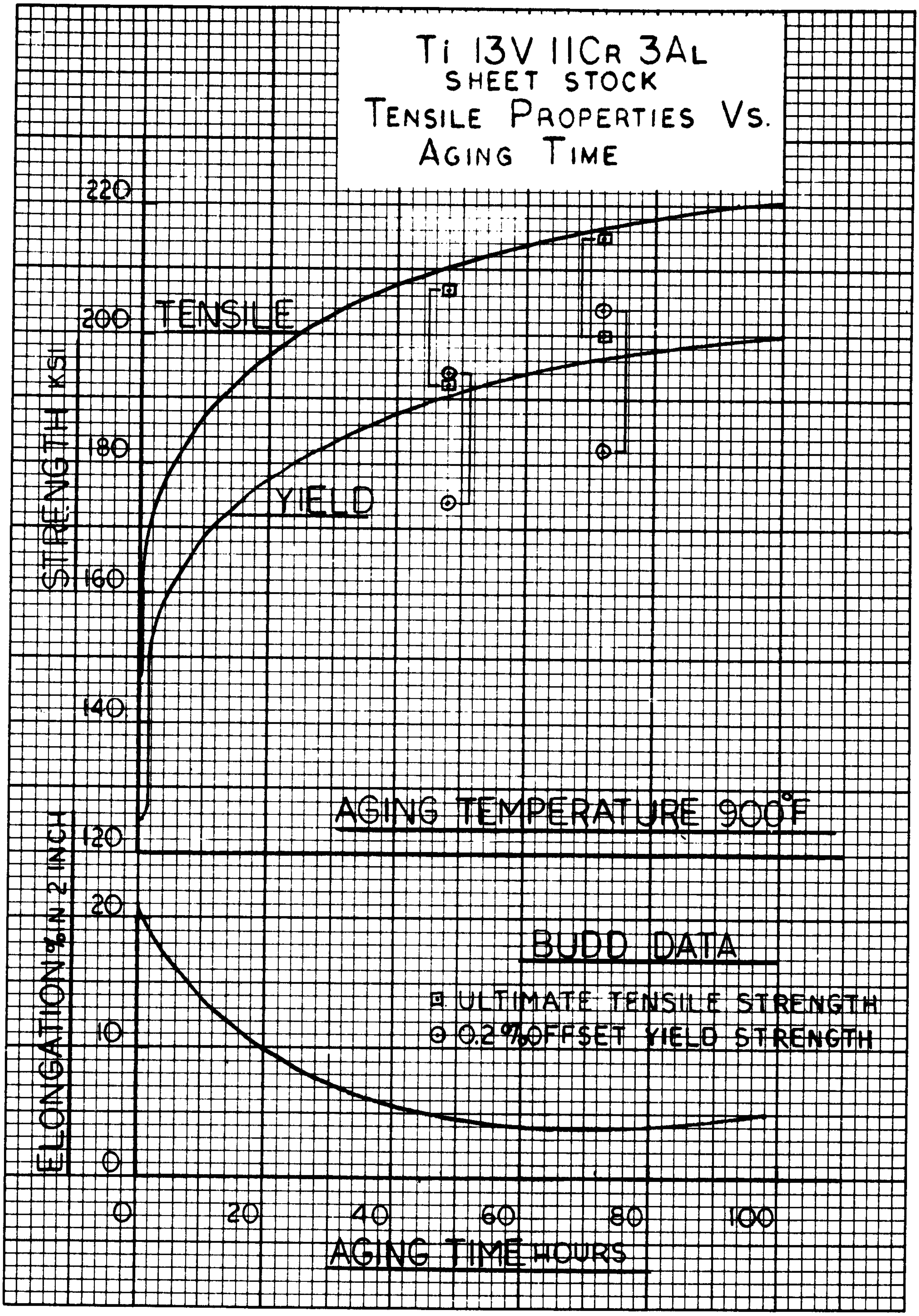

Ti 13V 11Cr 3Al
SHEET STOCK
TENSILE PROPERTIES Vs.
AGING TIME
220
200
180
160
140
120
20
10
0
TENSILE
YIELD
STRENGTH KSI
ELONGATION % IN 2 INCH
AGING TEMPERATURE 900°F
BUDD DATA
ULTIMATE TENSILE STRENGTH
0.2% OFFSET YIELD STRENGTH
0
20
40
60
80
100
AGING TIME HOURS

FIG. 6

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

MILL ANNEALED

GAGE AND HEAT NOS. AS NOTED

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

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 — 0.030"-0.032" GAGE — HEAT NOS. AS NOTED

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

TABLE 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 .2% Offset KSI	Ult. Tensile Strength KSI	% Elong. in 2 Inches	Rockwell 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

TABLE 6

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 .2% Offset KSI	Ult.Tensile Strength KSI	% Elong. in 2 Inches	Rockwell 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 accicular 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 accicular 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_3 + H_2O

FIGURE 7

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_3 + H_2O

FIGURE 8

Longitudinal 250X Mag.

Specimen ETNL - 1

Transverse 250X Mag.

Specimen ETNT - 1

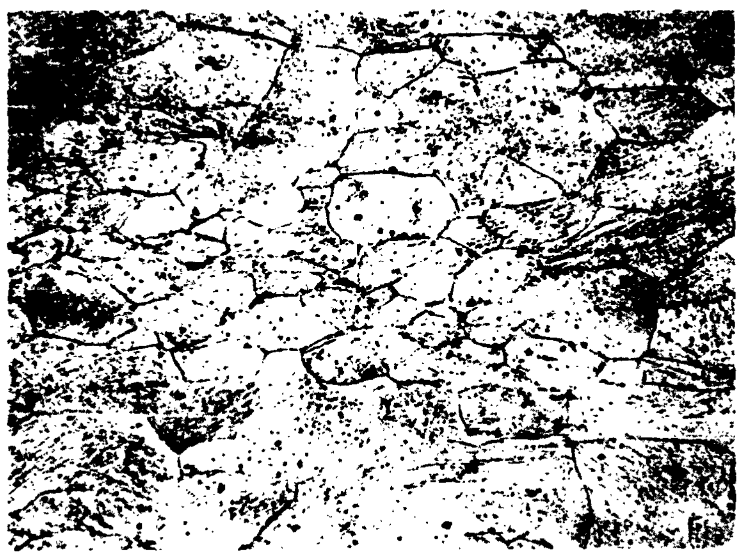
Ti 13V-11Cr-3Al
Ht. No. M-9571
Etchant: 2% HF + 40% HNO_3 + H_2O

0.030" Gage
Cold Rolled 25%

FIGURE 9

Longitudinal 250X Mag.

Specimen ENNL - 6



Transverse 250X Mag.

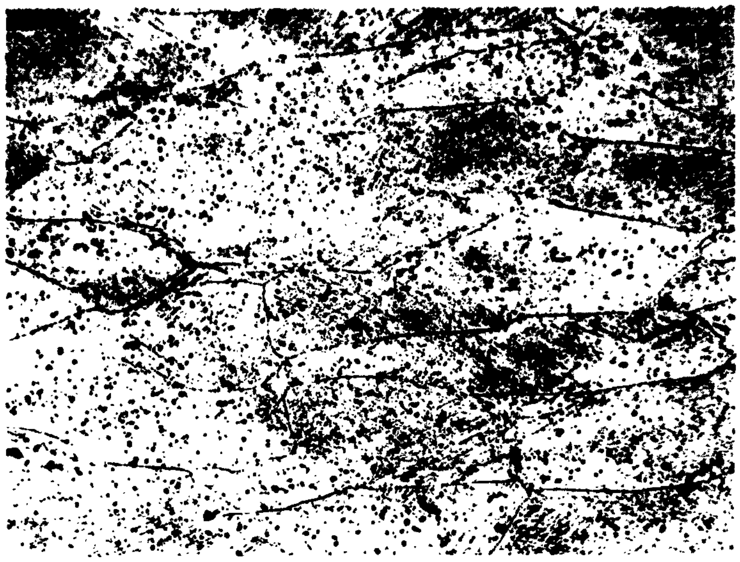
Specimen ENNT - 6

Ti 13V-11Cr-3Al 0.034" Gage

Ht.No. D260 Cold Rolled + Aged 900°F, 16Hrs.

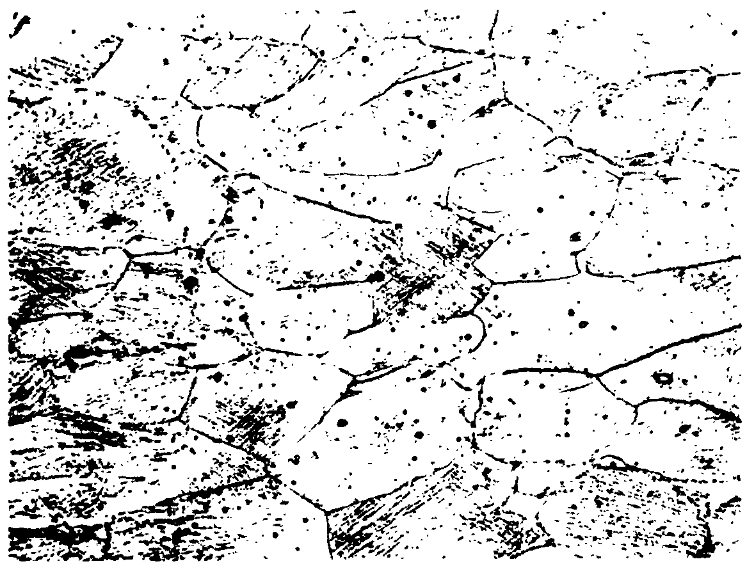
Etchant: 2% HF + 40% HNO_3 + H_2O

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_3 + H_2O

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_{Cl} 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. and Gage	Spec. No.	Direct.	Yield Strength KSI $\sigma_{Y.S.}$	Ult. Strength KSI $\sigma_{Ult.}$	%El. in 2 Inches	K_{C1} PSI $\sqrt{\text{inch}}$	$\frac{\sigma_{Y.S.}}{d}$ X10^6	$\frac{K_{C1}^2}{\pi \sigma_{Y.S.}^2}$
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. and Gage	Spec. No.	Direct.	Yield Strength KSI $\sigma_{Y.S.}$	Ult. Strength KSI $\sigma_{Ult.}$	%El. in 2 Inches	K_{C1} PSI $\sqrt{inch}$	$\frac{\sigma_{Y.S.}}{d} \times 10^6$	$\frac{K_{C1}^2}{\pi \sigma_{Y.S.}^2}$
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. and Gage	Spec. No.	Direct.	Yield Strength KSI $\sigma_{Y.S.}$	Ult. Strength KSI $\sigma_{Ult.}$	%El. in 2 Inches	K_{C1} PSI $\sqrt{Inch}$	$\frac{\sigma_{Y.S.}}{d}$ X10^6	$\frac{K_{C1}^2}{\pi \sigma_{Y.S.}^2}$
Aged 16Hrs. Ht.No.D260 .028"	ENBL-3	L	199	215	9	72,000	1.14	.041
Aged 48Hrs. Ht.No.9571 Sht.1 .029"	ENBL-1	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 Spec.No.	Annealed Min."T"Ratio	Aged 72 Hrs.900°F Spec.No.	Aged 72 Hrs.900°F 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 Sht.12	.061	L	-	-	EGGL-5	>8.3T
		T	EAGT-5	2.0T	EGGT-5	>8.3T
M-9584 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 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 Ti 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 900°F, 16 Hrs.		Cold Rolled 25% Aged @ 900°F, 48 Hrs.	
			Spec.No.	Min."T"Ratio	Spec.No.	Min."T"Ratio	Spec.No.	Min."T"Ratio
M-9571	.030	L	ETGL-1	>3T	-	-	-	-
Sht.1		T	ETGT-1	>3.5T	-	-	-	-
D260	.032	L	-	-	ENGL-3	>7T	-	-
Sht.2		T	-	-	ENGT-3	>11T	-	-
M-9571	.030	L	-	-	-	-	ENGL-2	17T
Sht.1		T	-	-	-	-	ENGT-2	>17T

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

TABLE 12

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 Dekatron Pulse Counting	0.060" Ti-13V-11Cr-3Al (Code E)
Electrodes	**Material Condition**
5/8" Dia. RWMA, Group A, Class 3, 2 1/2" Rad.	Solution Anneal and Pickled

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

Fig. 12

MECHANICAL PROPERTIES

Ti 13V-11Cr-3Al — RESISTANCE SPOT WELDED SPECIMENS

0.060" GAGE — HT. NO. AS NOTED

Condition	Tensile (Type S Specimen) Spec. No.	Load lbs.	Type Failure	Tensile-Shear (Type E Specimen) Spec. No.	Load, lbs.	Type Failure	$\frac{T}{TS}$ Ratio
Solution Annealed Ht.No.9853 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 Aged@900°F, 8Hrs. 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	2035	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.

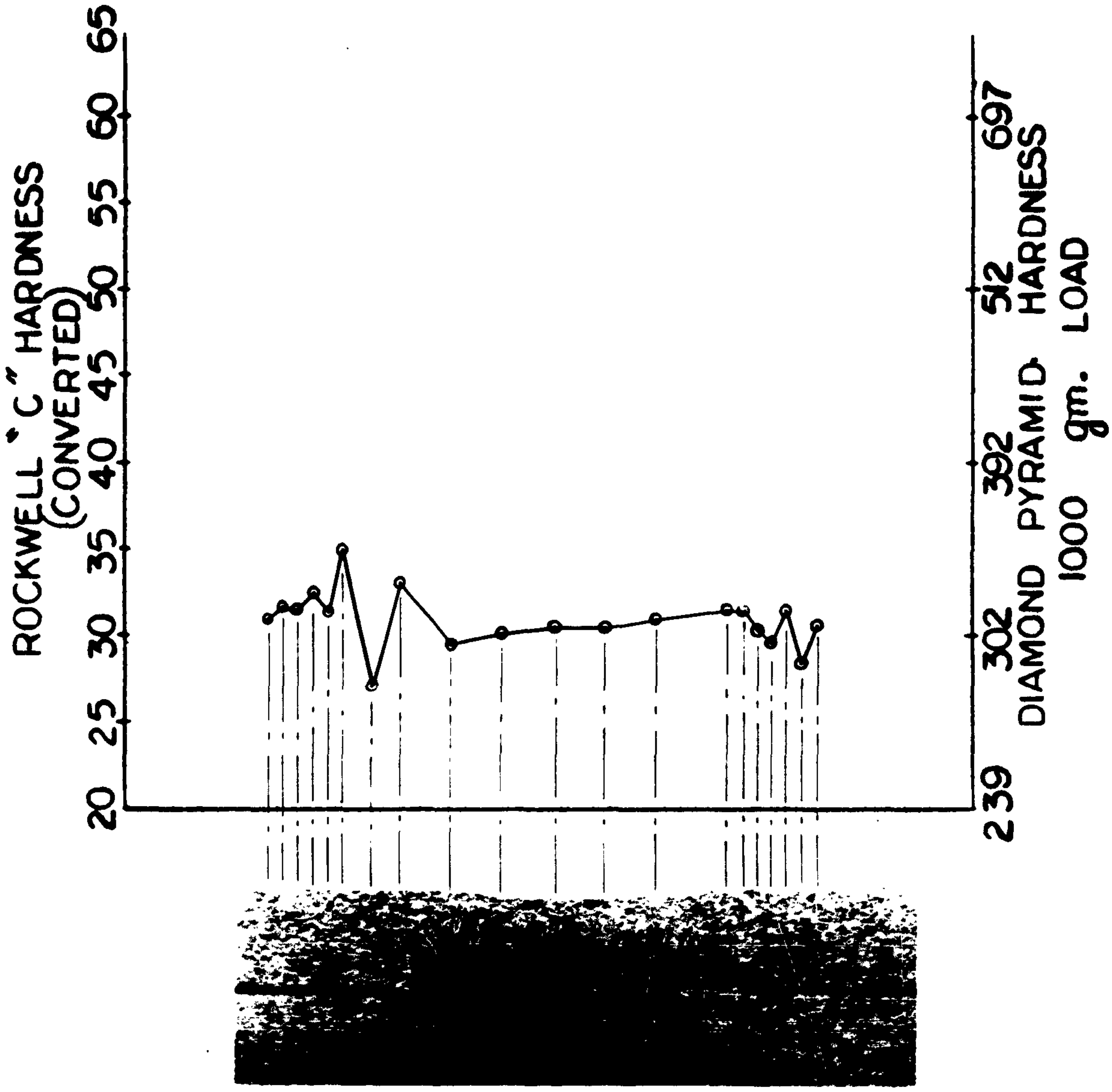
The photomicrographs of the heat affected zone and weld nugget of the resistance spot weld structure are shown as a composite in Figure 14. Specimen EAN-1 shows mostly weld nugget. The heat affected zone is shown by Specimen EAN-2. The large grain, equiaxed in the HAZ and columnar in the nugget is typical. 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. EA9-1 WELD TYPE Resistance Spot MAG. 10X

ETCHANT 2% HF + 10% HNO_3 + H_2O

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

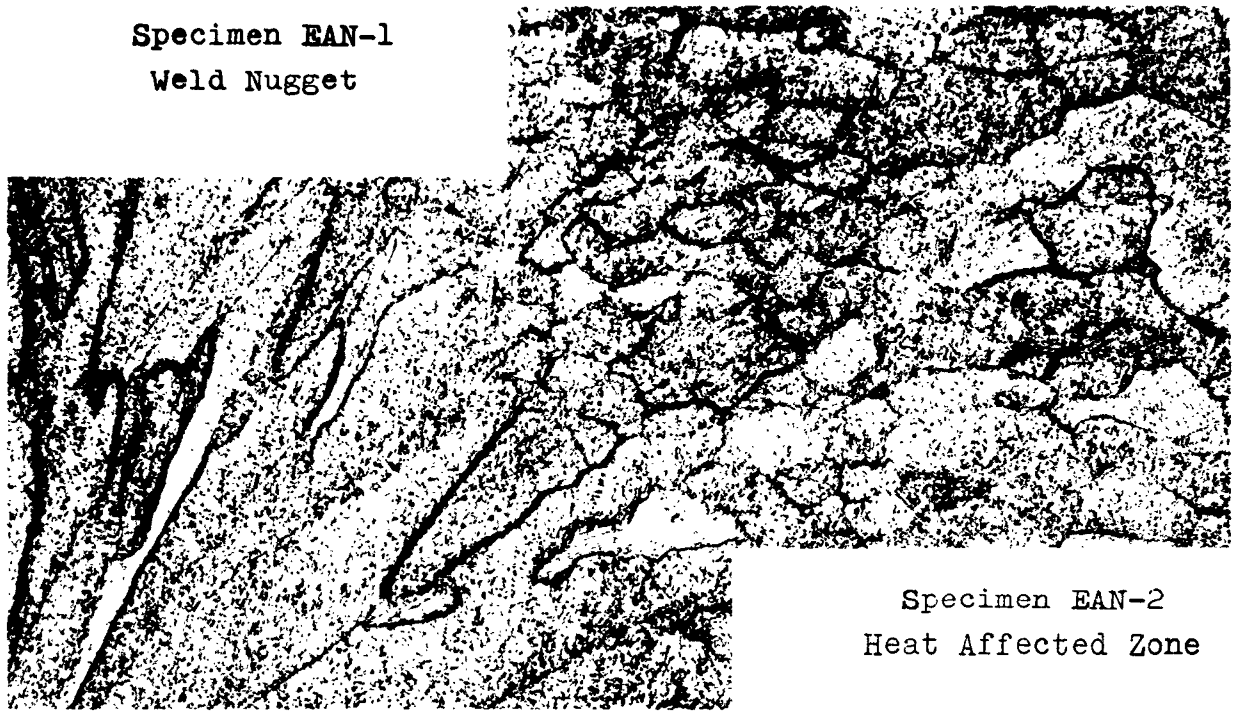
CONDITION Solution Annealed.

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_3

Figure 14

MATERIALS RESEARCH LABORATORY

Resistance Welding Data Sheet

Date May 11, 1961

Project 5017

Welding Machine	Material and Gage
150 KVA Single Phase AC with Dekatron Timing Control	0.060" Ti-13V-11Cr-3Al (Code E)
Electrodes	**Material Condition**
5/8" Dia. RWMA, Group A, Class 3; 2 1/2" Rad.	Cold Worked & Aged to 200 Kpsi Y.S. 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	2 Series 2	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.

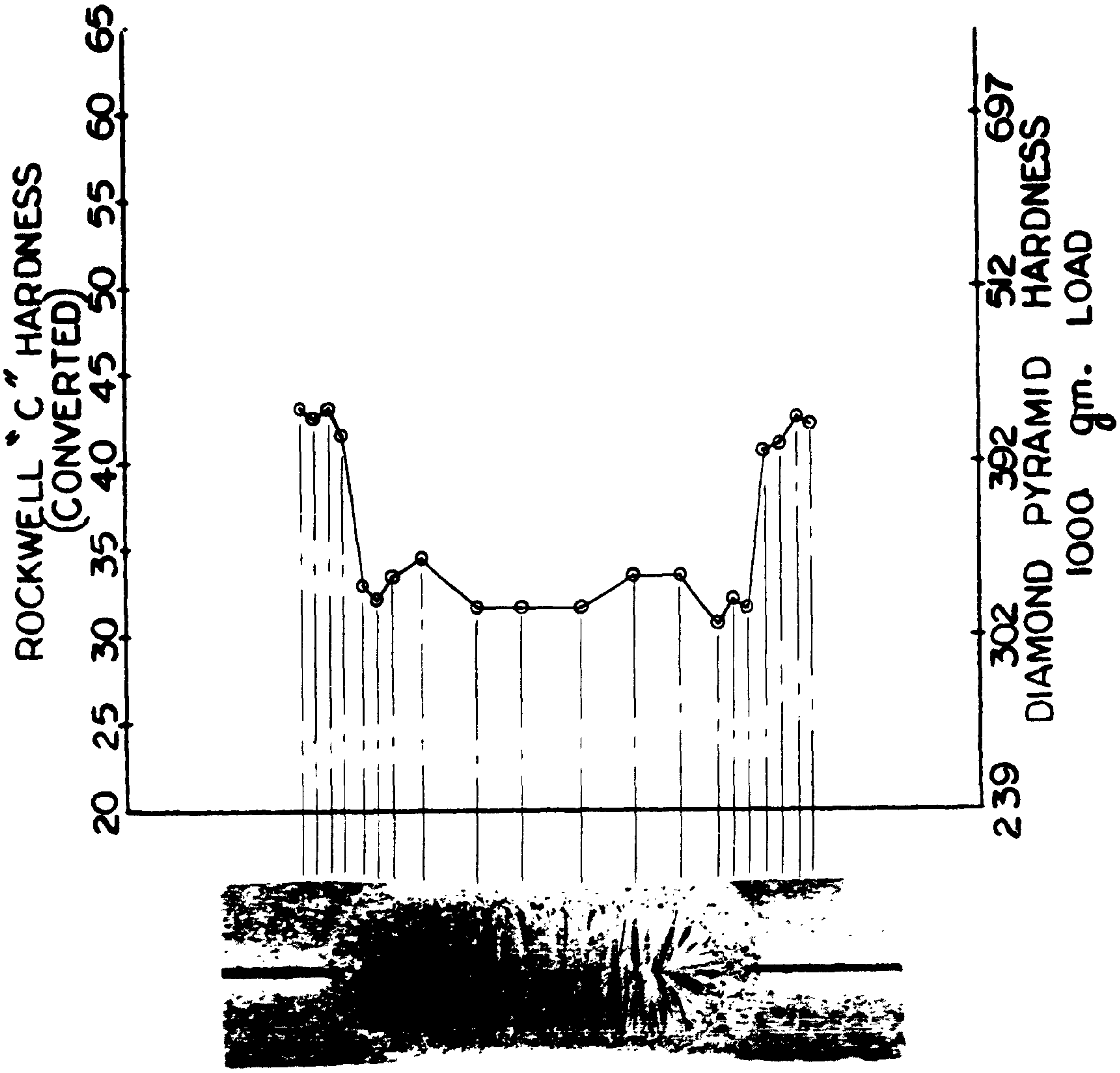
The electrode indentation is typical of titanium base alloys. The sheet separation is more pronounced than with other materials, being approximately 8% of the sheet thickness.

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

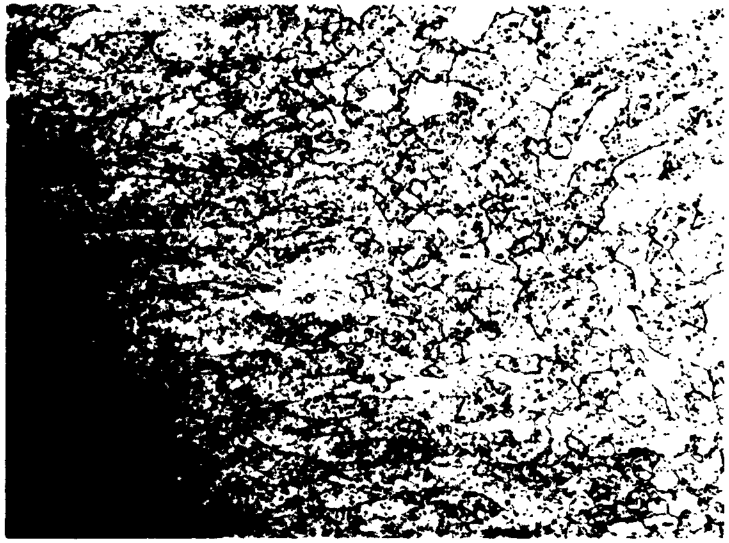
WELD CROSS SECTION
KENTRON MICRO HARDNESS TESTER
DIAMOND PYRAMID PENETRATOR



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

MATERIAL Ti 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   Resistance Spot Weld

100X Mag.   Etchant: 2% HF + 10% HNO_3

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.

<u>TIG Welding, Ti 13V-11Cr-3Al Alloy Sheet</u>

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 and Heat Number	Spec. No.	Type of Solution	Specific Gravity Start	Specific Gravity Finish	Total Hours	Results
Solution Annealed	EAK-1	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
Ht.No.M-9853	EAK-2	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
	EAK-3	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
	EAK-4	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
Cold Rolled and	ENK-1	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
Aged@900°F,8Hrs.	ENK-2	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
Ht.No.D575	ENK-3	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
	ENK-4	5% M_gCl_2*	1.020@83°F	1.023@73°F	116	OK
Solution Annealed	EAK-5	20% M_gCl_2*	1.075@89°F	1.078@90°F	126	OK
Ht.No.M-9853	EAK-6	20% M_gCl_2*	1.075@89°F	1.078@90°F	126	OK
	EAK-7	20% M_gCl_2*	1.075@89°F	1.078@90°F	126	OK
	EAK-8	20% M_gCl_2*	1.075@89°F	1.078@90°F	126	OK
Cold Rolled and	ENK-5	20% M_gCl_2*	1.075@89°F	1.078@90°F	126	Cracked 74 Hrs.
Aged@900°F,8Hrs.	ENK-6	20% M_gCl_2*	1.075@89°F	1.078@90°F	126	Cracked 126 Hrs.
Ht.No.D575	ENK-7	20% M_gCl_2*	1.075@89°F	1.078@90°F	126	Cracked 103 Hrs.
	ENK-8	20% M_gCl_2*	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

STRESS-CORROSION DATA OF Ti 13V-11Cr-3Al

0.060"-0.064" GAGE — RESISTANCE SPOT WELDED SPECIMENS, TYPE K

EDGES OF SPECIMENS NOT SEALED

Condition and Heat Number	Spec. No.	Type of Solution	Specific Gravity Start	Specific Gravity Finish	Total Hours	Results
Cold Rolled and	ENK-9	20% M_gCl_2*	1.076@89°F	1.082@89°F	78½	OK
Aged@900°F, 8Hrs.	ENK-10	20% M_gCl_2*	1.076@89°F	1.082@89°F	78½	OK
Ht.No. D575	ENK-11	20% M_gCl_2*	1.076@89°F	1.082@89°F	78½	OK
	ENK-12	20% M_gCl_2*	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.

TABLE 15

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

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

Item	Description
Electrode	
Type	2% thoriated tungsten
Size	3/32", tapered point
Stickout	3/8".
Torch	
Type	AIRCO Mod. C.
Attack angle	90°.
Lead angle	Zero
Root Shield	
Type	Copper, Budd Co. dwg. E2434-0121, (see prog. report #10).
Groove size	0.040" deep by 3/16" wide.
Gas ports	1/16" dia. spaced 3/4" apart.
Chill Bars	Copper, 3/4" X3-1/4" with 45° bevel to a 1/8" land.
Nozzle	Metal, 5/8" diameter.
ARC Voltage	12 volts at electrode tip.
DSCP Amperage	180 to 190 amperes.
Shielding Gas	
Nozzle	Argon, 30 cubic feet per hour.
Root	Argon, 3 cubic feet per hour
Follower	Follower shield was not used
Filler Wire	
Type	0.030" diameter, annealed beta titanium
Feed	18 inches per minute.
Welding Speed	7-1/2" per minute.
Preheat-Postheat	None
Power Source	Vicker's 300 amp. rectified.
Start. Mech.	AIRCO HF-1.

TABLE 17

Radiographic Examination of Weldments

Weldments were radiographed using a 200 KV Mitchell source, a 0.005" thick stainless steel penetrameter, 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. No.(1)	Stress Area T x W, Inches(2)	Yield Strength 0.2% Offset KSI	Ult.Tensile Strength KSI	%Elong. 2"	%Elong. ½"	Fracture Location (7)
(3) 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) Ht.No.9853	EADT-1	.067 X .503	134	136	21	42	BM
	EADT-2	.065 X .505	134	137	21	42	HAZ
	EADT-3	.065 X .505	134	138	21	42	HAZ
	EADT-4	.064 X .506	135	138	18	36	HAZ
(5) Ht.No.D575	EJCT-1	.060 X .484	163	168	2.5	10	HAZ
	EJCT-2	.061 X .482	160	162	3	12	HAZ
	EJCT-3	.062 X .483	160	163	2	8	HAZ
	EJCT-4	.062 X .504	161	165	3	12	HAZ
(6) Ht.No.D575	EJDT-1	.074 X .484	134	134	3.5	14	WD
	EJDT-2	.072 X .503	130	130	3	12	WD
	EJDT-3	.075 X .483	124	124	4	16	WD
	EJDT-4	.073 X .484	143	144	3.5	14	WD

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

TABLE 18

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"

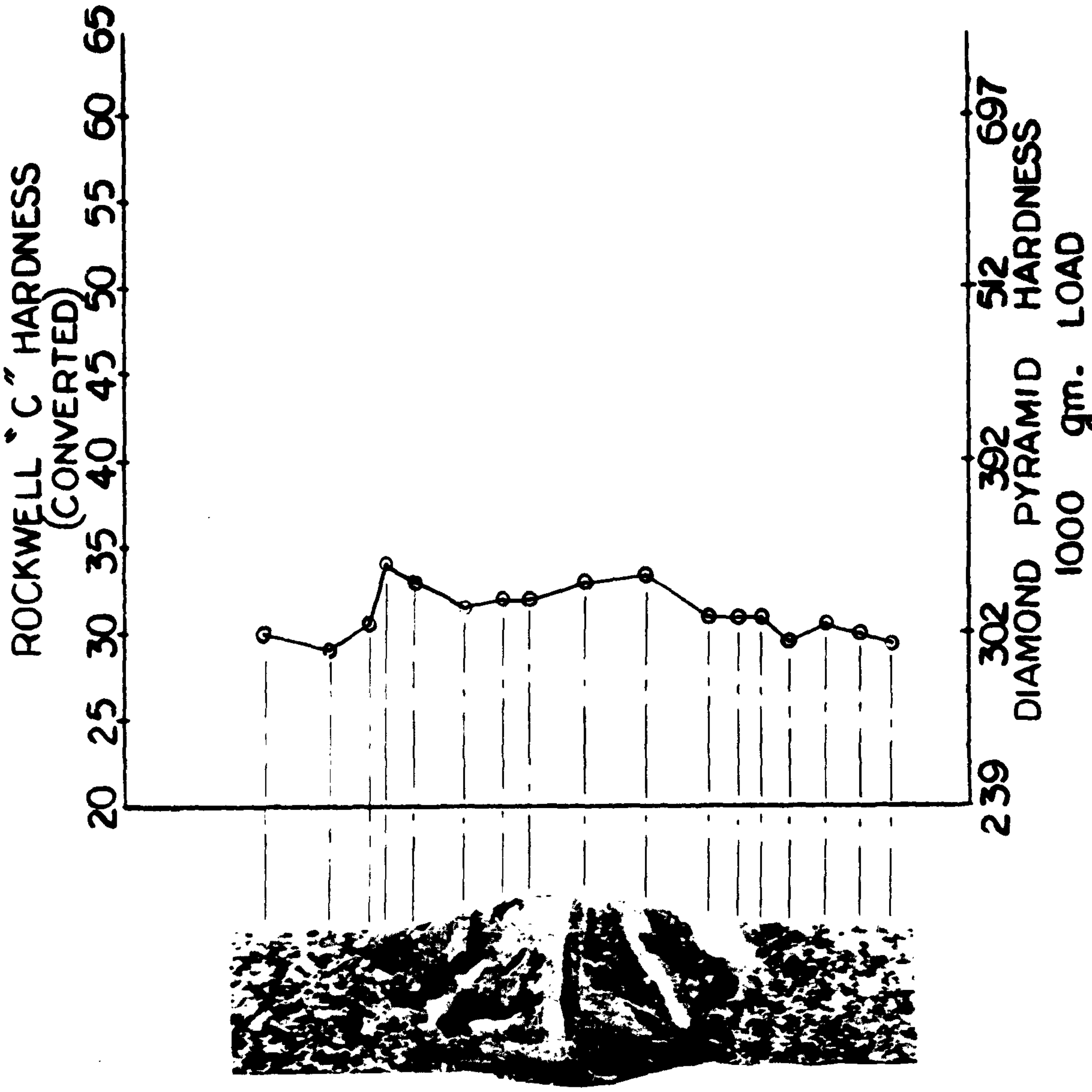
Weld thickness - 0.085" to 0.091"

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



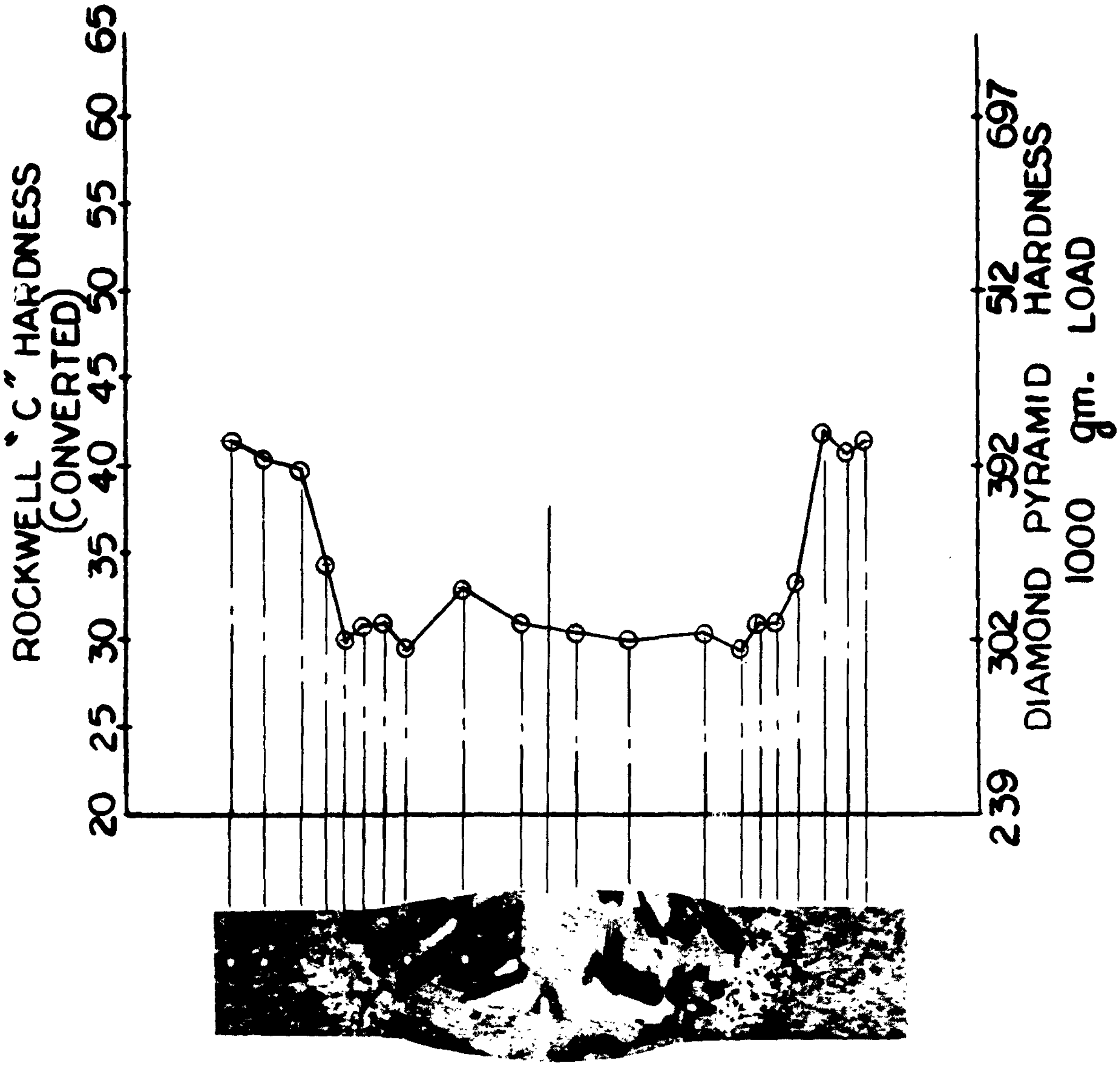
SPEC. NO. EA0-2 WELD TYPE ARC (TIG) MAG. 12X
ETCHANT 2% HF + 10% HNO_3 + H_2O

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

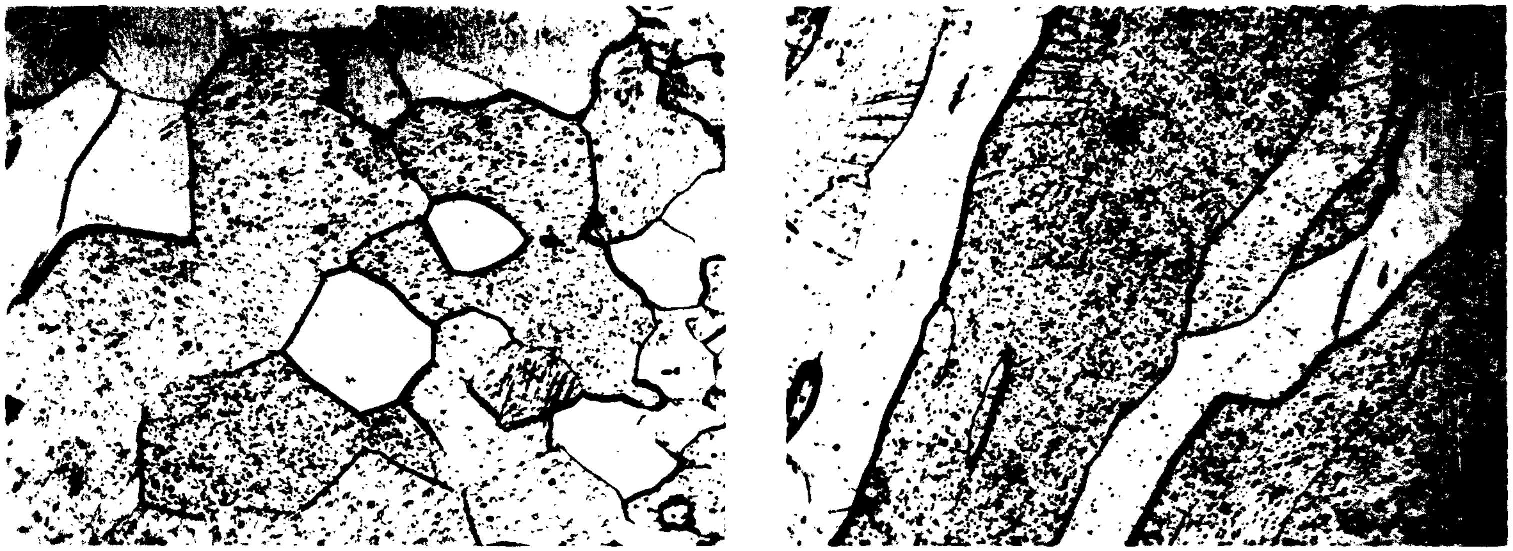
WELD CROSS SECTION
KENTRON MICRO HARDNESS TESTER
DIAMOND PYRAMID PENETRATOR



SPEC. NO. EJO-2 WELD TYPE TIG MAG. 12X
ETCHANT 2% HF + 10% HNO_3 + H_2O

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_3. 100X

FIG. 20

Base Metal HAZ Weld Metal

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_3. 100X

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 X 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 0.2% KSI	Ult.Tensile Strength KSI	Elong. % 2"
Annealed 1860° F 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
	BAAT - 1	T	49	139	38
	BAAT - 2	T	49	142	47
	BAAT - 3	T	48.5	132	28
	BAAT - 4	T	50	148	47
Annealed 1860°F, Air Cooled 1750°F -10 Min. Air Cool, -100°F-6Hr. Air Warm, 1750°F -10 Min. Air Cool, -100°F-6Hr. Air Warm, 935°F-1½Hrs., Air 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

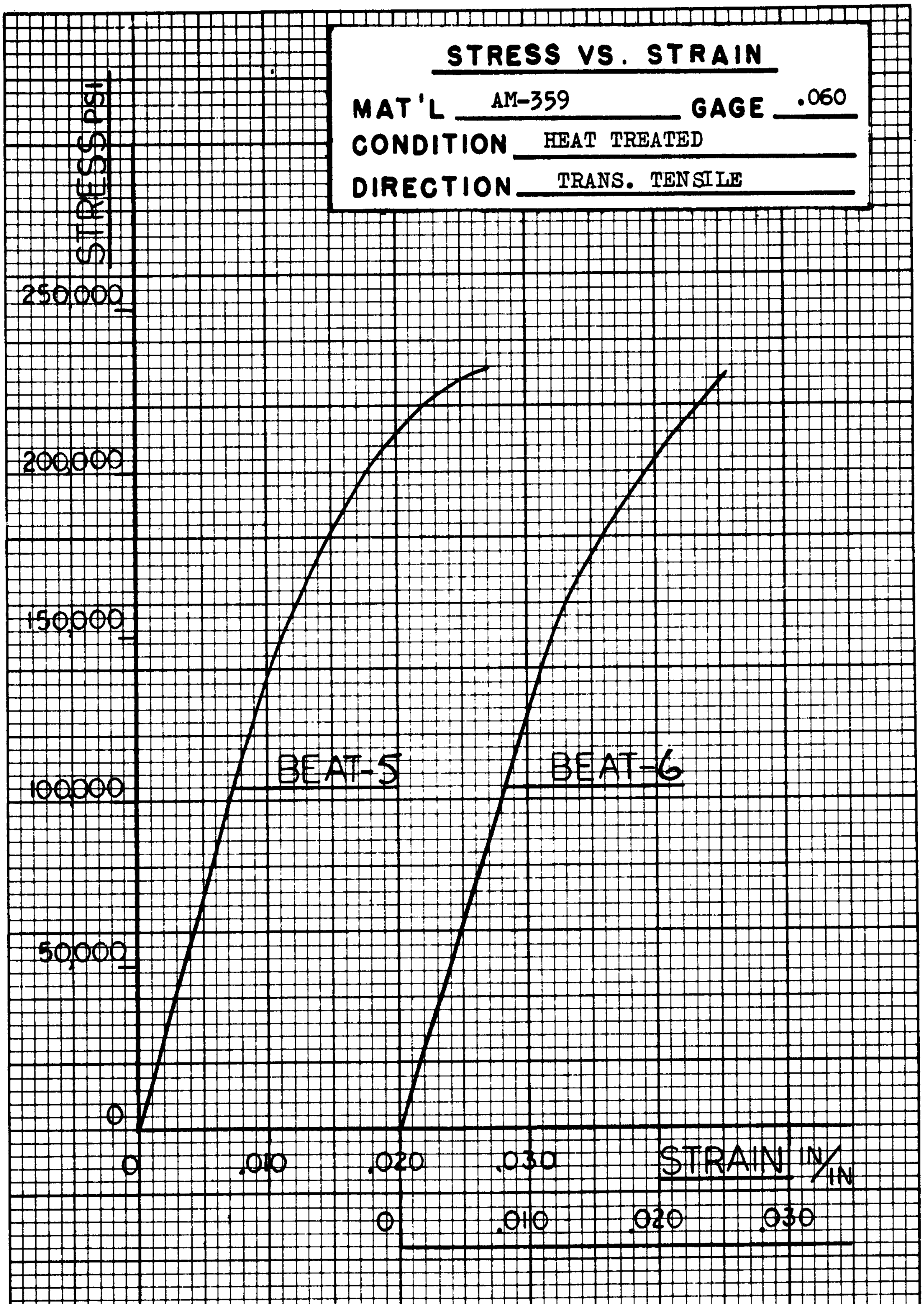
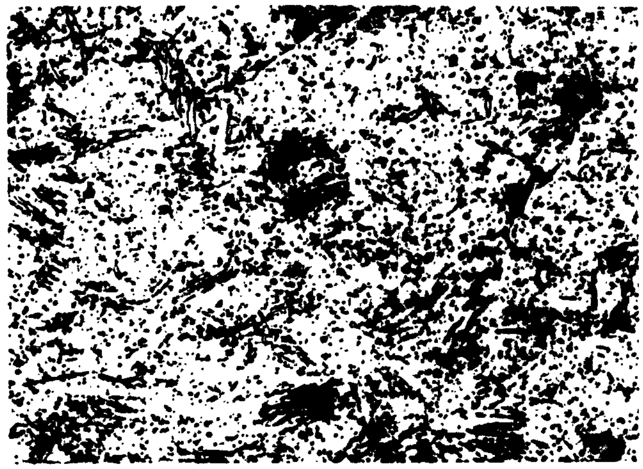
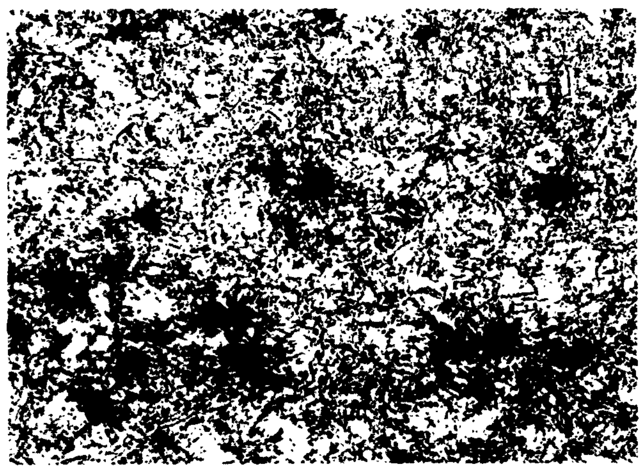

STRESS VS. STRAIN
MAT'L AM-359
GAGE .060
CONDITION HEAT TREATED
DIRECTION TRANS. TENSILE
STRESS PSI
250,000
200,000
150,000
100,000
50,000
0
BEAT-5
BEAT-6
0
.010
.020
.030
0
.010
.020
.030
STRAIN IN/IN

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 X 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 - percipitation 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.

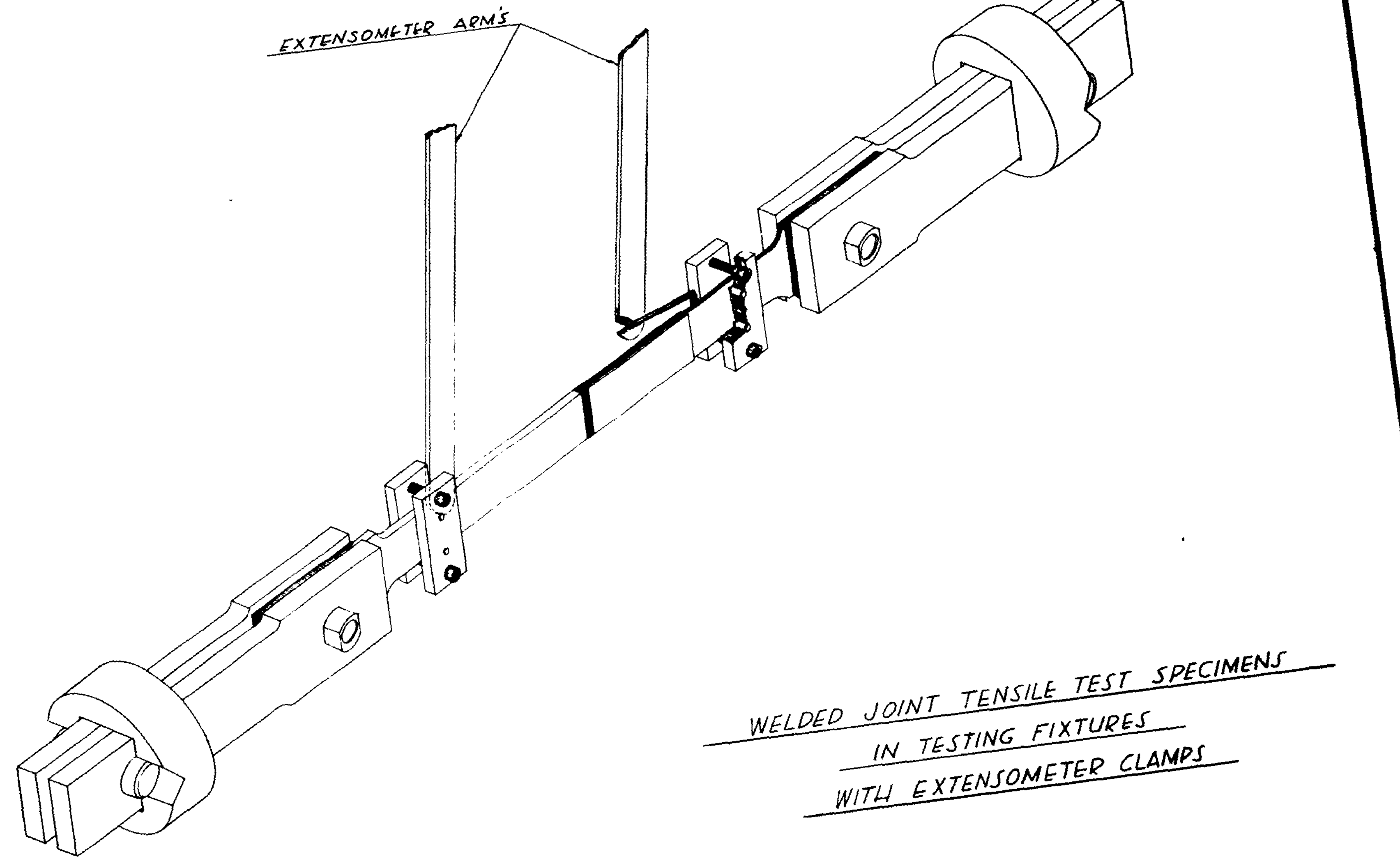
Certifications, tensile tests and chemical analysis were obtained for all the materials, including the welding wire, used in making the specimens. Spot resistance, seam resistance and fusion weld schedules were established prior to assembly operations for maximum weld strength values. This data was included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

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

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

TABLE 21

Specimen No. B480-SK-	Unit Failure Load*	Joint Efficiency**	Maximum strain in/in	Location of Initial Fracture	Location of Joint Failure
-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 Number B48-SK-	Doubler Spot Welds		Seam Welds in Shell Plate Assembly		Calculated Load on Spot Welds at Failure, lbs.	Maximum Strain in/in
	No. Weld	Pile-up Thickness	No. Welds	Pile-up Thickness		
-0007	2	3t	2	3t	11,300	.0256
-0008	2	4t	2	4t	8,250	.0125
-0009	2	4t	1 1	4t 2t	10,000	.0132
-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 1	3t 4t	1 1	4t 2t + 2t	9,500	.0194
-0014	1 1	3t 4t	2	4t	10,300	.0188
-0015	1 1	4t 3t	1 1	4t 2t + 2t	7,500	.0100

*NOTE: Under doubtful assumption load = ÷ between sheets

TABLE 22

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.

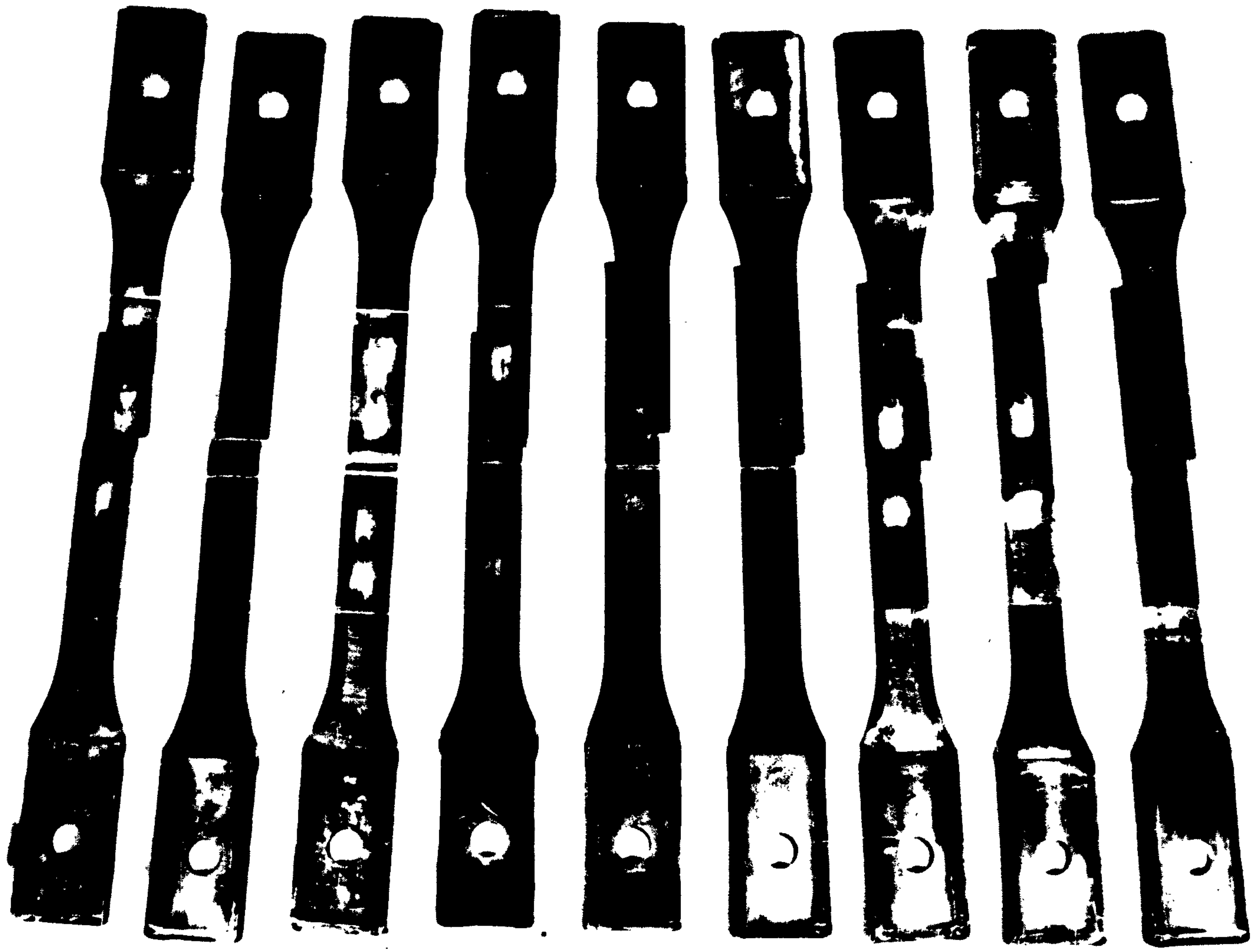
Figure 25 includes photographs of the AM 355-PH 15-7 Mo specimens after fracture. Location of the fracture with respect to weld patterns are illustrated.

<u>Electron Beam Welded Joints - JLS 300 Steel</u>

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.

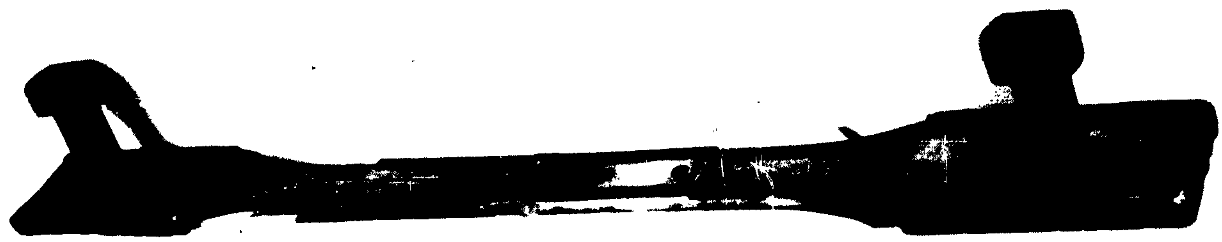
The joint designs are shown in Appendix B, progress report #9, March, 1961, drawings E2434-0116 and E2434-0117. The important characteristics of the joint are



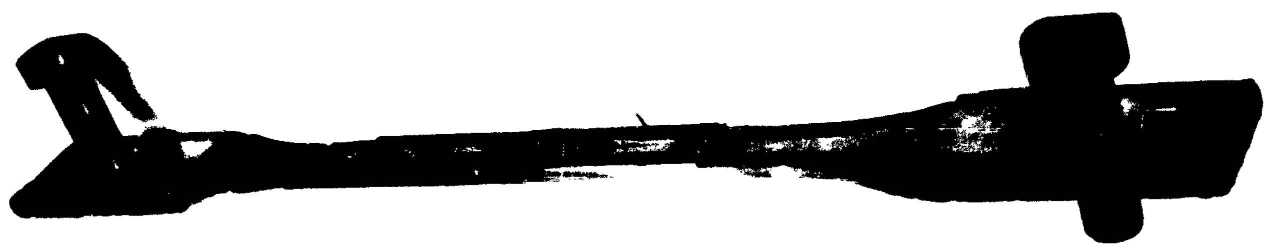
AM-355 SCCRT, PH 15-7 MO WELDED TENSILE TEST SPECIMENS SHOWING FRACTURE LOCATIONS

FIGURE 25

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



SPECIMEN B480-SK-0013
HEAD TO SHELL JOINT

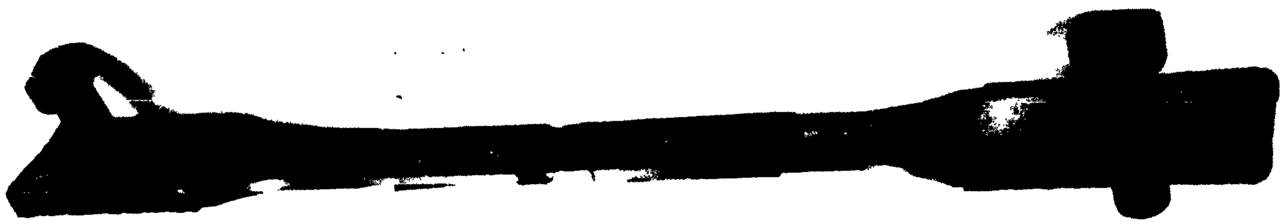


SPECIMEN B480-SK-0014
HEAD TO SHELL JOINT

SPECIMEN B480-SK-0015
HEAD TO SHELL JOINT

FIGURE 25

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



SPECIMEN B480-SK-0010
HEAD TO SHELL JOINT

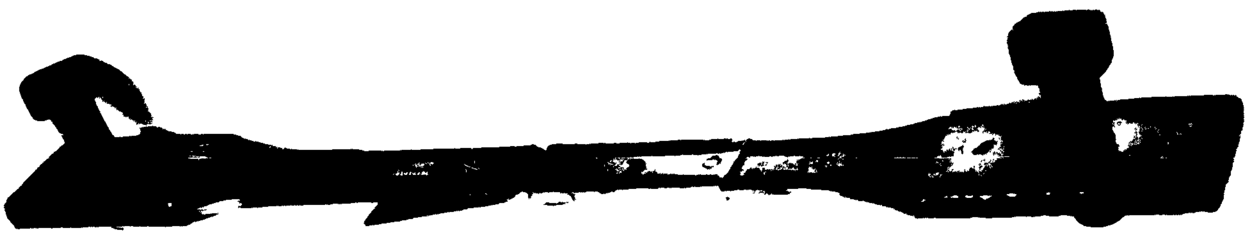
SPECIMEN B480-SK-0011
HEAD TO SHELL JOINT

SPECIMEN B480-SK-0012
HEAD TO SHELL JOINT

FIGURE 25

AM-355 SCCRT, 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 Number	Condition	L or T	0.2% Yield Strength KSI	Ultimate Tensile Strength KSI	Elong. % 2"	Elong. in ½" Across Weld Area
Base Metal	Strip-040" X 6½",	L	340 to 346	344 to 347	1.5 to 2.5	
	CR, Tempered	T	330 to 333	350 to 353		
TIG Welded	Base Metal as Welded	L	92 to 94	208 to 210	2.5 to 3.0	10 to 12%
TIG Welded	Base Metal, Weld Reinforcement 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

Element	Percent by Weight
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

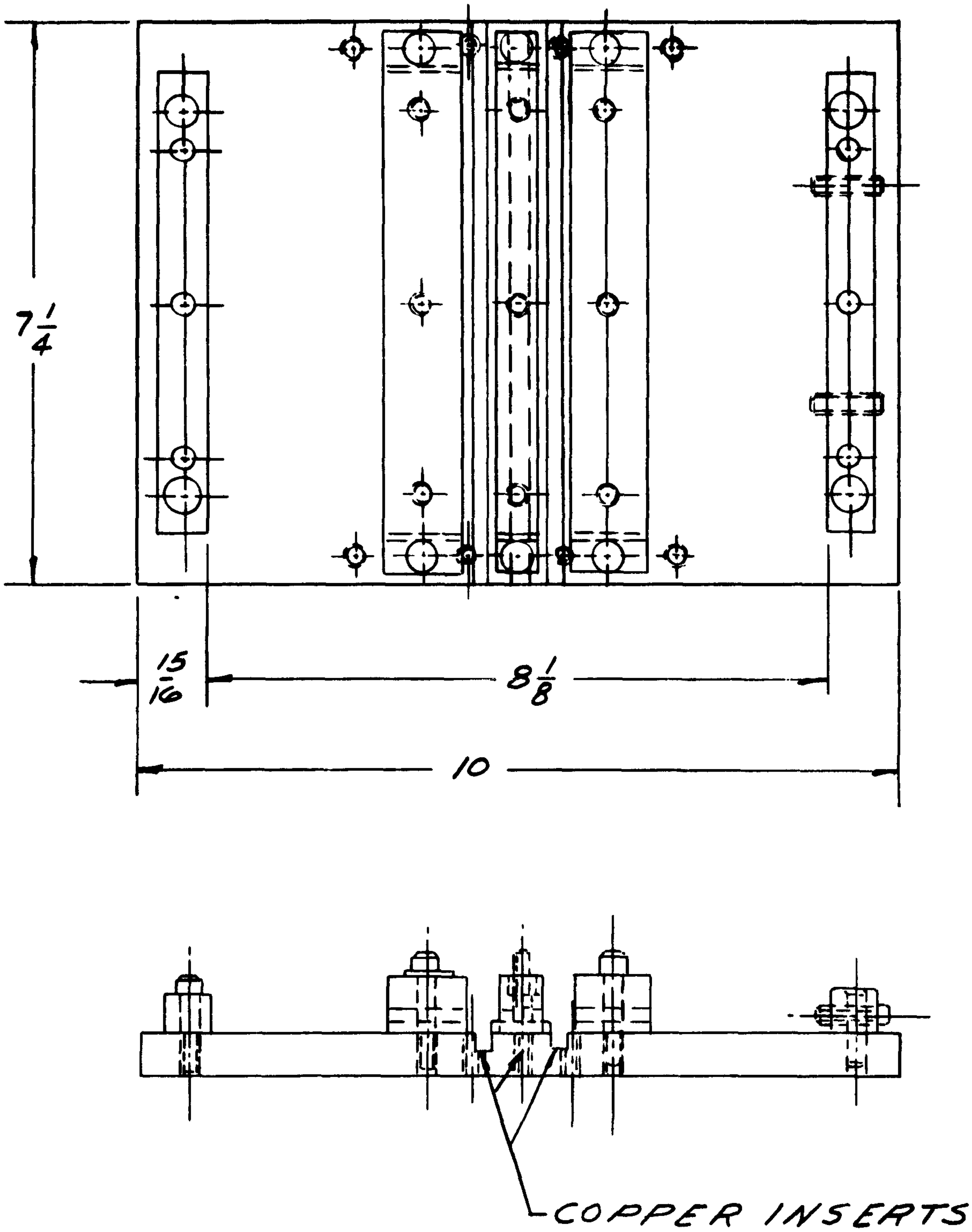
cleanliness, freedom from cracks and a fit up having less than 0.001" gap.

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 (Parallel to Weld)	- .050 (relative #, approx = 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. current
Vacuum	- 10^{-4} mm of Hg.
Number of Passes	- 1

TABLE 25

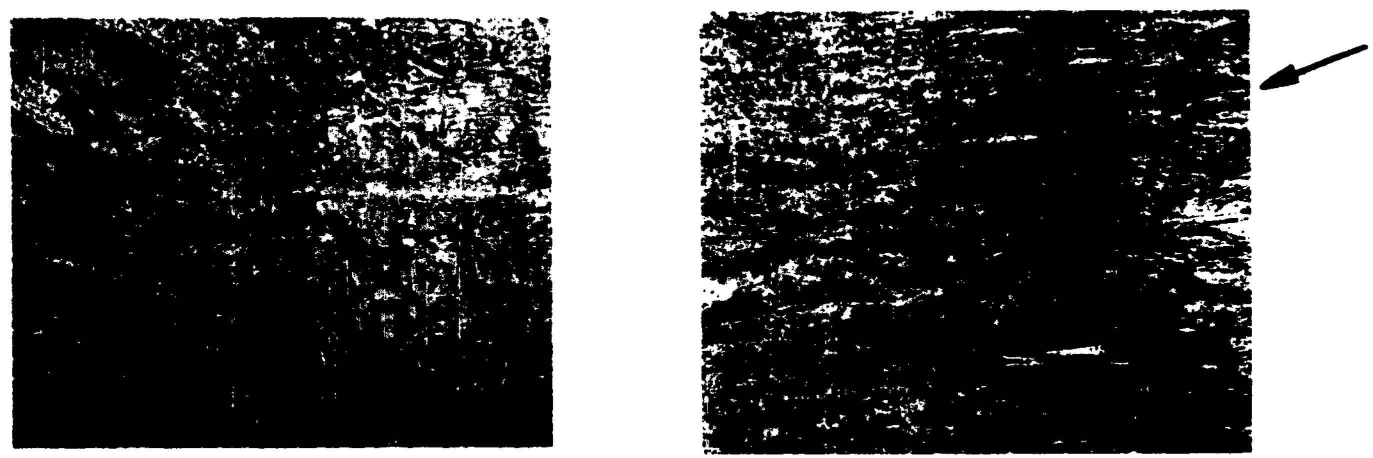
arc process employing AM 355 filler wire. This is attributed to the fine weld metal grain size and the very narrow heat affected zone.

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.



Material and Condition

JLS 300 Steel Strip, cold rolled, tempered to 340 Ksi yield strength, 040" thick. Electron beam welded at a vacuum of 10^{-4} 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 040" 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 .060"X6"X10"	40° Angle 060"X8"X10"	90° Angle 060X10X7
Solution Annealed	None	None	None	HT-D31 Sht 16(C2)
	Age Harden 900°F 40 Hr.	None	None	HT.D31 Sht 16 (C-1)
Cold Rolled 25% Age Hardened 900°F to 225/235 KSI Ultimate Tensile Strength	None	HT-D575 (J-6)	HT-D575 (J-5)	HT.-D575 (J-7)
	Age Harden 900°F 40 Hrs. Stress Relief 1025°F 10 Min.	None	None	HT-D575 (J-8)
Solution Anneal, Age Harden 72Hr. 900°F (1)	None	HT-D31 Sht 16(C-6)	HT.D31 Sht 16(C-5)	HT.D31 Sht 16 (C-3)
	Duplex Heat Treat	None	None	HT.D31 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 Strength (KSI)	Ultimate Tensile Strength (KSI)	Elong. % 2"	K_{Cl} 1000 psi in
HT. D31, Solution Annealed	L	188	210	6.0	71
+ Age Harden 900°F - 72Hr.	L	184	208	8.0	73
	L	183	206	8.0	73
	T	200	215	2.5	46
	T	188	209	6.5	55
HT.D575, Cold rolled	L	208	225	6.5	(2)
25% Age Hardened 900°F	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 interstitical 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

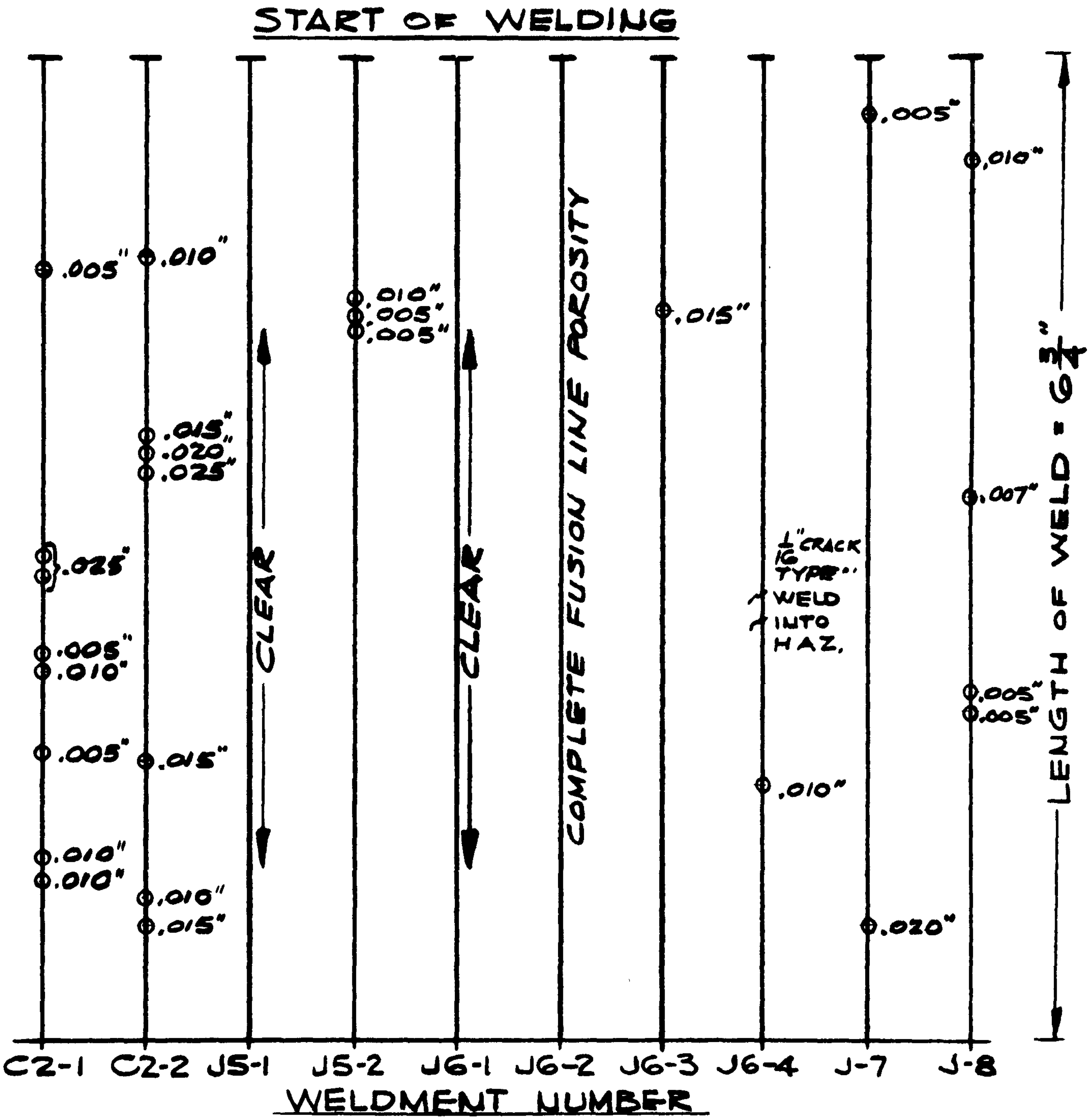
Coupons for tensile test were machined from the weldments as shown in Appendix B, progress report #9, March, 1961. Where possible, the coupons were removed from radiographic clear areas. However, some of the specimens contained porosity as large as 020" diameter, which apparently had little or no effect 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

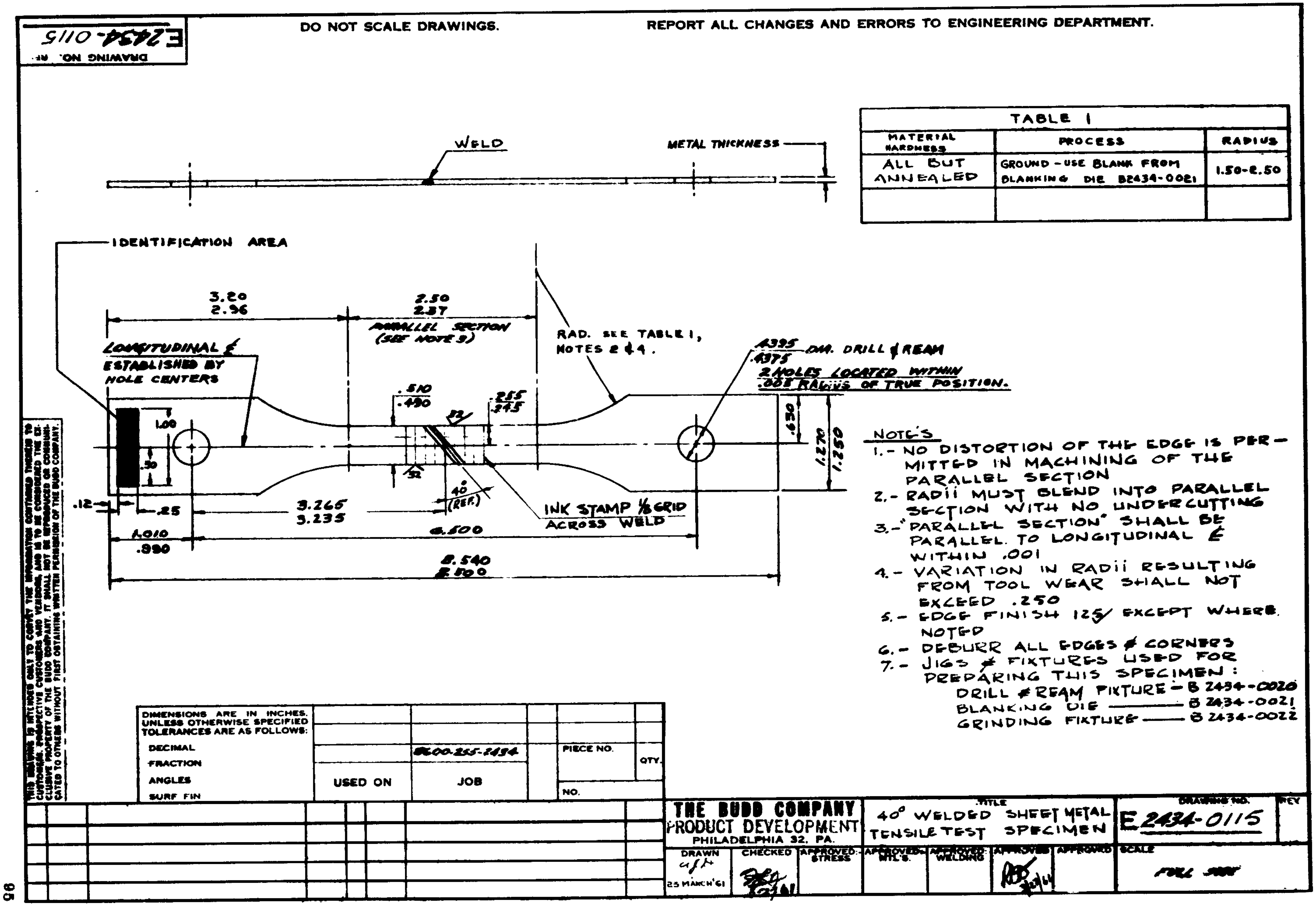
(1) Welding speed - 25 inches per minute all samples.
Focal spot - .006" dia. at metal surface.
Joint gap less than .001"
Filament - Tungsten coil at 40 Mil. Amperes relative meter reading
(2) Number shown is approx. length in inches.
Deflection was parallel to direction of welding.

TABLE 28



RADIOGRAPH INDICATIONS, ELECTRON BEAM WELDMENTS.
Ti, 13V, 11Cr, 3Al, SHEET.

FIG. 29



DRAWING NO.
E2434-0115
DO NOT SCALE DRAWINGS.
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT.
TABLE I
MATERIAL HARDNESS | PROCESS | RADIUS
ALL BUT ANNEALED | GROUND - USE BLANK FROM BLANKING DIE B2434-0021 | 1.50-2.50
WELD
METAL THICKNESS
IDENTIFICATION AREA
3.20 2.96
2.50 2.37
PARALLEL SECTION (SEE NOTE 3)
RAD. SEE TABLE I, NOTES 2 & 4.
LONGITUDINAL ℄ ESTABLISHED BY HOLE CENTERS
.4395 .4375 DIA. DRILL & REAM
2 HOLES LOCATED WITHIN .005 RADIUS OF TRUE POSITION.
.510 .490
.255 .245
1.00
.50
.630
1.270 1.250
40° (REF.)
INK STAMP 1/8 GRID ACROSS WELD
.12
.25
3.265 3.235
6.500
1.010 .990
8.540 8.500
NOTES
1.- NO DISTORTION OF THE EDGE IS PERMITTED IN MACHINING OF THE PARALLEL SECTION
2.- RADII MUST BLEND INTO PARALLEL SECTION WITH NO UNDERCUTTING
3.- "PARALLEL SECTION" SHALL BE PARALLEL TO LONGITUDINAL ℄ WITHIN .001
4.- VARIATION IN RADII RESULTING FROM TOOL WEAR SHALL NOT EXCEED .250
5.- EDGE FINISH 125 EXCEPT WHERE NOTED
6.- DEBURR ALL EDGES & CORNERS
7.- JIGS & FIXTURES USED FOR PREPARING THIS SPECIMEN:
DRILL & REAM FIXTURE — B 2434-0020
BLANKING DIE — B 2434-0021
GRINDING FIXTURE — B 2434-0022
DIMENSIONS ARE IN INCHES. UNLESS OTHERWISE SPECIFIED TOLERANCES ARE AS FOLLOWS:
DECIMAL
FRACTION
ANGLES
SURF FIN
USED ON
JOB
8600-255-2434
PIECE NO.
QTY.
NO.
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.
TITLE
40° WELDED SHEET METAL TENSILE TEST SPECIMEN
DRAWING NO.
E2434-0115
REV
DRAWN
25 MARCH '61
CHECKED
APPROVED: STRESS
APPROVED: MTL'S.
APPROVED: WELDING
APPROVED
APPROVED
SCALE

FIGURE 30

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 occuring 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

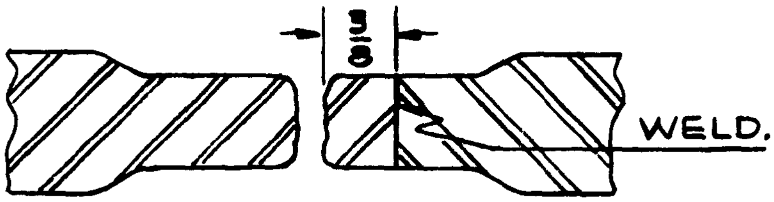
Sample Number	Condition of Weldment	Yield Strength to KSI	Ultimate Tensile Strength KSI	Elongation - % ¼"	½"	1"	2"	Fracture
C1-1	Solution Annealed, Weld, Age Harden	Missed	162	½	½		½	Brittle, Weld
C1-2	900°F, 40 Hr. (90°)	Excessive Porosity - not heat treated.						
C2-1	Solution Annealed,	146	146	4	4		9	Base Metal
C2-2	Weld. (90°)	(1)	139	-	-	6	-	Base Metal
C2-3		(1)	144	-	-	9	-	Base Metal
J5-1-2	Cold Rolled 25%, Aged	141	147	28	14		3½	Weld Metal
J5-1-2	900°F to 225 KSI	(1)	147	-	-	5	-	Weld Metal
J5-2-1	Ultimate Tensile	140.5	145	28	12		4	Weld Metal
J5-2-2	Strength Welded (40°)	(1)	145	-	-	6	-	Weld Metal
J6-1	Cold Rolled 25% Aged	151	188	8	8		4	(2)
J6-2	900°F to 225 KSI	Excessive Porosity						-
J6-3	Ultimate Tensile	(1)	187	-	-	7	-	(2)
J6-4	Strength Welded (20°)	To be Tested						
J7-1	CR 25%, 900°F, Age to	Specimen Cracked in Preparation						
J7-2	225 KSI U. T. S.	Missed	185	4	2	-	1½	Weld Metal
J7-3	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	Not Tested						
J8-2	225 KSI UTS. Weld	(1)	159	-	-	3	-	Weld Metal
J8-3	(90°)	(1)	151	-	-	3	-	Weld Metal

TABLE 29

SKETCHES OF TYPICAL TENSILE FRACTURES IN ELECTRON BEAM WELDMENTS OF -Ti, 13V, 11Cr, 3Al, SHEET.

SPECIMEN- C2-1.

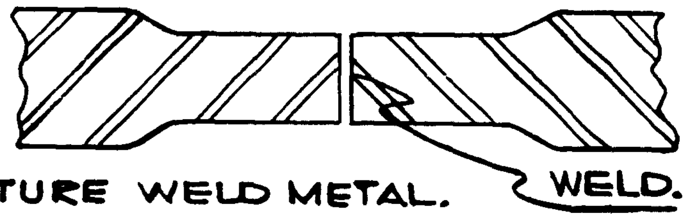
SOLUTION ANNEALED, WELD. BASE METAL FRACTURE.



DUCTILE FRACTURE, NECKING AND GOOD ELONGATION.

SPECIMEN -C1-1.

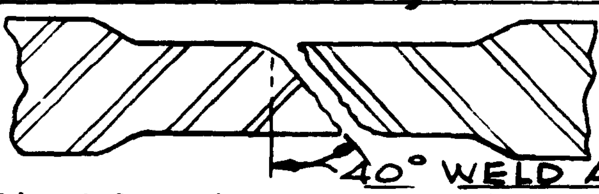
SOLUTION ANNEALED, WELD, AGE HARDEN.



BRITTLE FRACTURE WELD METAL.

SPECIMEN-J5-2-1.

COLD ROLLED 25%, AGE HARDEN, WELD

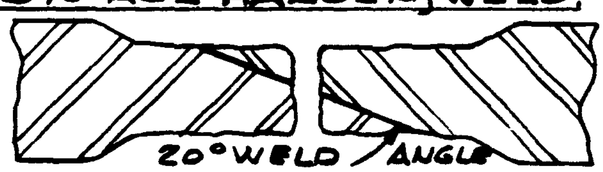


DUCTILE FAILURE IN WELD METAL.

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.

FIGURE 31

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° to 25° 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° - 40° and 20° 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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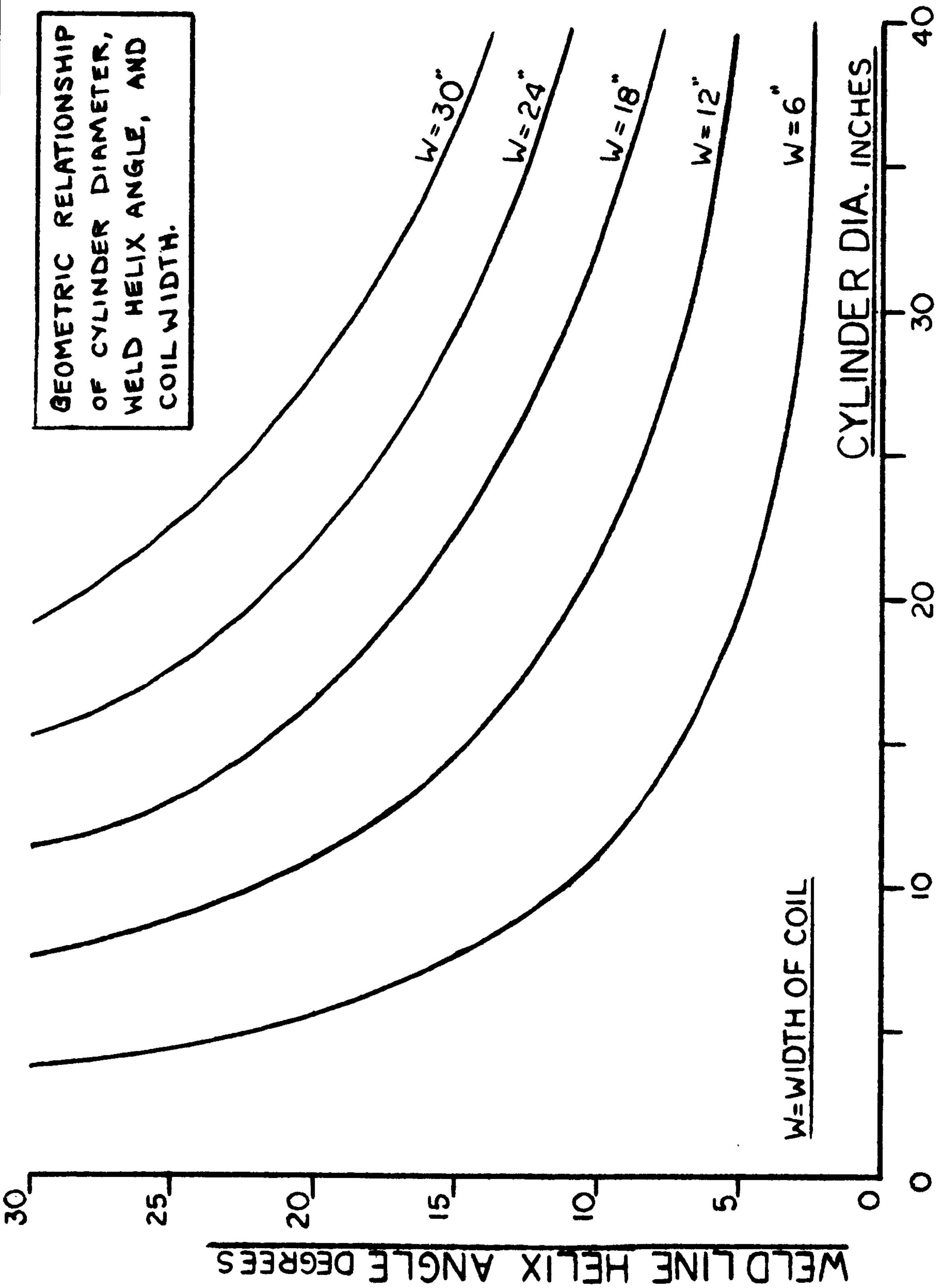


FIGURE – 32.

EFFECT OF HELIX ANGLE ON THE YIELD STRENGTH OF A CYLINDER

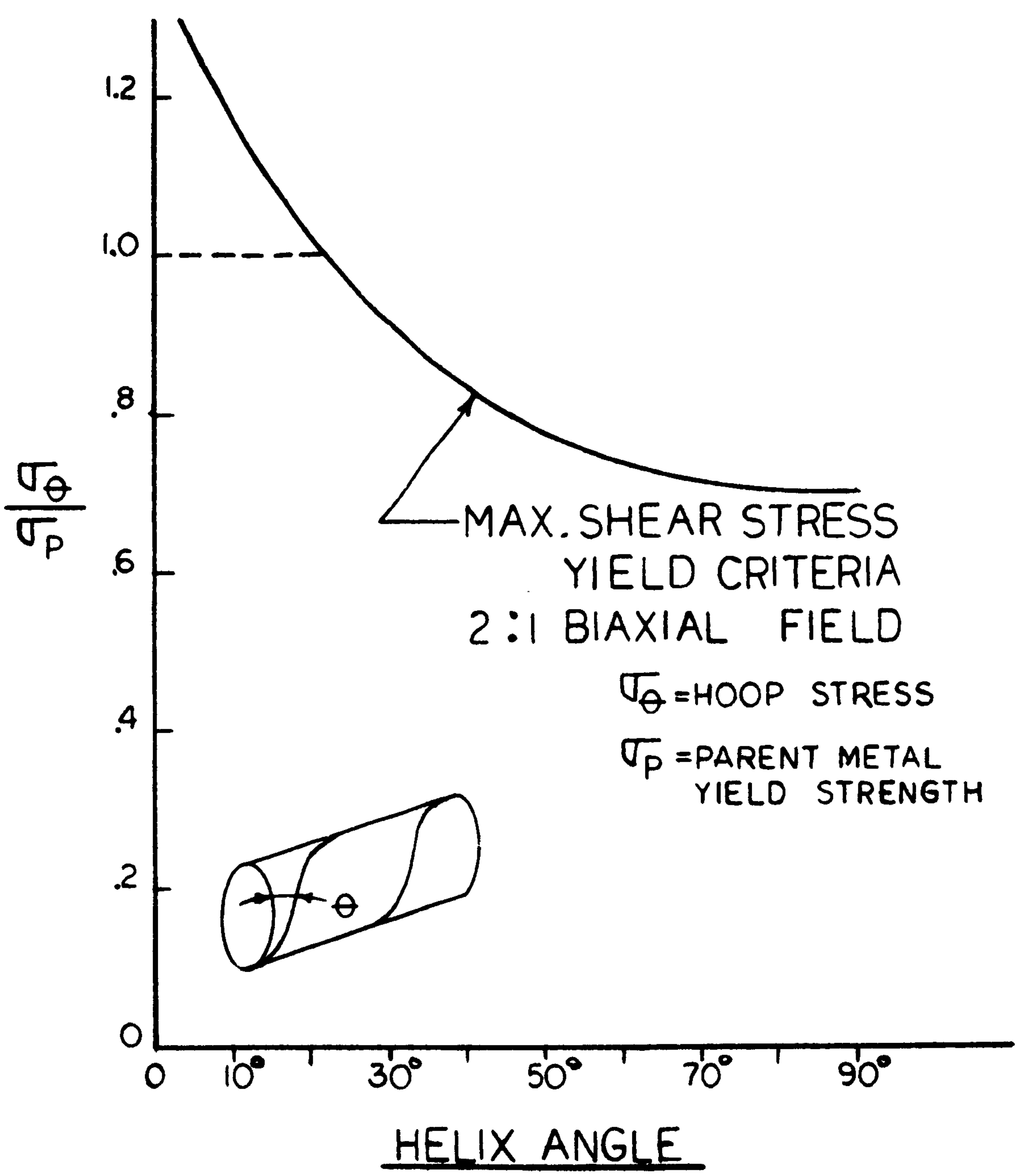


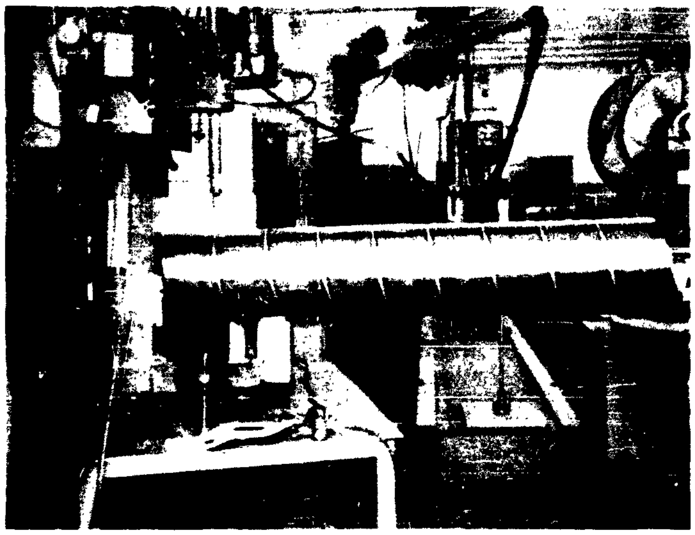
FIGURE-33

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 valicity 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.

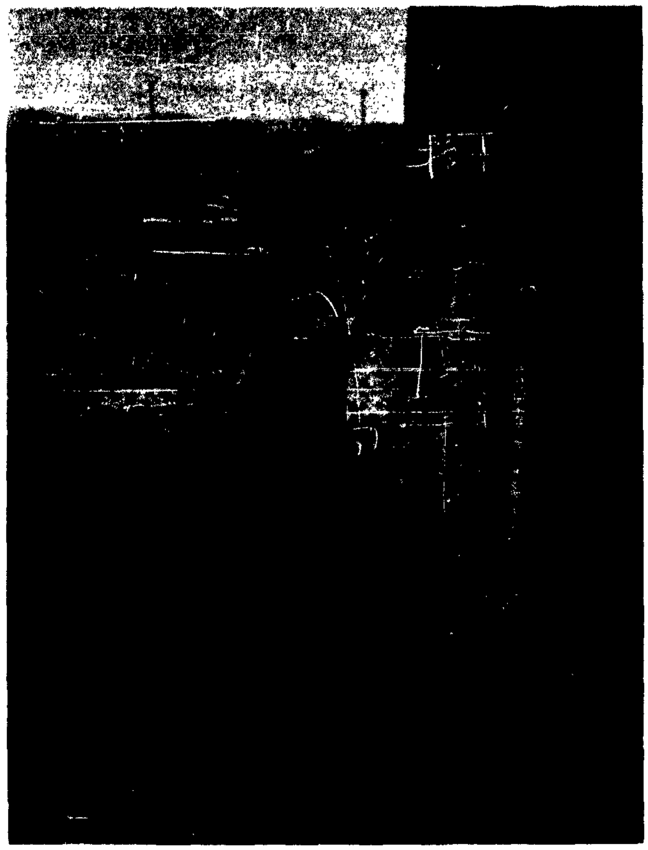
We are currently designing a fixture capable of welding 20" Dia. cylinders for the sub-scale program. This fixture will have sufficient power in the drive, and accuracy to enable us to weld cylinders in various alloys with reliable repeatability.

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

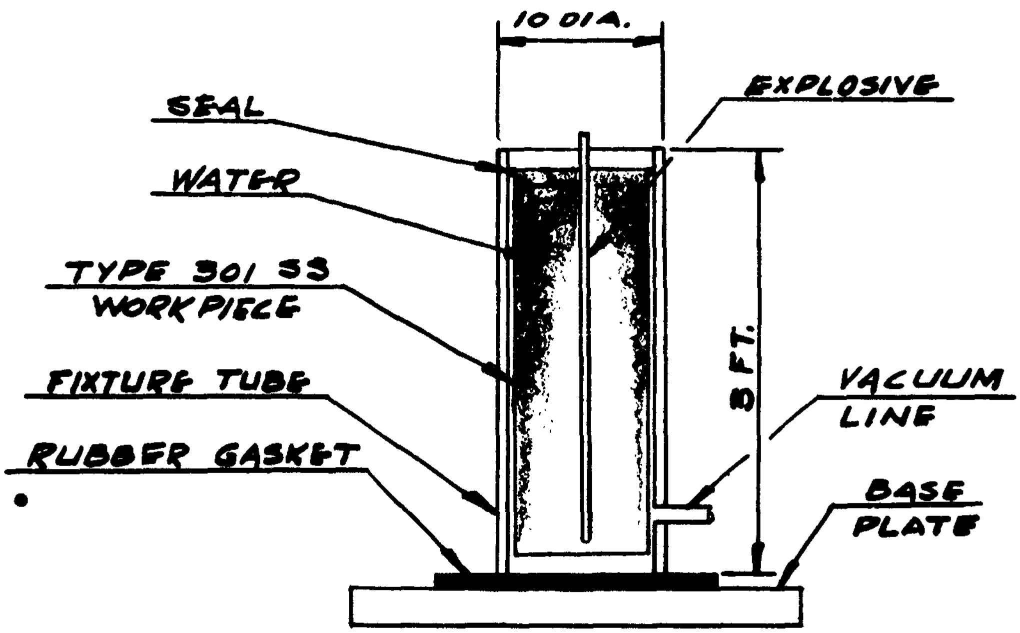


HELICAL WELDING FIXTURE AND
ARRANGEMENT - 10" CYLINDER

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 delivers 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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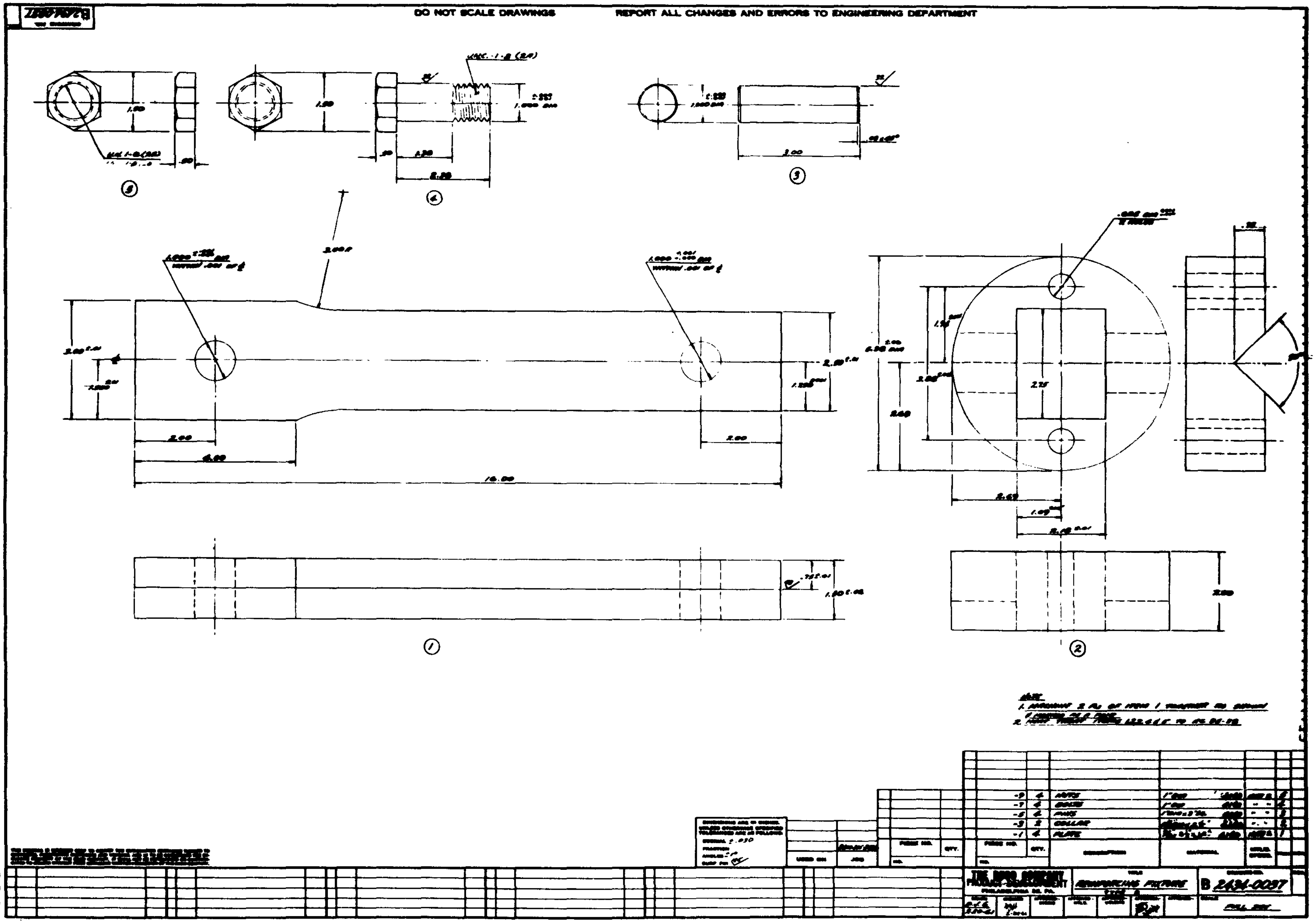
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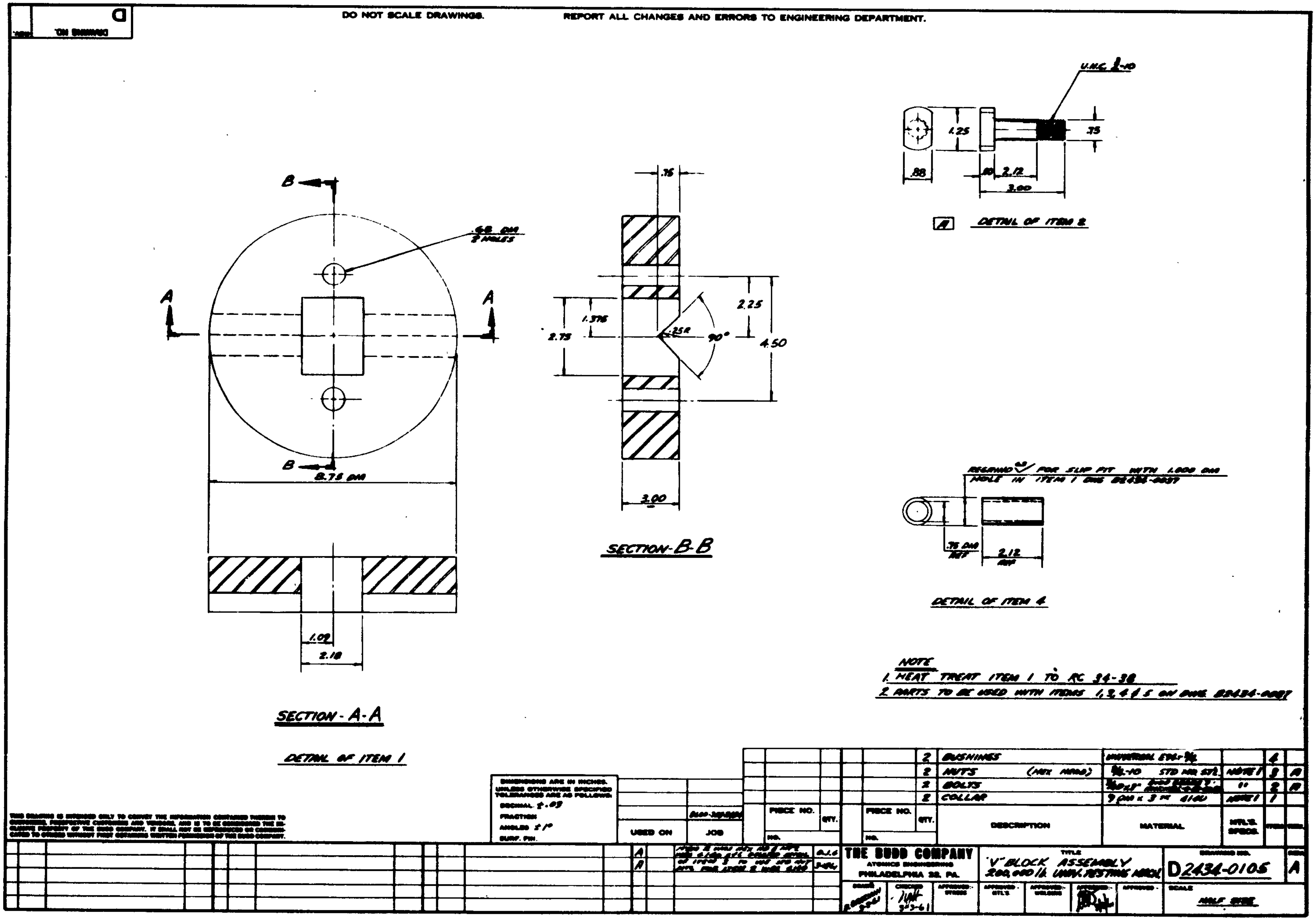

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DETAIL OF ITEM 1
SECTION-B-B
DETAIL OF ITEM 2
DETAIL OF ITEM 4
8.75 DIA
2.25
4.50
2.75
1.375
90°
3.00
1.25
.75
.88
2.12
NOTE
1. HEAT TREAT ITEM 1 TO RC 34-38
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ATOMICS ENGINEERING
PHILADELPHIA 32, PA.
"V" BLOCK ASSEMBLY
D2434-0105
HALF SIZE
BUSHINGS
NUTS
BOLTS
COLLAR
DESCRIPTION
MATERIAL

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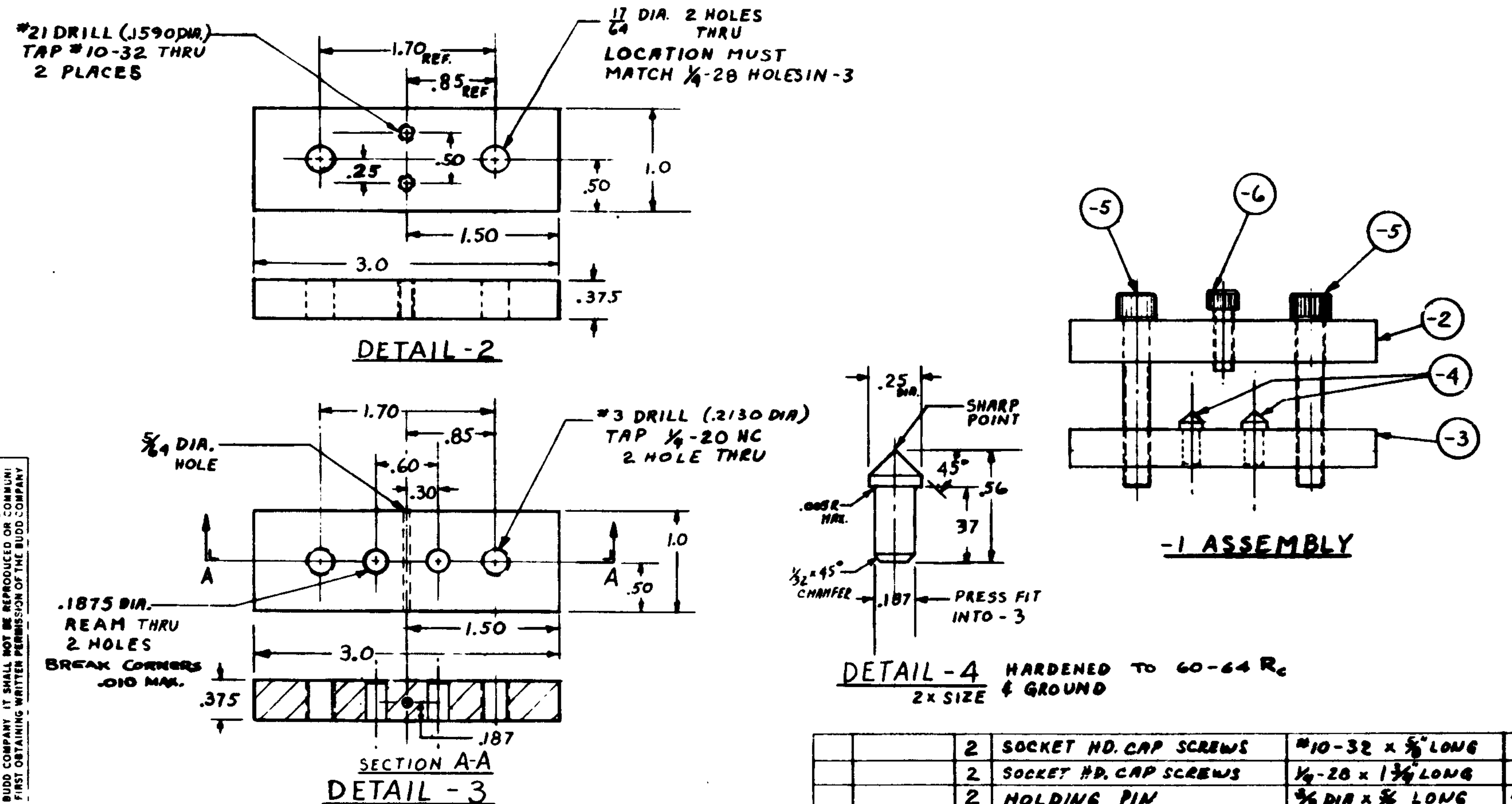

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	2	SOCKET HD. CAP SCREWS	1/4-28 x 1 3/4" LONG		-5	
	2	HOLDING PIN	3/16 DIA x 5/8 LONG	DRILL ROD	-4	
	1	HOLDING BAR	3/8 x 1 x 3	CRS	-3	
	1	PRESSURE BAR	3/8 x 1 x 3	CRS	-2	
	2	EXTENSOMETER CLAMP ASS'Y			-1	

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DECIMAL ± 1/16
FRACTION
ANGLES ± 2°
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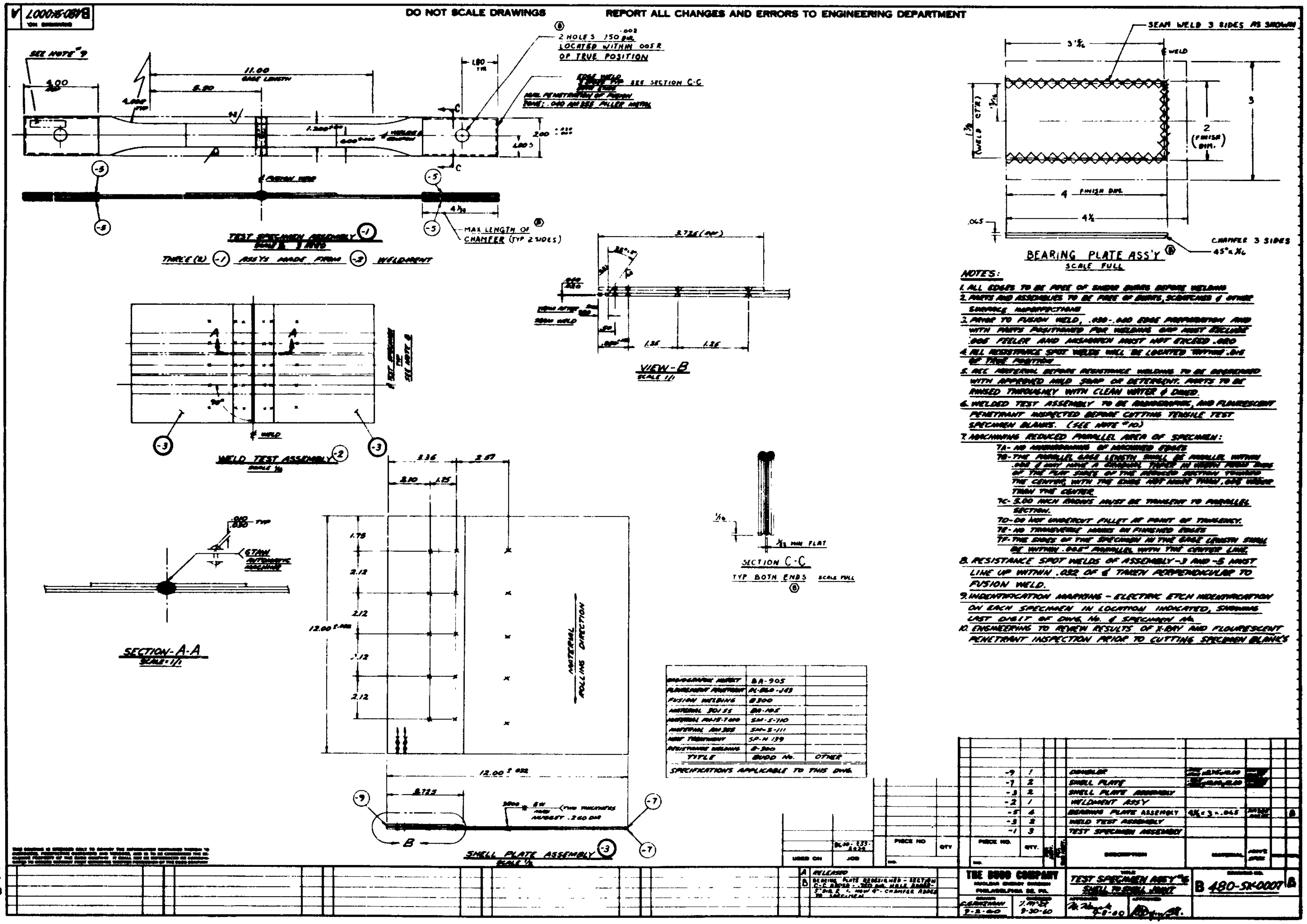
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SEE NOTE #9
2 HOLES .150 DIA. LOCATED WITHIN .005 R OF TRUE POSITION
SEE SECTION C-C
11.00 GAGE LENGTH
MAX LENGTH OF CHAMFER (TYP 2 SIDES)
TEST SPECIMEN ASSEMBLY -1
THREE (3) -1 ASSYS MADE FROM -2 WELDMENT
WELD TEST ASSEMBLY -2
SECTION-A-A
VIEW-B
SECTION C-C
TYP BOTH ENDS
SCALE FULL
MATERIAL ROLLING DIRECTION
SHELL PLATE ASSEMBLY -3
SEAM WELD 3 SIDES AS SHOWN
CHAMFER 3 SIDES 45° x 1/16
BEARING PLATE ASS'Y
SCALE FULL
NOTES:
1. ALL EDGES TO BE FREE OF SHEAR BURRS BEFORE WELDING
5. ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED.
7. MACHINING REDUCED PARALLEL AREA OF SPECIMEN:
8. RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF ℄ TAKEN PERPENDICULAR TO FUSION WELD.
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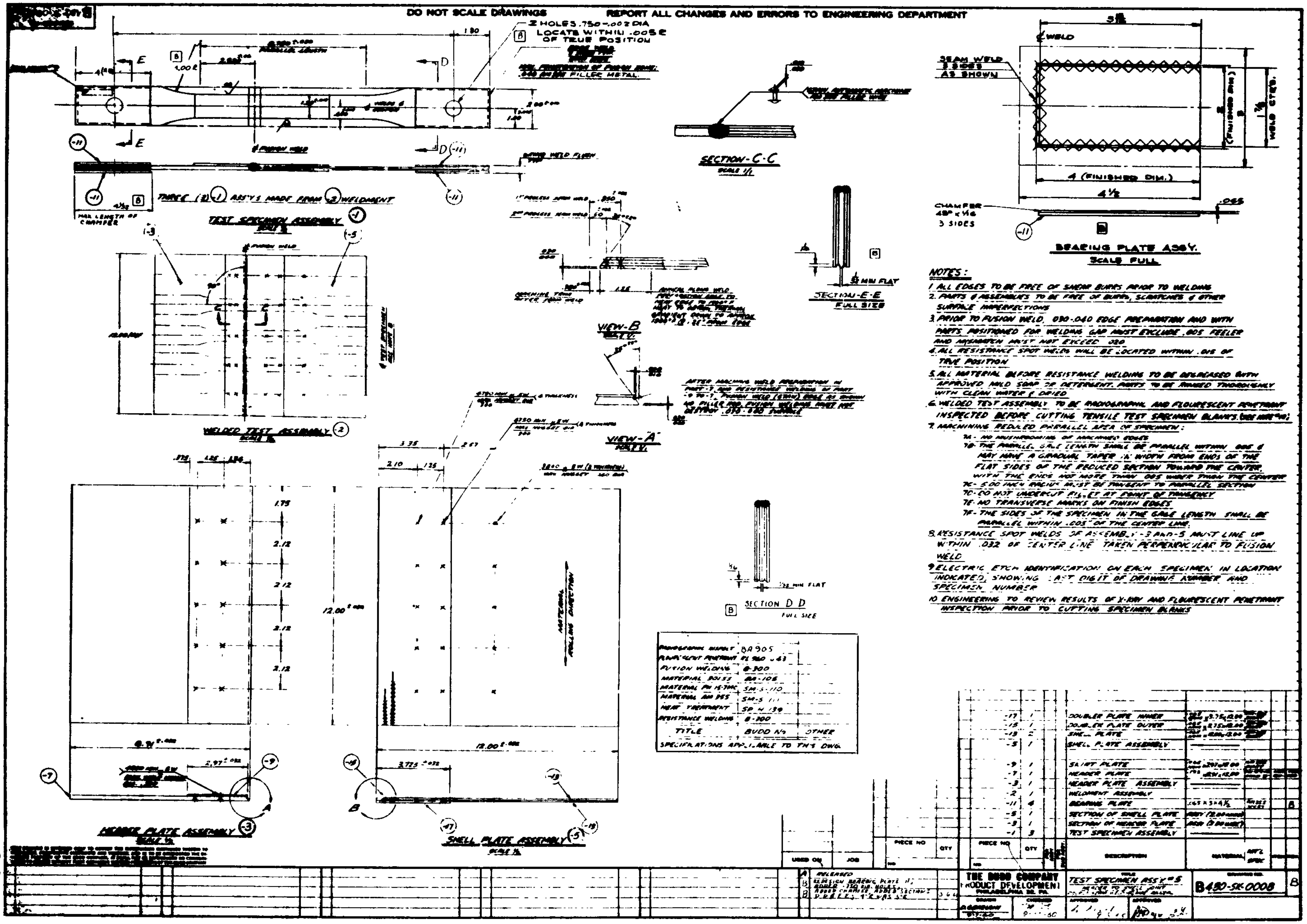
10. ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLOURESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS
SPECIFICATIONS APPLICABLE TO THIS DWG.
DOUBLER
SHELL PLATE
SHELL PLATE ASSEMBLY
WELDMENT ASSY
BEARING PLATE ASSEMBLY
WELD TEST ASSEMBLY
TEST SPECIMEN ASSEMBLY
THE BUDD COMPANY
PHILADELPHIA 32, PA.
TEST SPECIMEN ASSY'S SHELL TO SHELL JOINT
B 480-SK0007 B



DO NOT SCALE DRAWINGS
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
2 HOLES .750-.002 DIA LOCATE WITHIN .005E OF TRUE POSITION
THREE (3) -1 ASSY'S MADE FROM -2 WELDMENT
TEST SPECIMEN ASSEMBLY -1
WELDED TEST ASSEMBLY -2
HEADER PLATE ASSEMBLY -3
SHELL PLATE ASSEMBLY -5
SECTION-C-C
SECTION-E-E FULL SIZE
SECTION D D FULL SIZE
VIEW-A
VIEW-B
SEAM WELD 2 EDGES AS SHOWN
CHAMFER 45° x 1/16 3 SIDES
4 (FINISHED DIM.)
4 1/2
BEARING PLATE ASSY. SCALE FULL
NOTES:
1 ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS
3 PRIOR TO FUSION WELD, .030-.040 EDGE PREPARATION AND WITH PARTS POSITIONED FOR WELDING GAP MUST EXCLUDE .005 FEELER AND MISMATCH MUST NOT EXCEED .020
4. ALL RESISTANCE SPOT WELDS WILL BE LOCATED WITHIN .015 OF TRUE POSITION
5. ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED
6. WELDED TEST ASSEMBLY TO BE RADIOGRAPHIC AND FLOURESCENT PENETRANT INSPECTED BEFORE CUTTING TENSILE TEST SPECIMEN BLANKS (SEE NOTE 10)
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7B - THE PARALLEL GAGE LENGTH SHALL BE PARALLEL WITHIN .005 & MAY HAVE A GRADUAL TAPER IN WIDTH FROM ENDS OF THE FLAT SIDES OF THE REDUCED SECTION TOWARD THE CENTER, WITH THE ENDS NOT MORE THAN .005 WIDER THAN THE CENTER
7C - 5.00 INCH RADIUS MUST BE TANGENT TO PARALLEL SECTION
7D - DO NOT UNDERCUT FILLET AT POINT OF TANGENCY
7E - NO TRANSVERSE MARKS ON FINISH EDGES
7F - THE SIDES OF THE SPECIMEN IN THE GAGE LENGTH SHALL BE PARALLEL WITHIN .005" OF THE CENTER LINE.
8. RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD
9. ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED, SHOWING LAST DIGIT OF DRAWING NUMBER AND SPECIMEN NUMBER
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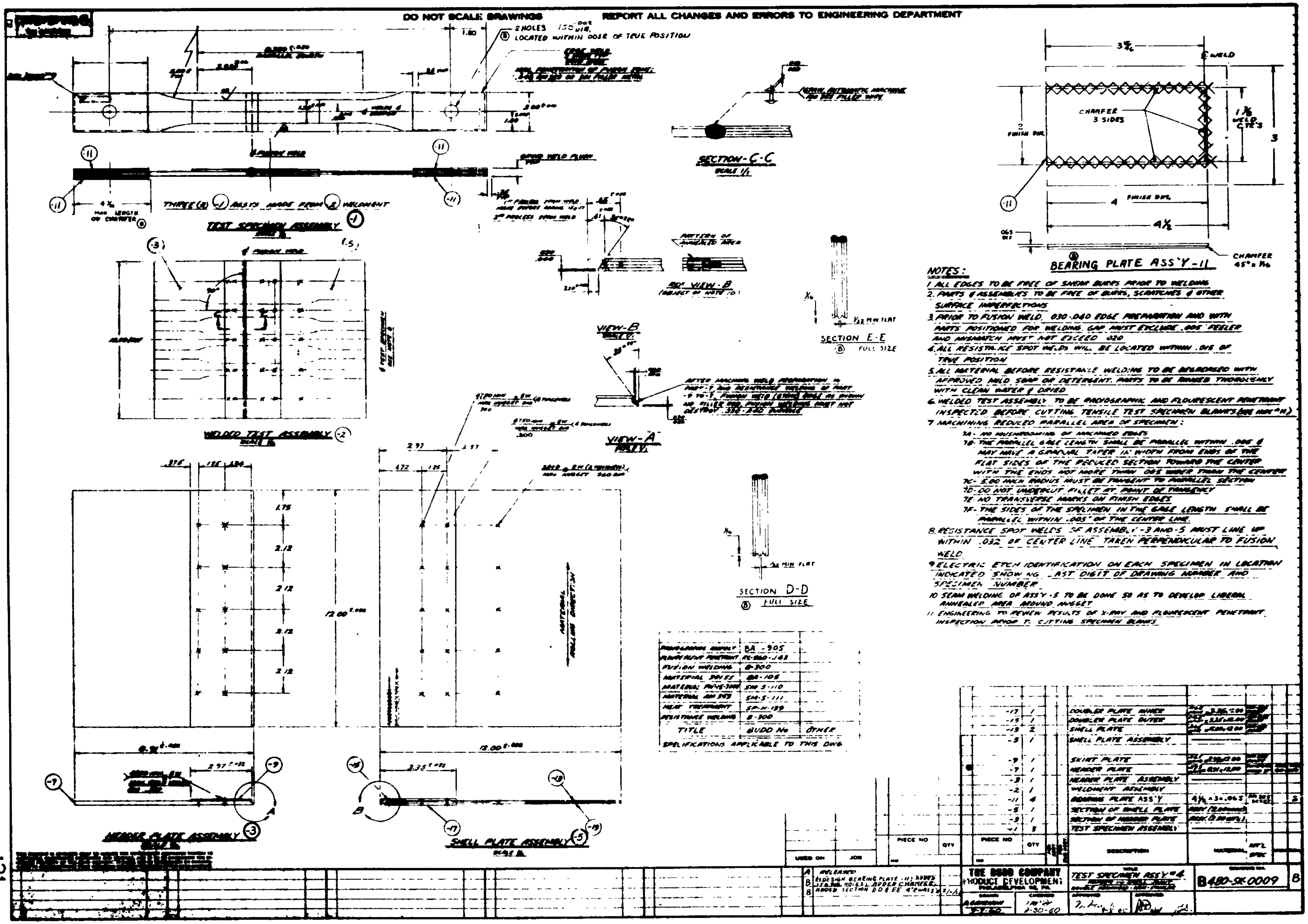
RADIOGRAPHIC INSPECT BA905
FUSION WELDING B-300
RESISTANCE WELDING B-300
SPECIFICATIONS APPLICABLE TO THIS DWG.
DOUBLER PLATE INNER
DOUBLER PLATE OUTER
SHELL PLATE
SHELL PLATE ASSEMBLY
SKIRT PLATE
HEADER PLATE
HEADER PLATE ASSEMBLY
WELDMENT ASSEMBLY
BEARING PLATE
SECTION OF SHELL PLATE
SECTION OF HEADER PLATE
TEST SPECIMEN ASSEMBLY
THE BUDD COMPANY PRODUCT DEVELOPMENT PHILADELPHIA 32, PA.
TEST SPECIMEN ASS'Y #5
B480-SK0008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LOCATED WITHIN .005 OF TRUE POSITION
THREE (3) -1 PARTS MADE FROM -2 WELDMENT
TEST SPECIMEN ASSEMBLY -1
SECTION-C-C
WELDED TEST ASSEMBLY -2
VIEW-B
VIEW-A
SECTION E-E
FULL SIZE
SECTION D-D
FULL SIZE
HEADER PLATE ASSEMBLY -3
SHELL PLATE ASSEMBLY -5
CHAMFER 3 SIDES
WELD CTR'S
FINISH DIM.
CHAMFER 45° x 1/16
BEARING PLATE ASS'Y -11
NOTES:
1 ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS
3 PRIOR TO FUSION WELD, .030-.040 EDGE PREPARATION AND WITH PARTS POSITIONED FOR WELDING GAP MUST EXCLUDE .005 FEELER AND MISMATCH MUST NOT EXCEED .020
4. ALL RESISTANCE SPOT WELDS WILL BE LOCATED WITHIN .015 OF TRUE POSITION
5. ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED
6 WELDED TEST ASSEMBLY TO BE RADIOGRAPHIC AND FLOURESCENT PENETRANT INSPECTED BEFORE CUTTING TENSILE TEST SPECIMEN BLANKS
7 MACHINING REDUCED PARALLEL AREA OF SPECIMEN:
7A- NO MUSHROOMING OF MACHINED EDGES
7B- THE PARALLEL GAGE LENGTH SHALL BE PARALLEL WITHIN .005 & MAY HAVE A GRADUAL TAPER IN WIDTH FROM ENDS OF THE FLAT SIDES OF THE REDUCED SECTION TOWARD THE CENTER WITH THE ENDS NOT MORE THAN .005 WIDER THAN THE CENTER
7C- 5.00 INCH RADIUS MUST BE TANGENT TO PARALLEL SECTION
7D- DO NOT UNDERCUT FILLET AT POINT OF TANGENCY
7E- NO TRANSVERSE MARKS ON FINISH EDGES
7F- THE SIDES OF THE SPECIMEN IN THE GAGE LENGTH SHALL BE PARALLEL WITHIN .005" OF THE CENTER LINE.
8. RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD
9 ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED SHOWING LAST DIGIT OF DRAWING NUMBER AND SPECIMEN NUMBER
10 SEAM WELDING OF ASSY -5 TO BE DONE SO AS TO DEVELOP LIBERAL ANNEALED AREA AROUND NUGGET
11 ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLOURESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS
BA-905
B-300
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BUDD No
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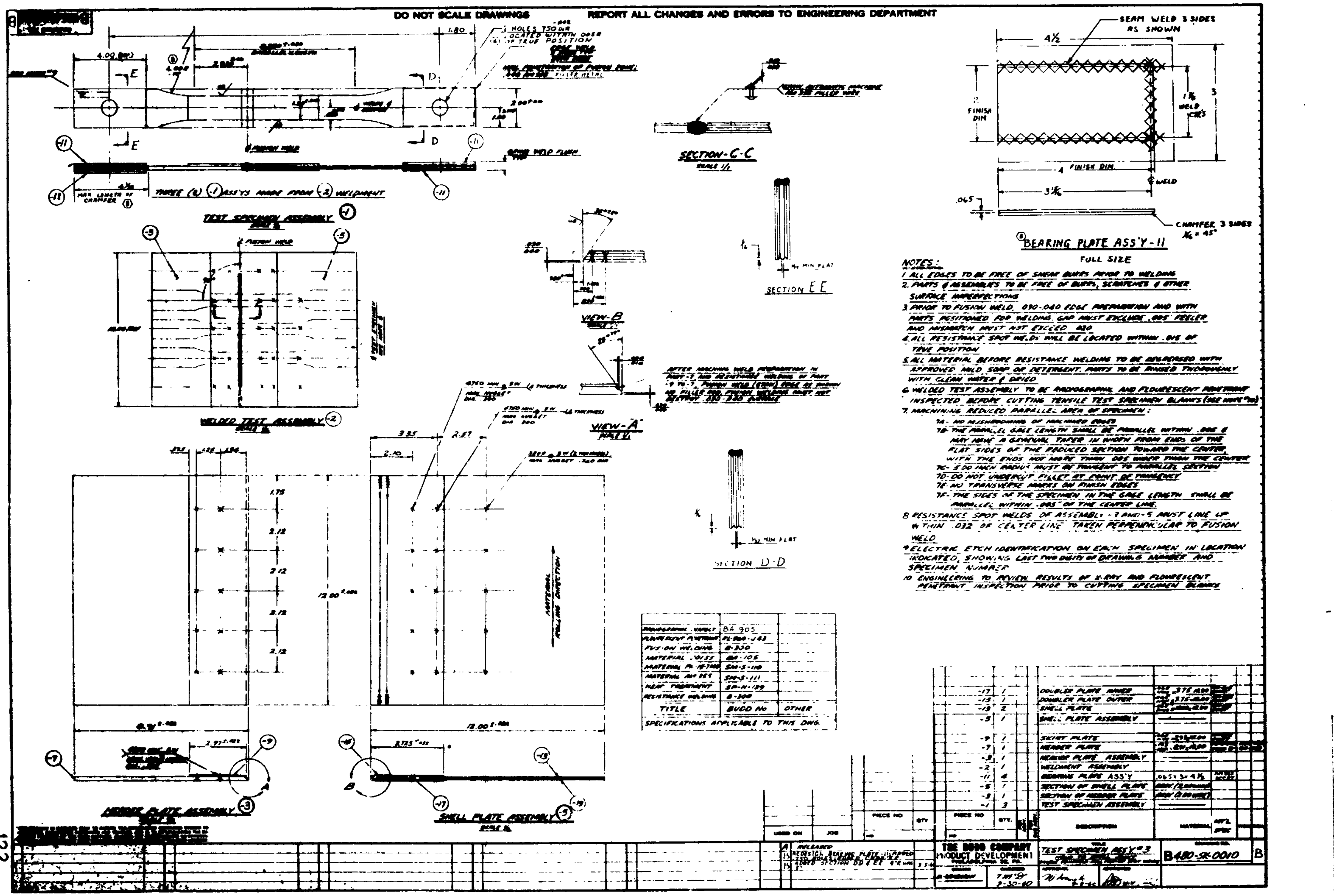
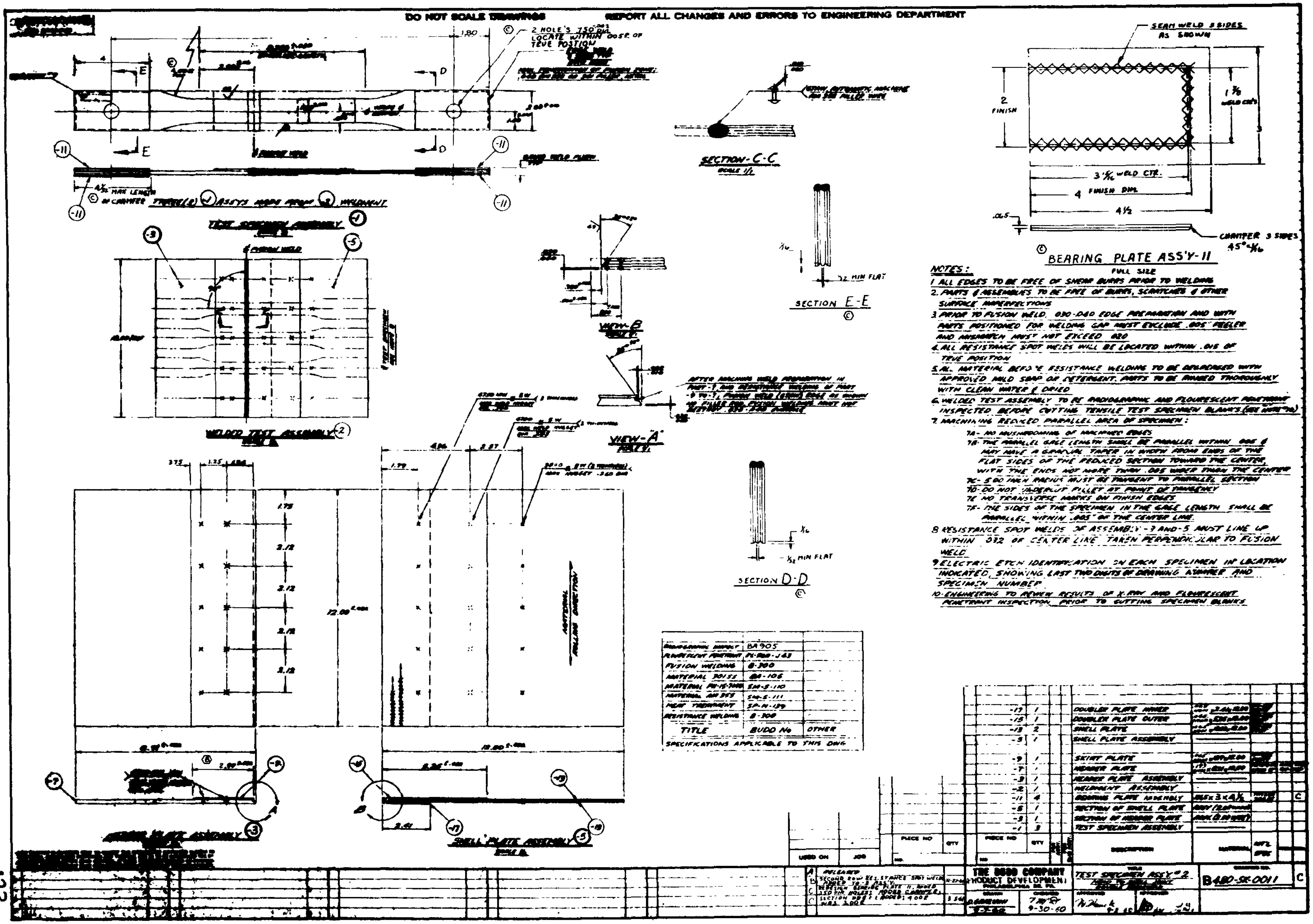
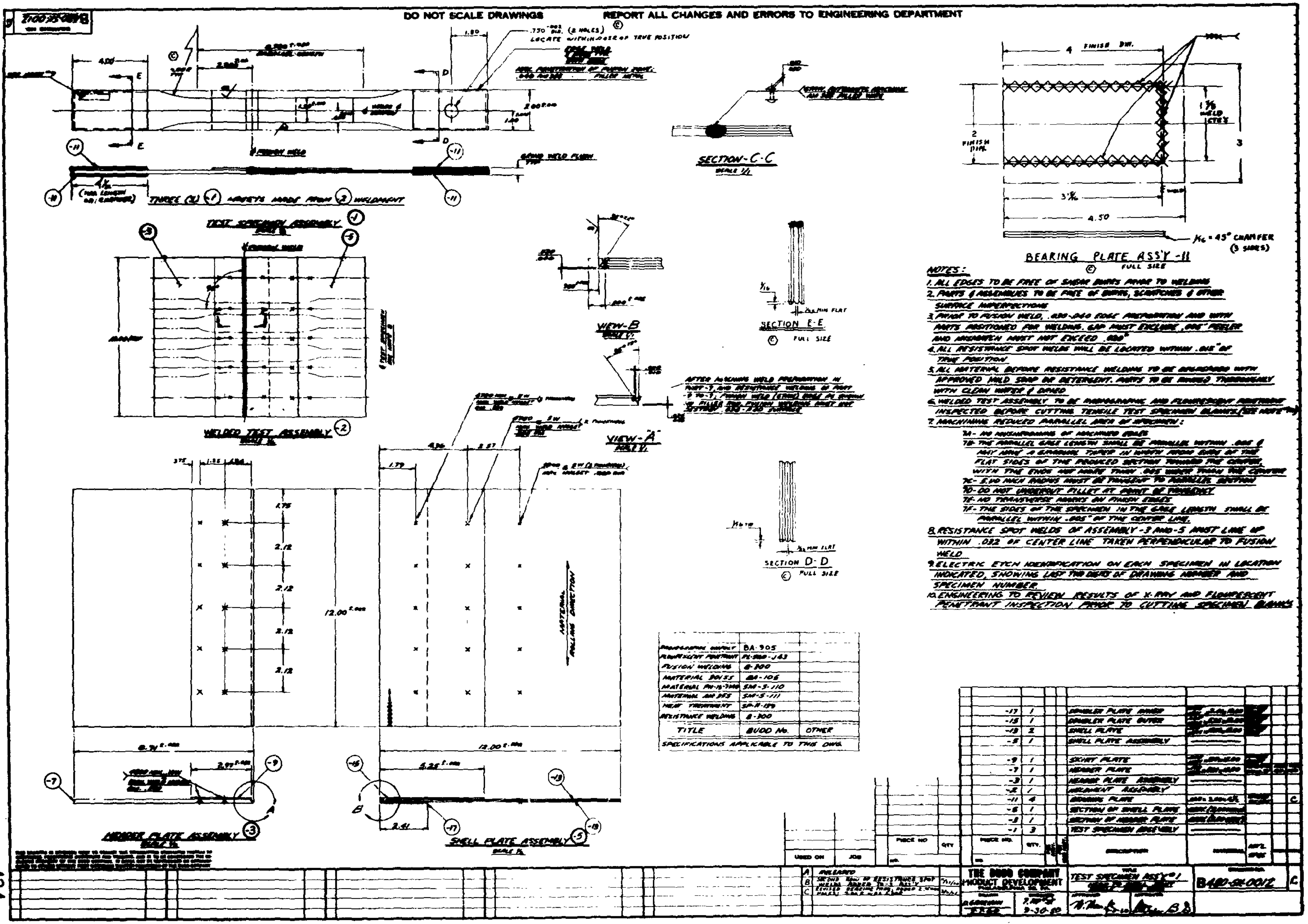
DOUBLER PLATE OUTER
SHELL PLATE
SHELL PLATE ASSEMBLY
SKIRT PLATE
HEADER PLATE
HEADER PLATE ASSEMBLY
WELDMENT ASSEMBLY
BEARING PLATE ASS'Y
SECTION OF SHELL PLATE
SECTION OF HEADER PLATE
TEST SPECIMEN ASSEMBLY
PIECE NO
QTY
DESCRIPTION
MATERIAL
THE BUDD COMPANY
PRODUCT DEVELOPMENT
TEST SPECIMEN ASS'Y #4
B480-SK0009
B


DO NOT SCALE DRAWINGS
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
SEAM WELD 3 SIDES AS SHOWN
4½
3
1⅞ WELD CRS
2 FINISH DIM
4 FINISH DIM.
3⅞
℄ WELD
.065
CHAMFER 3 SIDES ⅟₁₆ × 45°
BEARING PLATE ASS'Y -11
FULL SIZE
NOTES:
1 ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS
3 PRIOR TO FUSION WELD. .030-.040 EDGE PREPARATION AND WITH PARTS POSITIONED FOR WELDING. GAP MUST EXCLUDE .005 FEELER AND MISMATCH MUST NOT EXCEED .020
4. ALL RESISTANCE SPOT WELDS WILL BE LOCATED WITHIN .015 OF TRUE POSITION
5. ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED
6 WELDED TEST ASSEMBLY TO BE RADIOGRAPHIC AND FLOURESCENT PENETRANT INSPECTED BEFORE CUTTING TENSILE TEST SPECIMEN BLANKS (SEE NOTE 10)
7. MACHINING REDUCED PARALLEL AREA OF SPECIMEN:
7A- NO MISMATCHING OF MACHINED EDGES
7B- THE PARALLEL GAGE LENGTH SHALL BE PARALLEL WITHIN .005 & MAY HAVE A GRADUAL TAPER IN WIDTH FROM ENDS OF THE FLAT SIDES OF THE REDUCED SECTION TOWARD THE CENTER, WITH THE ENDS NOT MORE THAN .005 WIDER THAN THE CENTER
7C- 5.50 INCH RADIUS MUST BE TANGENT TO PARALLEL SECTION
7D- DO NOT UNDERCUT FILLET AT POINT OF TANGENCY
7E- NO TRANSVERSE MARKS ON FINISH EDGES
7F- THE SIDES OF THE SPECIMEN IN THE GAGE LENGTH SHALL BE PARALLEL WITHIN .005" OF THE CENTER LINE.
8 RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD
9 ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED, SHOWING LAST TWO DIGITS OF DRAWING NUMBER AND SPECIMEN NUMBER
10 ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLOURESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS
SECTION-C-C
SCALE 1/1
SECTION E E
SECTION D-D
VIEW-B
VIEW-"A"
TEST SPECIMEN ASSEMBLY -1
THREE (3) -1 ASSY'S MADE FROM -2 WELDMENT
WELDED TEST ASSEMBLY -2
HEADER PLATE ASSEMBLY -3
SHELL PLATE ASSEMBLY -5
℄ FUSION WELD
MATERIAL ROLLING DIRECTION
4.00 (REF)
1.80
4.000
2.000
12.00
3.35
2.27
2.10
1.75
2.12
RADIOGRAPHIC INSPECT	BA 905	
FLOURESCENT PENETRANT	PL-500-J43	
FUSION WELDING	B-300	
MATERIAL 301 SS	BA-105	
MATERIAL PH 15-7MO	SM-5-110	
MATERIAL AM 355	SM-5-111	
HEAT TREATMENT	SP-H-139	
RESISTANCE WELDING	B-300	
TITLE	BUDD No	OTHER
SPECIFICATIONS APPLICABLE TO THIS DWG.		

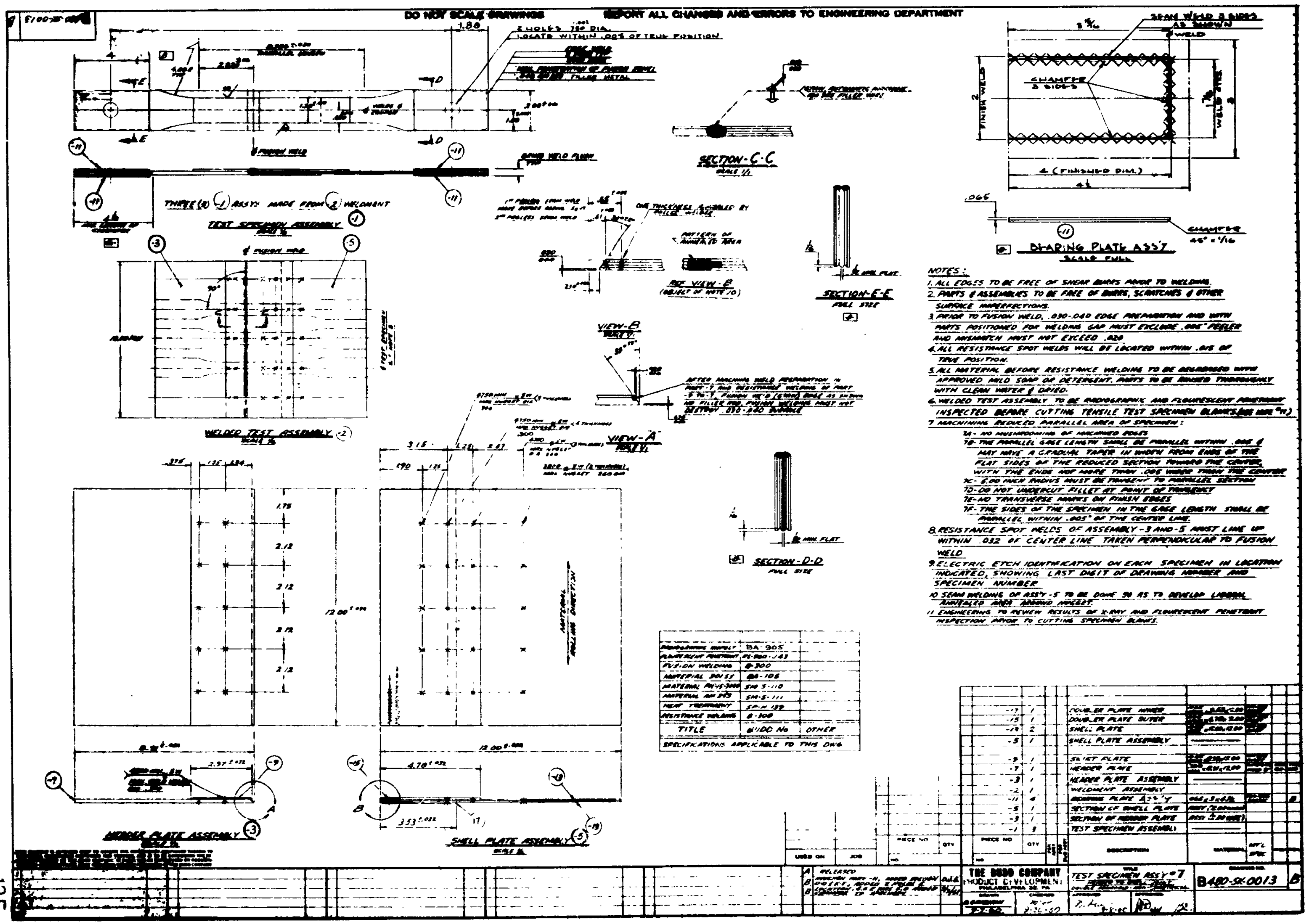
PIECE NO	QTY.	DESCRIPTION	MATERIAL
-17	1	DOUBLER PLATE INNER	.375
-15	1	DOUBLER PLATE OUTER	.375
-13	2	SHELL PLATE	
-5	1	SHELL PLATE ASSEMBLY	
-9	1	SKIRT PLATE	
-7	1	HEADER PLATE	
-3	1	HEADER PLATE ASSEMBLY	
-2	1	WELDMENT ASSEMBLY	
-11	4	BEARING PLATE ASS'Y	.065 × 3 × 4½
-5	1	SECTION OF SHELL PLATE	
-3	1	SECTION OF HEADER PLATE	
-1	3	TEST SPECIMEN ASSEMBLY	

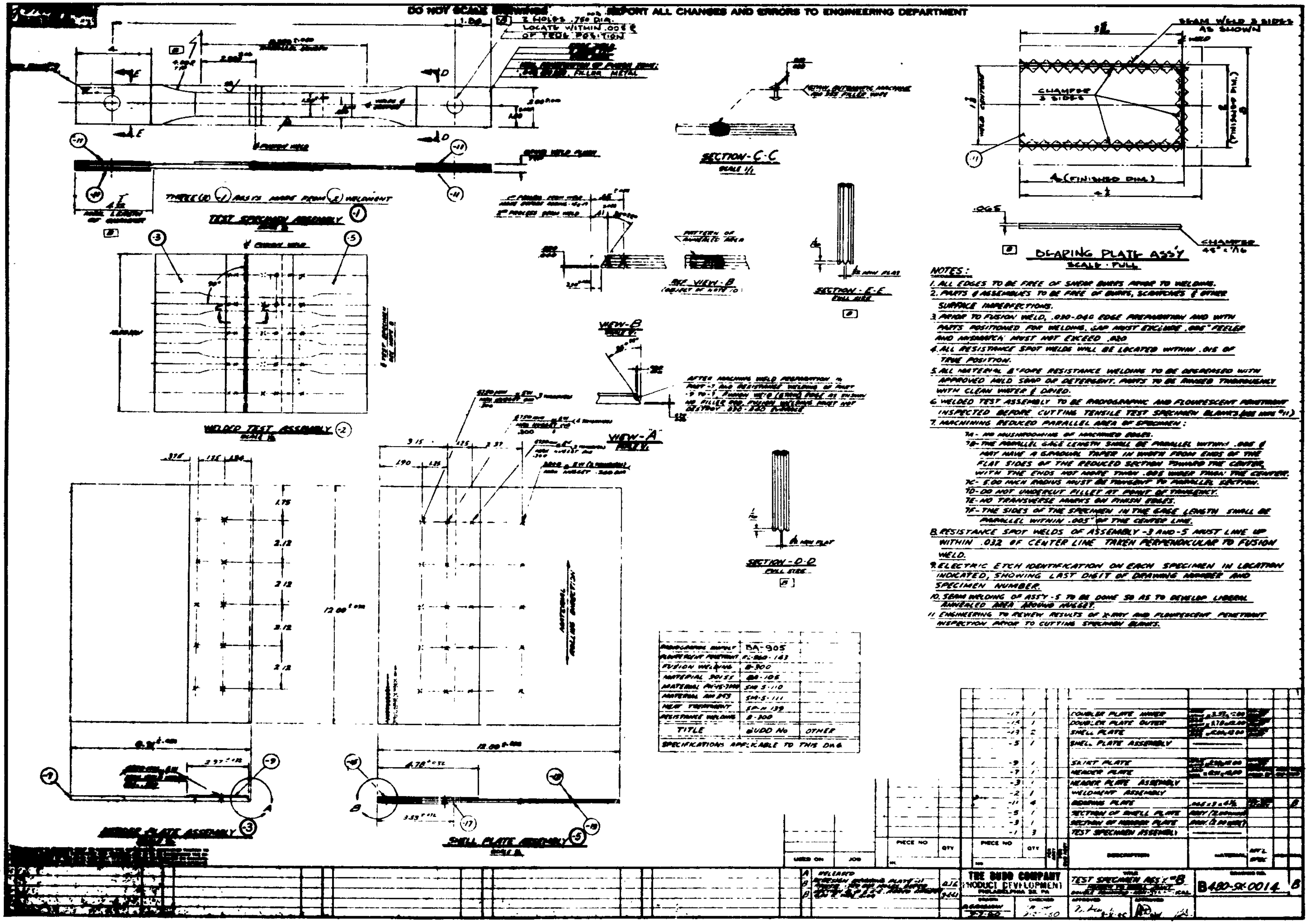
USED ON
JOB
A RELEASED
B REDESIGN BEARING PLATE -11 ADDED .250 HOLES
B ADDED SECTION DD & EE
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.
TEST SPECIMEN ASS'Y #3
B480-SK-0010
B
2-30-60

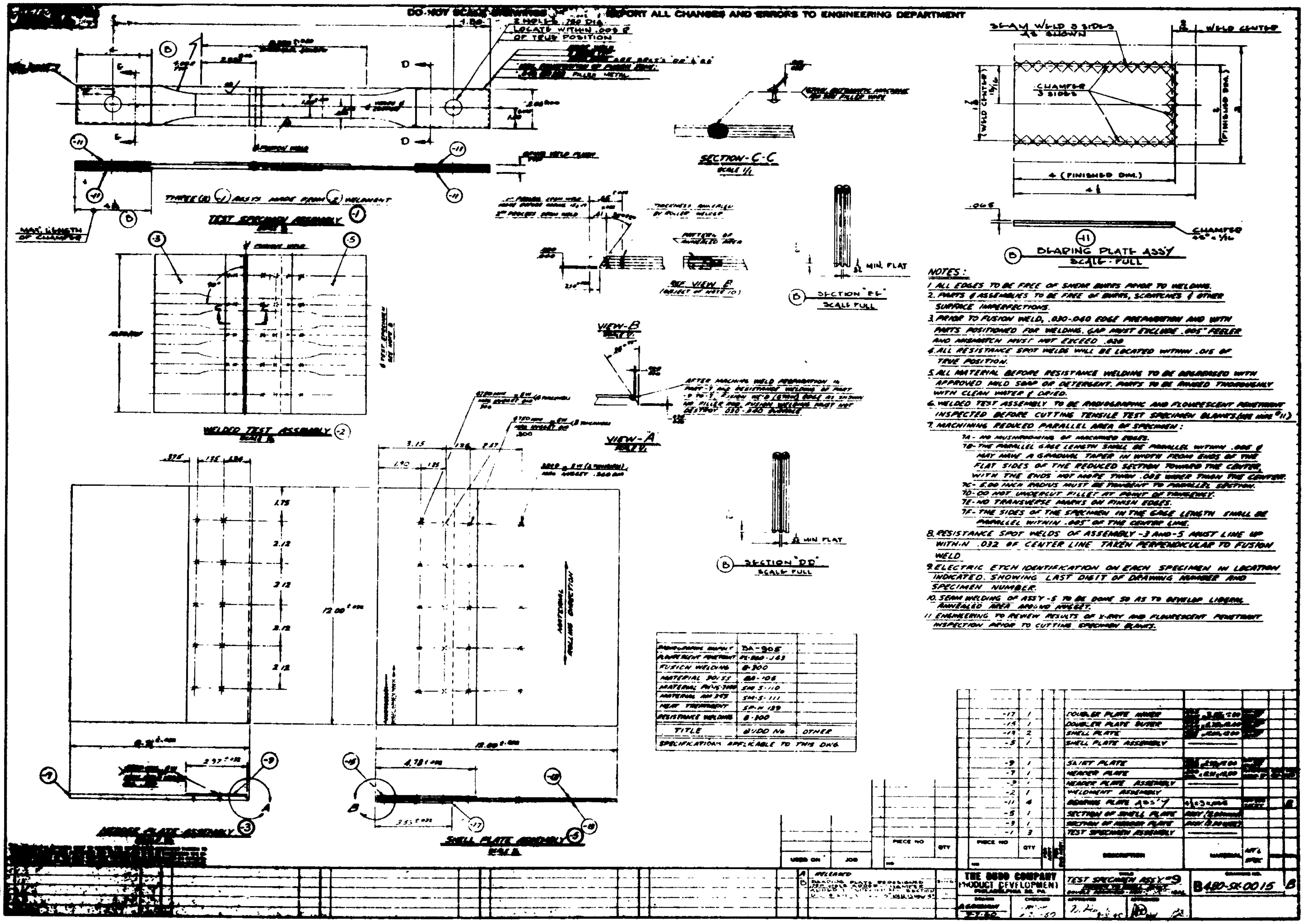

DO NOT SCALE DRAWINGS
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
2 HOLE'S .750 DIA. LOCATE WITHIN .005 OF TRUE POSITION
TEST SPECIMEN ASSEMBLY -1
SECTION-C-C
SCALE 1/1
SECTION E-E
SECTION D-D
1/32 MIN FLAT
WELDED TEST ASSEMBLY -2
VIEW-B
VIEW-A
SHELL PLATE ASSEMBLY -5
SEAM WELD 3 SIDES AS SHOWN
2 FINISH
3 5/16 WELD CTR.
4 FINISH DIM.
4 1/2
CHAMFER 3 SIDES 45°x1/16
BEARING PLATE ASS'Y-11
FULL SIZE
NOTES:
1 ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS
3 PRIOR TO FUSION WELD. .030-.040 EDGE PREPARATION AND WITH PARTS POSITIONED FOR WELDING GAP MUST EXCLUDE .005" FEELER AND MISMATCH MUST NOT EXCEED .020
4 ALL RESISTANCE SPOT WELDS WILL BE LOCATED WITHIN .015 OF TRUE POSITION
5 ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED
6 WELDED TEST ASSEMBLY TO BE RADIOGRAPHIC AND FLOURESCENT PENETRANT INSPECTED BEFORE CUTTING TENSILE TEST SPECIMEN BLANKS (SEE NOTE 10)
7 MACHINING REDUCED PARALLEL AREA OF SPECIMEN:
7A- NO MUSHROOMING OF MACHINED EDGES
7B- THE PARALLEL GAGE LENGTH SHALL BE PARALLEL WITHIN .005 & MAY HAVE A GRADUAL TAPER IN WIDTH FROM ENDS OF THE FLAT SIDES OF THE REDUCED SECTION TOWARD THE CENTER, WITH THE ENDS NOT MORE THAN .005 WIDER THAN THE CENTER
7C- 5.00 INCH RADIUS MUST BE TANGENT TO PARALLEL SECTION
7D- DO NOT UNDERCUT FILLET AT POINT OF TANGENCY
7E NO TRANSVERSE MARKS ON FINISH EDGES
7F- THE SIDES OF THE SPECIMEN IN THE GAGE LENGTH SHALL BE PARALLEL WITHIN .005" OF THE CENTER LINE.
8 RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD
9 ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED, SHOWING LAST TWO DIGITS OF DRAWING NUMBER AND SPECIMEN NUMBER
10- ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLOURESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS
TITLE
BUDD No
OTHER
SPECIFICATIONS APPLICABLE TO THIS DWG.
DOUBLER PLATE INNER
DOUBLER PLATE OUTER
SHELL PLATE
SHELL PLATE ASSEMBLY
SKIRT PLATE
HEADER PLATE
HEADER PLATE ASSEMBLY
WELDMENT ASSEMBLY
BEARING PLATE ASSEMBLY
SECTION OF SHELL PLATE
SECTION OF HEADER PLATE
TEST SPECIMEN ASSEMBLY
THE BUDD COMPANY
PRODUCT DEVELOPMENT
TEST SPECIMEN ASS'Y #2
B480-SK-0011
9-30-60



DO NOT SCALE DRAWINGS
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
LOCATE WITHIN .005 OF TRUE POSITION
THREE (3) -1 MADE FROM -2 WELDMENT
TEST SPECIMEN ASSEMBLY -1
WELDED TEST ASSEMBLY -2
SECTION - C-C
VIEW-B
VIEW-"A"
SECTION E-E
FULL SIZE
SECTION D-D
FULL SIZE
MATERIAL ROLLING DIRECTION
HEADER PLATE ASSEMBLY -3
SHELL PLATE ASSEMBLY -5
BEARING PLATE ASS'Y -11
FULL SIZE
1/16 × 45° CHAMFER (3 SIDES)
FINISH DIM.
4.50
NOTES:
1. ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS
8. RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD
9. ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED, SHOWING LAST TWO DIGITS OF DRAWING NUMBER AND SPECIMEN NUMBER.
10. ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLUORESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS
BA-905
B-300
BA-106
SM-5-110
SM-5-111
TITLE
BUDD No.
OTHER
SPECIFICATIONS APPLICABLE TO THIS DWG.
THE BUDD COMPANY
PRODUCT DEVELOPMENT
TEST SPECIMEN ASS'Y
B480-SK-0012
9-30-60


DO NOT SCALE DRAWINGS
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
2 HOLES .250 DIA.
LOCATE WITHIN .005 OF TRUE POSITION
THREE (3) -1 ASSYS MADE FROM -2 WELDMENT
TEST SPECIMEN ASSEMBLY -1
SECTION - C-C
SCALE 1/1
VIEW - B
VIEW - A
SECTION - E-E
FULL SIZE
SECTION - D-D
FULL SIZE
WELDED TEST ASSEMBLY -2
HEADER PLATE ASSEMBLY -3
SHELL PLATE ASSEMBLY -5
4 (FINISHED DIM.)
CHAMFER 45° x 1/16
BEARING PLATE ASS'Y
SCALE FULL
NOTES:
1. ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING.
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS.
3. PRIOR TO FUSION WELD, .030-.040 EDGE PREPARATION AND WITH PARTS POSITIONED FOR WELDING GAP MUST EXCLUDE .005" FEELER AND MISMATCH MUST NOT EXCEED .020
4. ALL RESISTANCE SPOT WELDS WILL BE LOCATED WITHIN .015 OF TRUE POSITION.
5. ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED.
6. WELDED TEST ASSEMBLY TO BE RADIOGRAPHIC AND FLOURESCENT PENETRANT INSPECTED BEFORE CUTTING TENSILE TEST SPECIMEN BLANKS (SEE NOTE 11)
7. MACHINING REDUCED PARALLEL AREA OF SPECIMEN:
7A - NO MUSHROOMING OF MACHINED EDGES
7B - THE PARALLEL GAGE LENGTH SHALL BE PARALLEL WITHIN .005 & MAY HAVE A GRADUAL TAPER IN WIDTH FROM ENDS OF THE FLAT SIDES OF THE REDUCED SECTION TOWARD THE CENTER, WITH THE ENDS NOT MORE THAN .005 WIDER THAN THE CENTER
7C - 5.00 INCH RADIUS MUST BE TANGENT TO PARALLEL SECTION
7D - DO NOT UNDERCUT FILLET AT POINT OF TANGENCY
7E - NO TRANSVERSE MARKS ON FINISH EDGES
7F - THE SIDES OF THE SPECIMEN IN THE GAGE LENGTH SHALL BE PARALLEL WITHIN .005" OF THE CENTER LINE.
8. RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD
9. ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED, SHOWING LAST DIGIT OF DRAWING NUMBER AND SPECIMEN NUMBER
10. SEAM WELDING OF ASS'Y -5 TO BE DONE SO AS TO DEVELOP RIBBON ANNEALED AREA AROUND NUGGET.
11. ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLOURESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS.
BA-905
B-300
BA-105
SM 5-110
SM-5-111
SP-H 139
B-300
TITLE
BUDD No
OTHER
SPECIFICATIONS APPLICABLE TO THIS DWG
-17 1 DOUBLER PLATE INNER
-15 1 DOUBLER PLATE OUTER
-19 2 SHELL PLATE
-5 1 SHELL PLATE ASSEMBLY
-9 1 SKIRT PLATE
-7 1 HEADER PLATE
-3 1 HEADER PLATE ASSEMBLY
-2 1 WELDMENT ASSEMBLY
-11 4 BEARING PLATE ASS'Y
-5 1 SECTION OF SHELL PLATE
-3 1 SECTION OF HEADER PLATE
-1 3 TEST SPECIMEN ASSEMBLY
PIECE NO
QTY
DESCRIPTION
MATERIAL
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.
TEST SPECIMEN ASSY #7
B480-SK-0013
B
9-30-60


DO NOT SCALE DRAWING
REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
2 HOLES .750 DIA. LOCATE WITHIN .005 OF TRUE POSITION
TEST SPECIMEN ASSEMBLY -1
WELDED TEST ASSEMBLY -2
SECTION - C-C
SECTION - E-E
SECTION - D-D
VIEW - A
VIEW - B
BEARING PLATE ASS'Y
SCALE - FULL
CHAMFER 3 SIDES
CHAMFER 45° x 1/16
SEAM WELD 3 SIDES AS SHOWN
NOTES:
1. ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING.
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS.
3. PRIOR TO FUSION WELD, .030-.040 EDGE PREPARATION AND WITH PARTS POSITIONED FOR WELDING, GAP MUST EXCLUDE .006" FEELER AND MISMATCH MUST NOT EXCEED .020
4. ALL RESISTANCE SPOT WELDS WILL BE LOCATED WITHIN .015 OF TRUE POSITION.
5. ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED.
6. WELDED TEST ASSEMBLY TO BE RADIOGRAPHIC AND FLOURESCENT PENETRANT INSPECTED BEFORE CUTTING TENSILE TEST SPECIMEN BLANKS (SEE NOTE 11)
7. MACHINING REDUCED PARALLEL AREA OF SPECIMEN:
7A - NO MUSHROOMING OF MACHINED EDGES.
7B - THE PARALLEL GAGE LENGTH SHALL BE PARALLEL WITHIN .005 & MAY HAVE A GRADUAL TAPER IN WIDTH FROM ENDS OF THE FLAT SIDES OF THE REDUCED SECTION TOWARD THE CENTER, WITH THE ENDS NOT MORE THAN .005 WIDER THAN THE CENTER.
7C - 5.00 INCH RADIUS MUST BE TANGENT TO PARALLEL SECTION.
7D - DO NOT UNDERCUT FILLET AT POINT OF TANGENCY.
7E - NO TRANSVERSE MARKS ON FINISH EDGES.
7F - THE SIDES OF THE SPECIMEN IN THE GAGE LENGTH SHALL BE PARALLEL WITHIN .005" OF THE CENTER LINE.
8. RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD.
9. ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED, SHOWING LAST DIGIT OF DRAWING NUMBER AND SPECIMEN NUMBER.
10. SEAM WELDING OF ASSY -5 TO BE DONE SO AS TO DEVELOP LIBERAL ANNEALED AREA AROUND NUGGET.
11. ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLUORESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS.
BA-905
B-300
BA-105
SM-5-110
SM-5-111
B-300
TITLE
BUDD No
OTHER
SPECIFICATIONS APPLICABLE TO THIS DWG
DOUBLER PLATE INNER
DOUBLER PLATE OUTER
SHELL PLATE
SHELL PLATE ASSEMBLY
SKIRT PLATE
HEADER PLATE
HEADER PLATE ASSEMBLY
WELDMENT ASSEMBLY
BEARING PLATE
SECTION OF SHELL PLATE
SECTION OF HEADER PLATE
TEST SPECIMEN ASSEMBLY
PIECE NO
QTY
DESCRIPTION
MATERIAL
HEADER PLATE ASSEMBLY -3
SHELL PLATE ASSEMBLY -5
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA
TEST SPECIMEN ASSY #B
B480-SK-0014
B


DO NOT SCALE DRAWINGS — REPORT ALL CHANGES AND ERRORS TO ENGINEERING DEPARTMENT
2 HOLES .750 DIA
LOCATE WITHIN .005 R OF TRUE POSITION
THREE (3) -1 ASSYS MADE FROM -2 WELDMENT
TEST SPECIMEN ASSEMBLY -1
MAX LENGTH OF CHAMFER
WELDED TEST ASSEMBLY -2
SECTION-C-C SCALE 1/1
SECTION "EE" SCALE FULL
SECTION "DD" SCALE FULL
MIN FLAT
VIEW-B
VIEW-A
MATERIAL ROLLING DIRECTION
HEADER PLATE ASSEMBLY -3
SHELL PLATE ASSEMBLY -5
SEAM WELD 3 SIDES AS SHOWN
WELD CENTER
CHAMFER 3 SIDES
4 (FINISHED DIM.)
CHAMFER 45° x 1/16
-11
DOUBLING PLATE ASSY
SCALE - FULL
NOTES:
1 ALL EDGES TO BE FREE OF SHEAR BURRS PRIOR TO WELDING.
2. PARTS & ASSEMBLIES TO BE FREE OF BURRS, SCRATCHES & OTHER SURFACE IMPERFECTIONS.
3. PRIOR TO FUSION WELD, .030-.040 EDGE PREPARATION AND WITH PARTS POSITIONED FOR WELDING. GAP MUST EXCLUDE .005" FEELER AND MISMATCH MUST NOT EXCEED .030
4. ALL RESISTANCE SPOT WELDS WILL BE LOCATED WITHIN .015 OF TRUE POSITION.
5. ALL MATERIAL BEFORE RESISTANCE WELDING TO BE DEGREASED WITH APPROVED MILD SOAP OR DETERGENT. PARTS TO BE RINSED THOROUGHLY WITH CLEAN WATER & DRIED.
6. WELDED TEST ASSEMBLY TO BE RADIOGRAPHIC AND FLOURESCENT PENETRANT INSPECTED BEFORE CUTTING TENSILE TEST SPECIMEN BLANKS (SEE NOTE #11)
7. MACHINING REDUCED PARALLEL AREA OF SPECIMEN:
7A - NO MUSHROOMING OF MACHINED EDGES.
7B - THE PARALLEL GAGE LENGTH SHALL BE PARALLEL WITHIN .005 & MAY HAVE A GRADUAL TAPER IN WIDTH FROM ENDS OF THE FLAT SIDES OF THE REDUCED SECTION TOWARD THE CENTER, WITH THE ENDS NOT MORE THAN .005 WIDER THAN THE CENTER.
7C - 5.00 INCH RADIUS MUST BE TANGENT TO PARALLEL SECTION.
7D - DO NOT UNDERCUT FILLET AT POINT OF TANGENCY.
7E - NO TRANSVERSE MARKS ON FINISH EDGES.
7F - THE SIDES OF THE SPECIMEN IN THE GAGE LENGTH SHALL BE PARALLEL WITHIN .005" OF THE CENTER LINE.
8. RESISTANCE SPOT WELDS OF ASSEMBLY -3 AND -5 MUST LINE UP WITHIN .032 OF CENTER LINE TAKEN PERPENDICULAR TO FUSION WELD
9. ELECTRIC ETCH IDENTIFICATION ON EACH SPECIMEN IN LOCATION INDICATED. SHOWING LAST DIGIT OF DRAWING NUMBER AND SPECIMEN NUMBER.
10. SEAM WELDING OF ASSY -5 TO BE DONE SO AS TO DEVELOP LIBERAL ANNEALED AREA AROUND NUGGET.
11 ENGINEERING TO REVIEW RESULTS OF X-RAY AND FLOURESCENT PENETRANT INSPECTION PRIOR TO CUTTING SPECIMEN BLANKS.
RADIOGRAPHIC INSPECT | BA-905
FLOURESCENT PENETRANT | PL-860-J43
FUSION WELDING | B-300
MATERIAL 301 SS | BA-106
MATERIAL AMS 5... | SM 5-110
MATERIAL AM 355 | SM-5-111
HEAT TREATMENT | SP-H 139
RESISTANCE WELDING | B-300
TITLE | BUDD No | OTHER
SPECIFICATIONS APPLICABLE TO THIS DWG
-17 | 1 | DOUBLER PLATE INNER
-15 | 1 | DOUBLER PLATE OUTER
-13 | 2 | SHELL PLATE
-5 | 1 | SHELL PLATE ASSEMBLY
-9 | 1 | SKIRT PLATE
-7 | 1 | HEADER PLATE
-3 | 1 | HEADER PLATE ASSEMBLY
-2 | 1 | WELDMENT ASSEMBLY
-11 | 4 | DOUBLING PLATE ASS'Y
-5 | 1 | SECTION OF SHELL PLATE
-3 | 1 | SECTION OF HEADER PLATE
-1 | 3 | TEST SPECIMEN ASSEMBLY
PIECE NO | QTY | DESCRIPTION | MATERIAL | MAT'L SPEC
USED ON | JOB
A RELEASED
THE BUDD COMPANY
PRODUCT DEVELOPMENT
PHILADELPHIA 32, PA.
TEST SPECIMEN ASSY #9
B480-SK0015 B

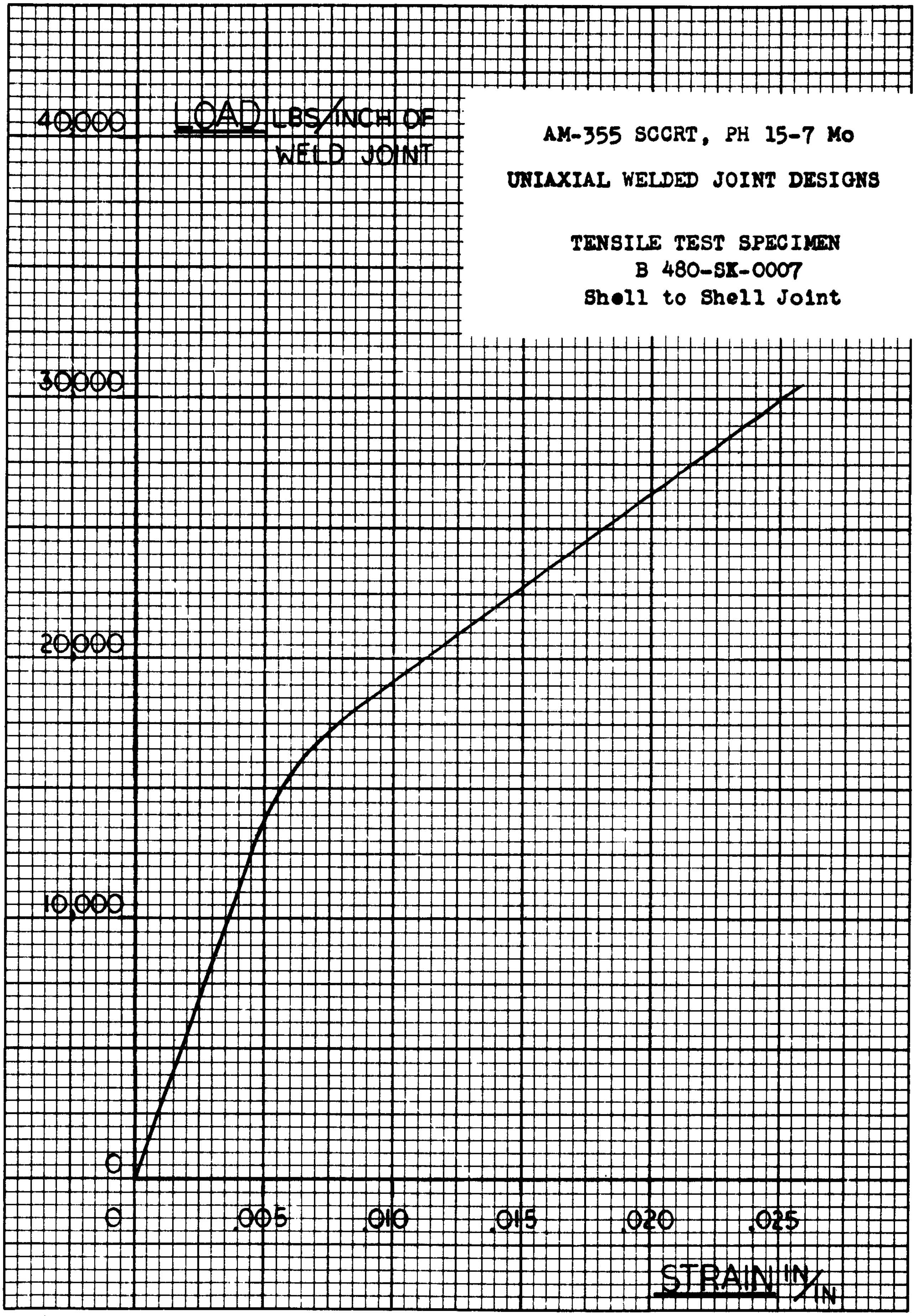
APPENDIX C

PREPARED BY: Fox, C.R.	THE BUDD COMPANY PRODUCT DEVELOPMENT PHILADELPHIA, PA.	PAGE NO. OF
CHECKED BY:		REPORT NO.
DATE:	AM-355 SCCRT, PH 15-7 MO UNIAXIAL WELDED JOINT DESIGNS	PROJECT NO.

DISCUSSION OF JOINT FAILURE

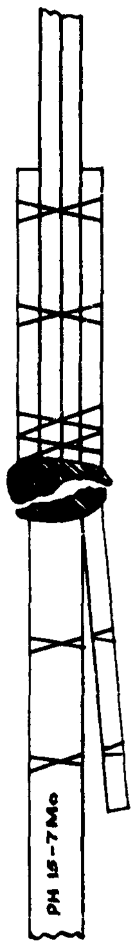
TENSILE TEST SPECIMEN B 480-SK-0007
Shell to Shell Joint

1. Initial failure occured 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.


AM-355 SCCRT, PH 15-7 Mo
UNIAXIAL WELDED JOINT DESIGNS
TENSILE TEST SPECIMEN
B 480-SK-0007
Shell to Shell Joint
LOAD LBS/INCH OF WELD JOINT
40,000
30,000
20,000
10,000
0
0
.005
.010
.015
.020
.025
STRAIN IN/IN

PREPARED BY: Fox, C.R.	THE BUDD COMPANY PRODUCT DEVELOPMENT PHILADELPHIA, PA.	PAGE NO. OF
CHECKED BY:		REPORT NO.
DATE:	AM-355 SCCRT, PH-15-7-MO UNIAXIAL WELDED JOINT DESIGNS	PROJECT NO.

DISCUSSION OF JOINT FAILURE



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

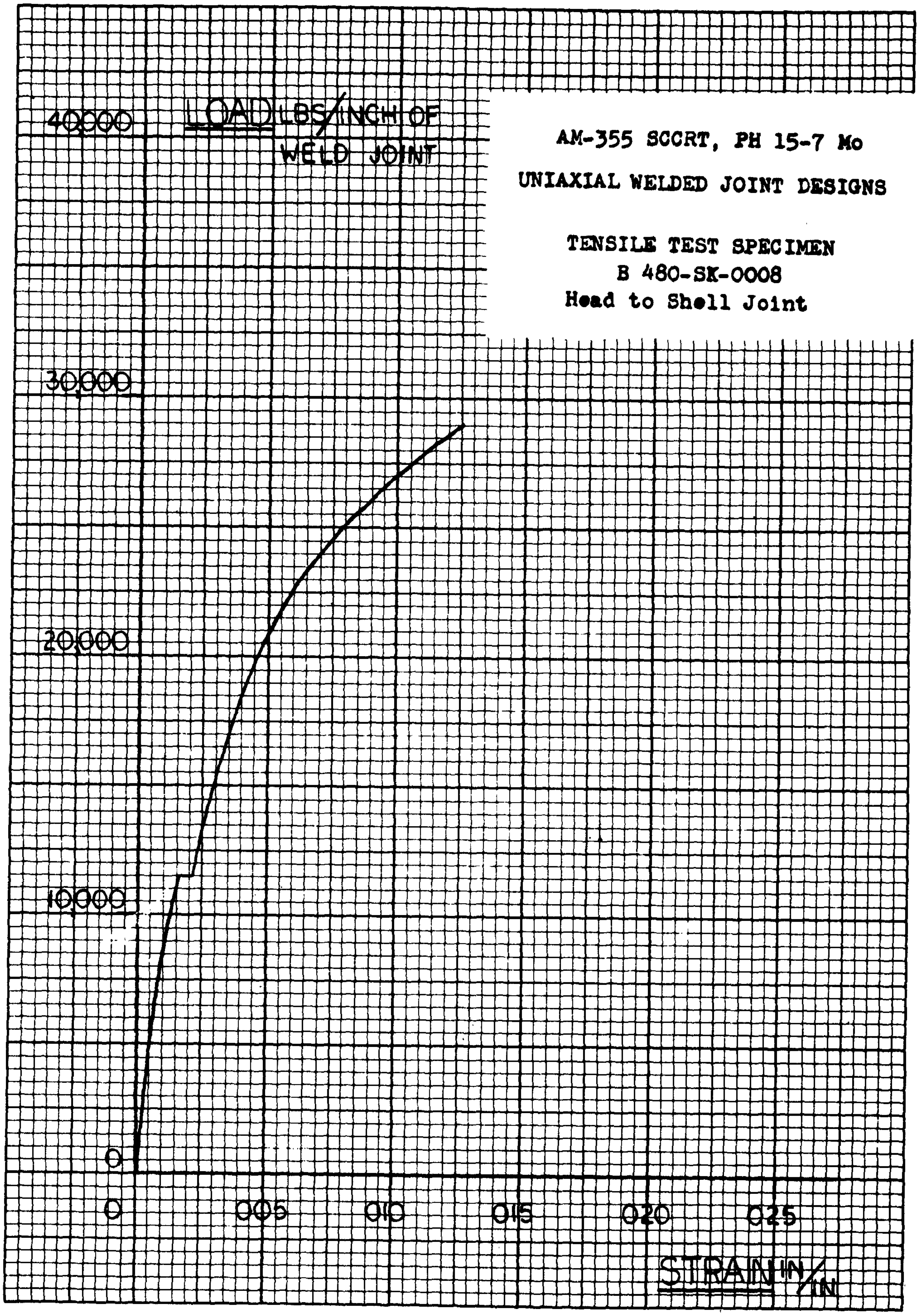
1. Initial failure occurred in the two spot welds holding the AM-355 doubler to the PH 15-7 Mo plate. These welds sheared at approximately 28,000 pounds per linear inch of fusion weld. At this load the spot welds were carrying a total of 8250 pounds.

   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.

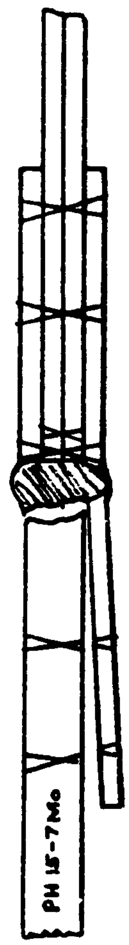
2. The joint failed in the fusion weld at a load of 28,850 pounds per linear inch of fusion weld. A maximum strain of 0.0125 inches per inch was recorded.

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.

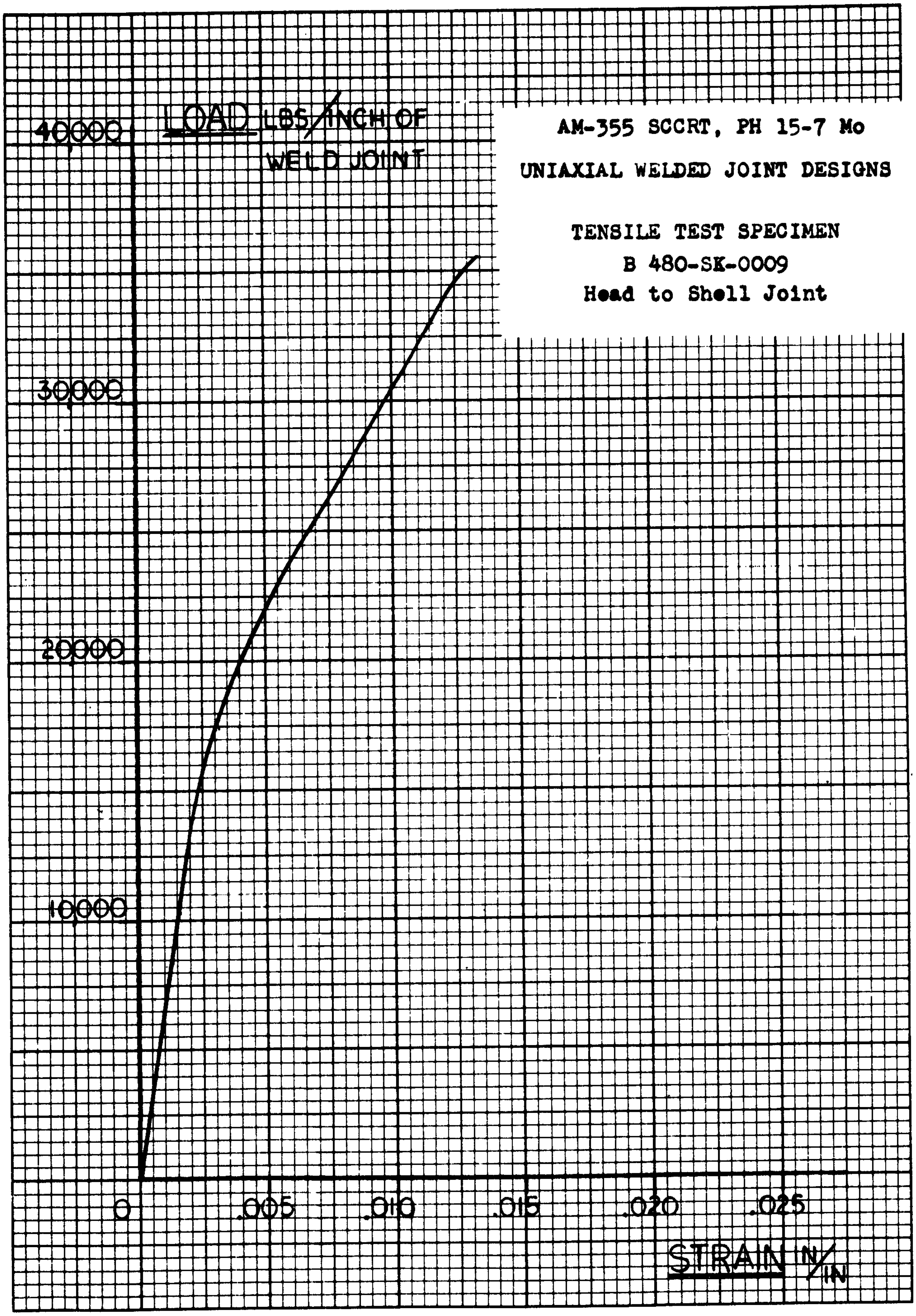

AM-355 SCCRT, PH 15-7 Mo
UNIAXIAL WELDED JOINT DESIGNS
TENSILE TEST SPECIMEN
B 480-SK-0008
Head to Shell Joint
LOAD LBS/INCH OF WELD JOINT
40,000
30,000
20,000
10,000
0
0
.005
.010
.015
.020
.025
STRAIN IN/IN

DISCUSSION OF JOINT FAILURE



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

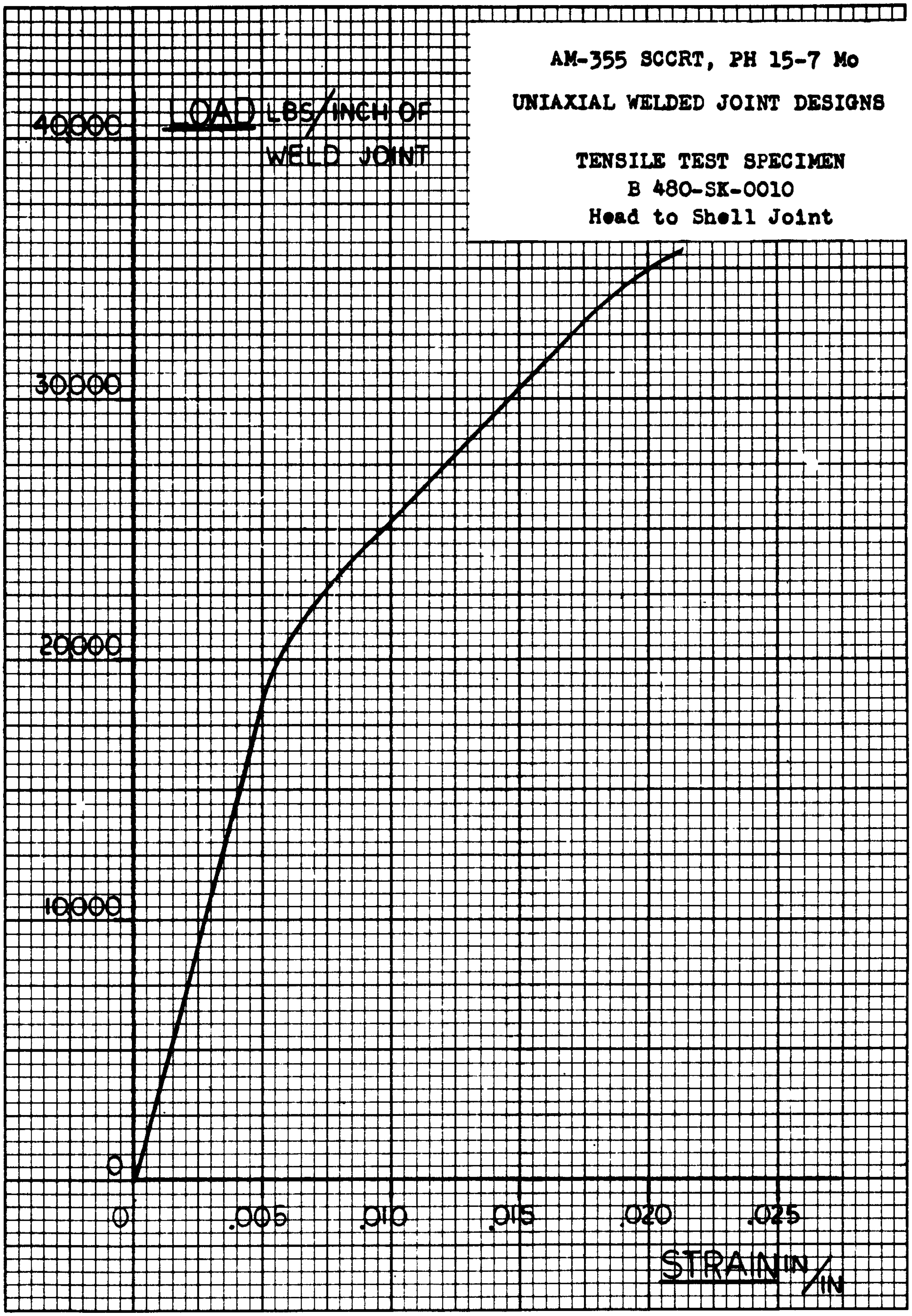
1. Initial failure occurred in the spot welds holding the AM-355 doubler to the PH 15-7 Mo plate. These spot welds failed in shear.
2. There was noticeable straining in the fusion weld area before the spot weld failures. When the doubler on the PH 15-7 Mo plate was no longer transmitting its share of 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.


LOAD LBS/INCH OF WELD JOINT
40000
30000
20000
10000
0
.005
.010
.015
.020
.025
STRAIN IN/IN
AM-355 SCCRT, PH 15-7 Mo
UNIAXIAL WELDED JOINT DESIGNS
TENSILE TEST SPECIMEN
B 480-SK-0009
Head to Shell Joint

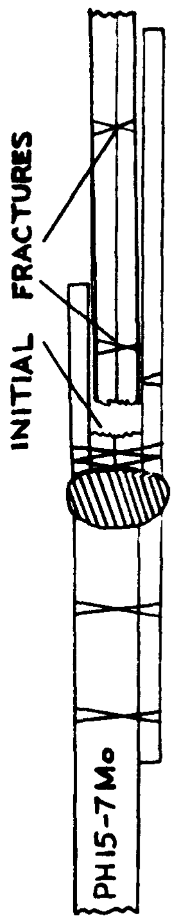
DISCUSSION OF JOINT FAILURE

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
LOAD LBS/INCH OF WELD JOINT
40000
30000
20000
10000
0
0
.005
.010
.015
.020
.025
STRAIN IN/IN

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

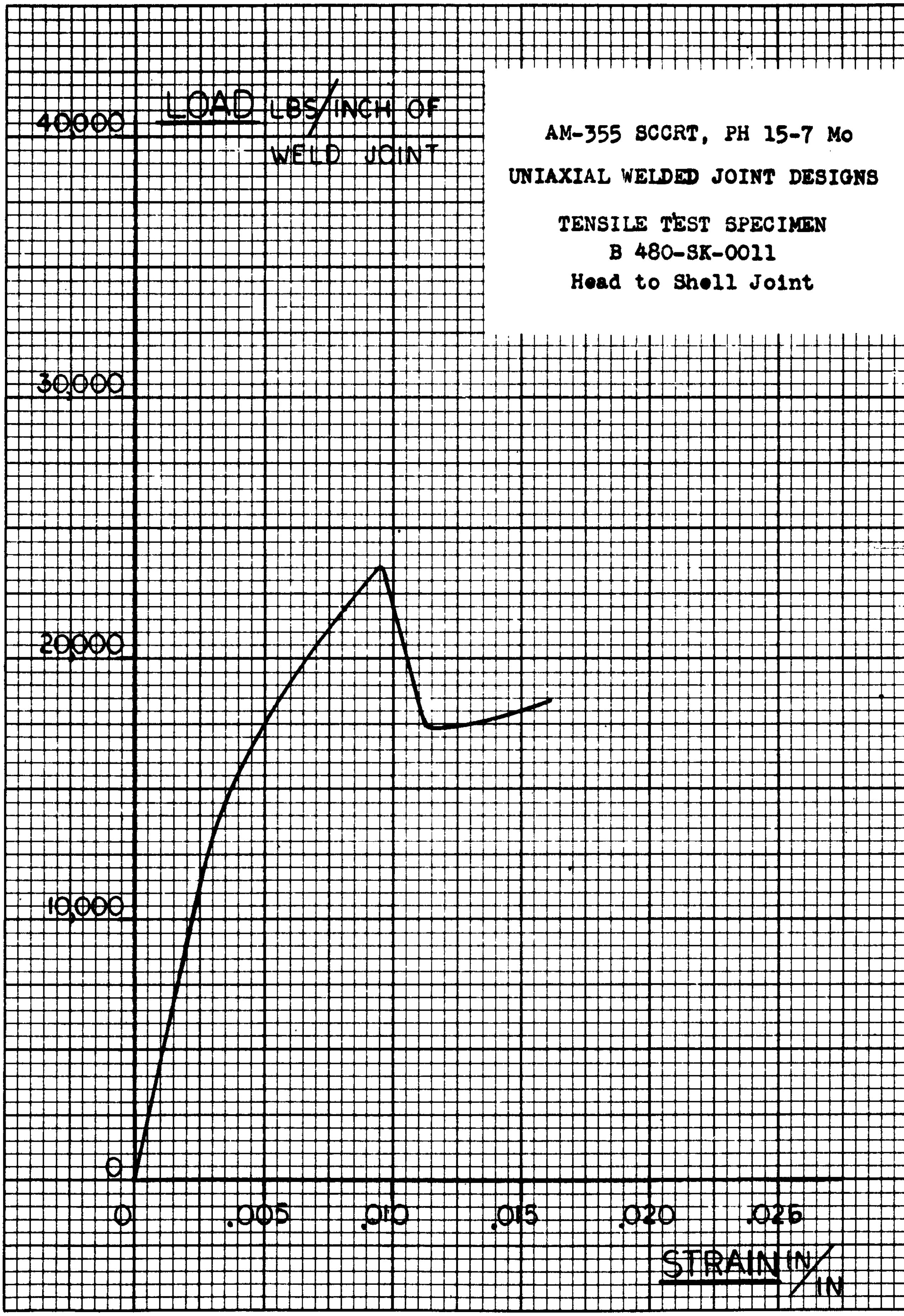


DISCUSSION OF JOINT FAILURE

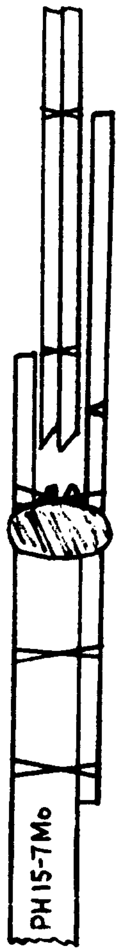
TENSILE TEST SPECIMEN B 480-SK-0011
Head to Shell Joint

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.



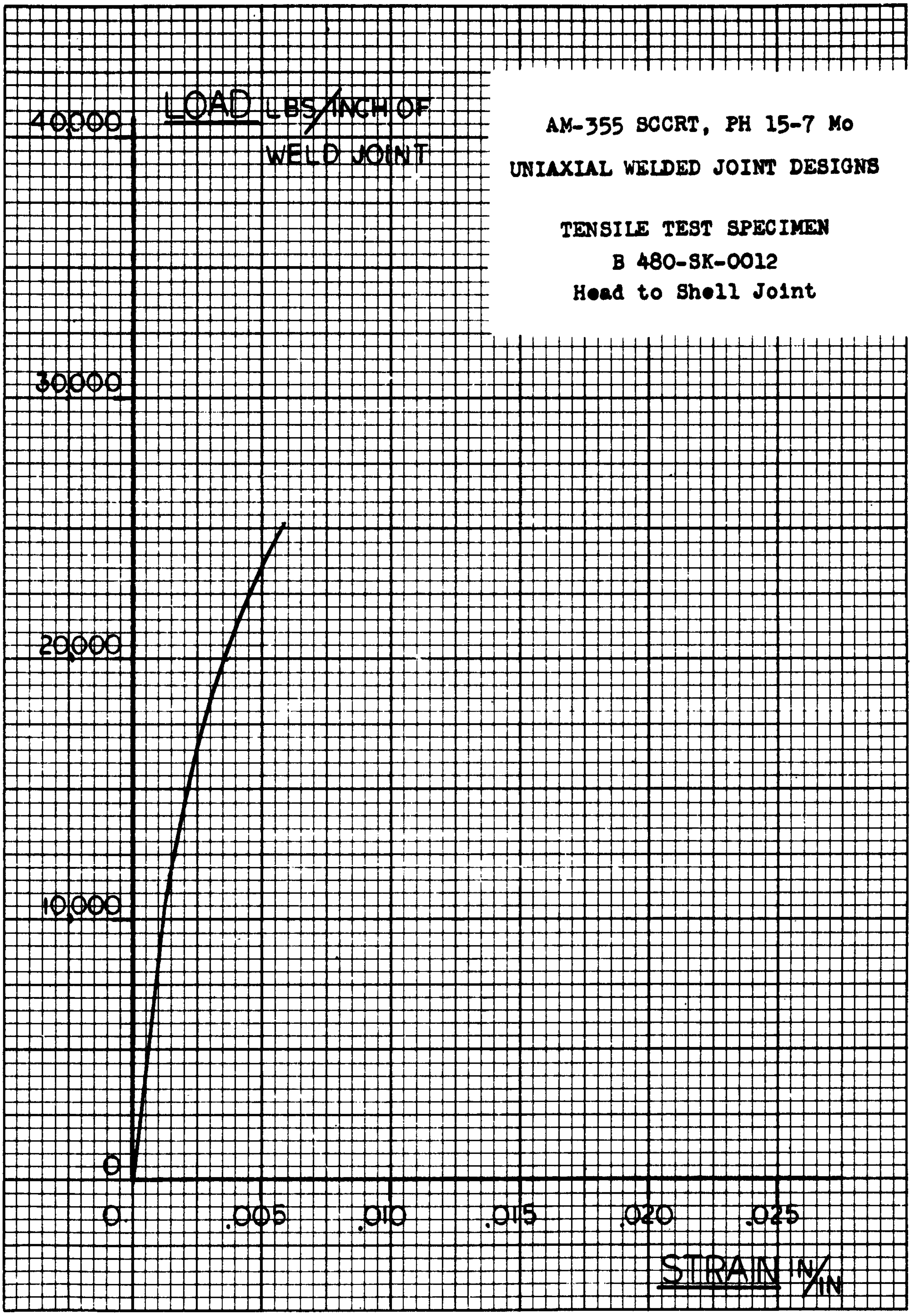
AM-355 SCCRT, PH 15-7 Mo
UNIAXIAL WELDED JOINT DESIGNS
TENSILE TEST SPECIMEN
B 480-SK-0011
Head to Shell Joint



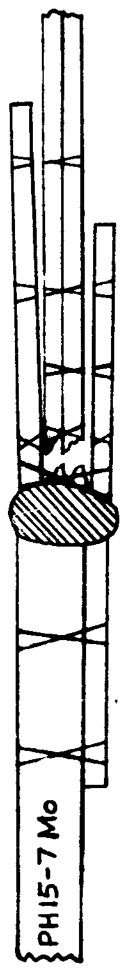
DISCUSSION OF JOINT FAILURE

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.


AM-355 SCCRT, PH 15-7 Mo
UNIAXIAL WELDED JOINT DESIGNS
TENSILE TEST SPECIMEN
B 480-SK-0012
Head to Shell Joint
LOAD LBS/INCH OF WELD JOINT
40,000
30,000
20,000
10,000
0
0.
.005
.010
.015
.020
.025
STRAIN IN/IN

PREPARED BY: Fox, C.R.	**THE BUDD COMPANY** **PRODUCT DEVELOPMENT** PHILADELPHIA, PA.	PAGE NO. OF
CHECKED BY:		REPORT NO.
DATE:	AM-355 SCCRT, PH 15-7 MO UNIAXIAL WELDED JOINT DESIGNS	PROJECT NO.



DISCUSSION OF JOINT FAILURE

TENSILE TEST SPECIMEN B 480-SK-0013

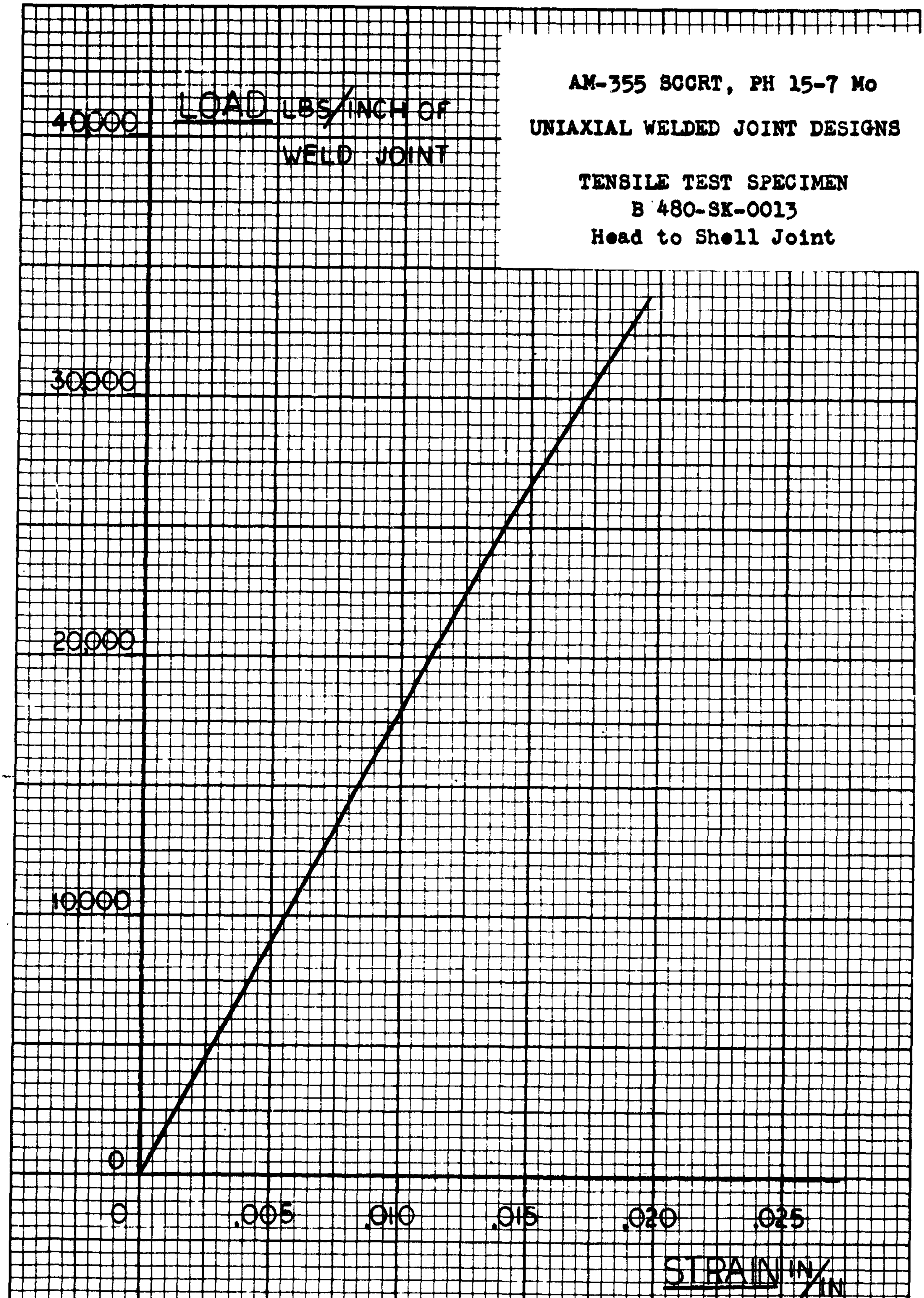
Head to Shell Joint

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.

AM-355 SCCRT, PH 15-7 Mo

UNIAXIAL WELDED JOINT DESIGNS

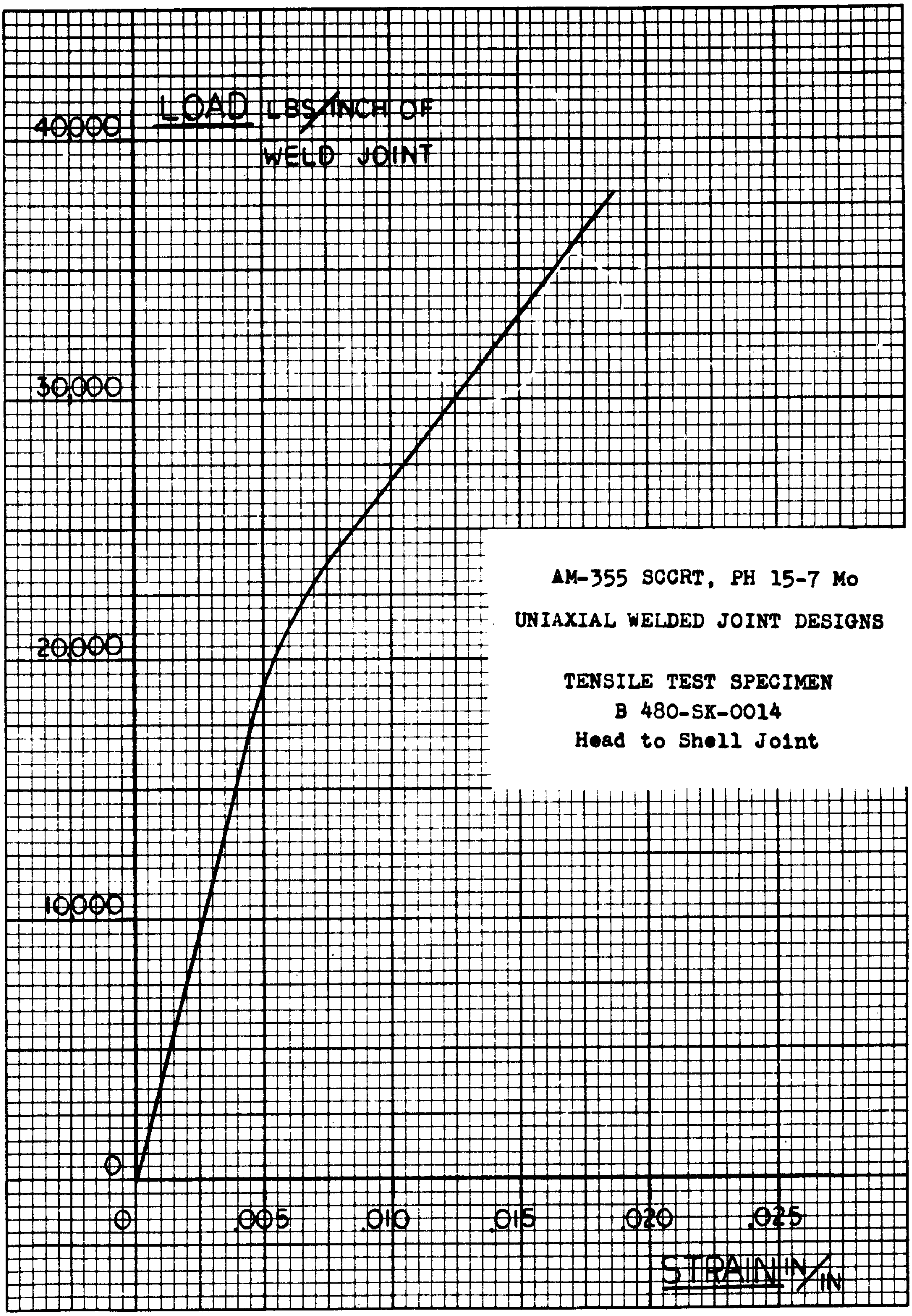
TENSILE TEST SPECIMEN
B 480-SK-0013
Head to Shell Joint



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.



AM-355 SCCRT, PH 15-7 Mo

UNIAXIAL WELDED JOINT DESIGNS

TENSILE TEST SPECIMEN
B 480-SK-0014
Head to Shell Joint

PREPARED BY: Fox, C.R.	THE BUDD COMPANY PRODUCT DEVELOPMENT PHILADELPHIA, PA.	PAGE NO. OF
CHECKED BY:		REPORT NO.
DATE:	AM-355 SCCRT, PH 15-7 MO UNIAXIAL WELDED JOINT DESIGNS	PROJECT NO.

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.

AM-355 SCCRT, PH 15-7 Mo

UNIAXIAL WELDED JOINT DESIGNS

TENSILE TEST SPECIMEN

B 480-SK-0015

Head to Shell Joint