WANL-PR(P)-010
NASA-CR-54975

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 2.00

Microfiche (MF) .75

ff 653 July 65

FACILITY FORM 602

N66 27743	
(ACCESSION NUMBER)	(THRU)
30	1
(PAGES)	(CODE)
CR-54975	17
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

DETERMINATION OF THE WELDABILITY AND ELEVATED TEMPERATURE STABILITY OF REFRACTORY METAL ALLOYS

Tenth Quarterly Report

by

G. G. Lessmann and D. R. Stoner

prepared for

National Aeronautics and Space Administration
Lewis Research Center
Space Power Systems Division
Under Contract NAS 3-2540

Astronuclear Laboratory
Westinghouse Electric Corporation

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Covering the Period

September 21, 1965 to December 20, 1965

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Contract NAS 3-2540

Technical Management
NASA-Lewis Research Center
Cleveland, Ohio
Space Power Systems Division
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FOREWORD

This report describes work accomplished under Contract NAS 3-2540 during the period September 21, 1965 to December 20, 1965. This program is being administered by R. T. Begley of the Astronuclear Laboratory, Westinghouse Electric Corporation. G. G. Lessmann and D. R. Stoner are responsible for the performance of this investigation.

Mr. P. E. Moorhead of the National Aeronautics and Space Administration is Technical Manager of this program.

TABLE OF CONTENTS

Astronuclear Laboratory

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

This is the Tenth Quarterly Progress Report describing work accomplished under Contract NAS 3-2540. The objective of this program is to determine the weldability and long time elevated temperature stability of promising refractory metal alloys in order to select those most suitable for use in advanced alkali-metal space electric power systems. Alloys included in this investigation are listed in Table 1. A detailed discussion of the program and program objectives was presented in the First Quarterly Report.[1] As an addition to this program, an evaluation of the effect of oxygen contamination on the weldability and thermal stability of refractory metal alloys has been undertaken. Three alloys, including T-111, T-222, and FS-85 will be evaluated. A detailed discussion and outline of this study was presented in the Seventh Quarterly Report.[2]

Process and test controls employed throughout this program emphasize the important influence of interstitial elements on the properties of refractory metal alloys. Stringent process and test procedures are required, including continuous monitoring of the TIG weld chamber atmosphere, electron beam welding in a 10^{-6} torr vacuum, aging in furnaces employing hydrocarbon free pumping systems providing pressures less than 10^{-8} torr, and chemical sampling following successive stages of the evaluation for verification of these process controls.

Equipment requirements and set-up, and procedures for welding and testing, have been described in previous progress reports. Any improvements in processes, changes in procedures, or additional processes and procedures are described in this report.

II. SUMMARY

Thermal stability studies were initiated. This phase of the program includes long time-high temperature aging studies conducted in ultra-high vacuum furnaces operating at approximately 10^{-10} torr pressure. Aging temperatures range from 1500°F to 2400°F, while selected aging times extend to 10,000 hours. Base metal, gas tungsten arc welds, and electron beam welds are included. All specimens were machined to final test configuration prior to aging to avoid accidental machining losses after the considerable investment of time and effort accrued during aging. 2700 bend specimens and 610 tensile specimens were prepared, inspected, and post weld annealed for the aging studies.

The 100 hour aging study was completed and the effect on bend ductile-to-brittle transition behavior was determined. A detailed discussion of this data will be deferred until more aging runs are completed.

The first phase of the oxygen contamination program has been completed and all results except tensile test data are available. The weld restraint patch tests have been completed and no tendency towards hot or cold cracking was observed as the oxygen content was increased. All of the Second Phase samples have been oxygen contaminated, diffusion annealed and welded, and the 1000 hour aging treatments have been initiated.

III. TECHNICAL PROGRAM

A. 10,000 HOUR THERMAL STABILITY STUDY

Elevated temperature thermal stability studies of the refractory metal alloys were initiated during this period. Incorporation of this effort into the weldability evaluation reflects the long time application orientation of this program. This is a logical phase of the weldability study since damaging instabilities are most likely to occur in the weld or adjacent thermally disturbed base metal. The purpose of this phase is to identify high temperature thermal responses, their causes and effects, and use this information as an application oriented weldability rating of refractory metal alloys.

Aging is accomplished in ultra-high vacuum furnaces which are roughed out and held at vacuum with "oil-free" pumping systems, Figure 1. The systems were designed to hold a vacuum of 10^{-8} torr or better using 500 l/sec sputter-ion pumps. Actual pressures during aging runs are running at about 10^{-10} torr or lower. The use of exceptionally clean vacuum furnace systems are desirable in this program because of the extreme reactivity of the refractory metal alloys. Furnace performance characteristics under load were previously determined and reported.[3,4]

Alloy performance in the aging study will be evaluated on the basis of ductility, as defined by ductile-to-brittle transition behavior, strength and fracture behavior at ambient and elevated temperature, and metallurgical structure. Bend testing will be conducted in both longitudinal and transverse directions for all conditions. Procedures for bend and tensile testing, as well as specimen designs, will be the same as employed in the weldability evaluations.[5,6] Welding and post weld annealing schedules used in specimen preparation reflect conditions for optimized ductility. The optimum schedules employed are listed in Table 2.

The scope of the aging study can be gaged from Figure 2 which shows the aging times chosen for each alloy for each of the four aging temperatures, $1500^{\circ}F$, $1800^{\circ}F$, $2100^{\circ}F$, and $2400^{\circ}F$. This effort alone requires 2700 bend specimens. Longitudinal and transverse bend transition curves for base metal, gas tungsten arc welds and electron beam welds will be generated following each long time age. Not all alloys will receive a full evaluation, reflecting the screening aspect of the weldability study.

A typical tensile test schedule for one alloy processed through a complete aging study is shown in Figure 3. All the tensile specimens required for the aging study have been prepared. Weld specimens were ground with flat parallel surfaces. Both base and weld specimens received optimum post-weld anneals as did bend specimens (see Table 2). Elevated temperature tensile tests are conducted at pressures of approximately 10^{-6} torr.

The tensile test loading for the aging study is as follows:

Weld and Base Metal Elevated Temperature Tensiles	366
Weld Room Temperature Tensiles	131
Base Metal Room Temperature Tensiles	113
Total Tensile Tests	610

Results — During this period all specimens were prepared for the entire program, the 100 hour age was completed at all four temperatures, and testing of the bend specimens from this run were completed. The 100 hour age bend test data are summarized in Table 3. Also included are data from a preliminary screening test run at 1700°F. Additional pre-screen aging data on non-post weld annealed FS-85, T-111, and T-222 were presented in a previous report.[2]

The solid solution alloys demonstrated little, if any, thermal aging responses as measured by shifts in the bend ductile-to-brittle transition temperature after 100-hour aging, Table 3. T-111 and T-222 gas tungsten arc welds seem to be responding to the 2100°F age. In the absence of additional data, it is not clear if this represents normal scatter or a real response. The remaining alloys show stronger and more definite trends which should become more clearly defined as data from longer ages becomes available. It seems reasonably certain that all the higher strength alloys (i.e. those containing a reactive element either zirconium or hafnium) will respond to aging in varying degrees.

B. EFFECT OF OXYGEN CONTAMINATION ON WELDABILITY

The effect of oxygen contamination on the weldability and thermal stability of three selected refractory metal alloys (FS-85, T-111, and T-222) is being evaluated as an additional program to the overall weldability study. Gaseous oxidation with a low partial pressure of oxygen in helium carrier gas is being used to contaminate 0.035-inch alloy sheet. At the doping temperatures employed, from $800^{\circ}F$ to $1100^{\circ}F$, and a oxygen partial pressure range of 10^{-1} to 1 torr, an adherent oxide film is produced which is subsequently diffusion annealed at higher temperatures. The apparatus and process control are described in detail in a preceding report.[2] Figure 4 outlines the overall contamination program. The overall program specimen requirements are shown in Figure 5.

Phase I is complete with all the data available except tensile test results. The oxygen contamination, diffusion annealing, welding, and specimen preparation has been completed for the second phase and the 1000 hour ultra-high vacuum aging at three temperatures is being started. Bend ductility and tensile testing will follow the aging operation. Bend ductility and tensile tests will include both weld and base metal specimens in this phase of the program. Table 4 is a complete listing of the 120 Phase I specimens which include restraint tests, bend ductility tests, and tensile tests. The oxygen contamination, calculated in weight ppm from the weight gain after diffusion annealing, is listed with the specimen identification number. Good correlation has been obtained between chemical analysis and weight gain and a complete summary will be included in a later report.

The weld restraint patch tests have been completed and the results are shown in Table 5. No evidence of cracking, either in the weld or base metal, was observed and thus no correlation was obtained betwen oxygen level and weld restraint sensitivity. Weld restraint results are presented for the 100 ppm, 200 ppm, and 1000 ppm oxygen levels in this report. The results of the two other oxygen levels, uncontaminated, and 500 ppm oxygen,were presented in a previous report.[7]

The patch tests are fabricated from two 2 inch x 4 inch sheet specimens wherein the first weld is a butt weld forming a 4 inch square specimen on which a circle and final cross is welded. A dye penetrant inspected sample is shown in Figure 6. The initial butt weld was overpenetrated in the high oxygen level T-222 sample and the sample was ruined. Re-shearing and subsequent weld repair was unsuccessful because of the extreme brittleness of the specimen. It must be emphasized that considerable work was involved in preparing bend ductility and tensile specimens at the higher oxygen levels, since shearing could not be used on the brittle specimens. Bend specimens were prepared and tensile specimens were rough cut using electro-discharge machining and an abrasive cutoff wheel.

IV. FUTURE WORK

The 1000 hour aging run of the thermal stability study should be completed and preliminary test results obtained.

Three 1000 hour aging runs will be begun at temperatures of 1500°F, 1800°F, and 2200°F for the oxygen contamination program. Tensile testing for Phase I will be completed and the results evaluated.

V. REFERENCES

1. G. G. Lessmann and D. R. Stoner, "Determination of the Weldability and Thermal Stability of Refractory Metal Alloys", First Quarterly Progress Report, Westinghouse Astronuclear Laboratory, WANL-PR-(P)-001.

2. G. G. Lessmann and D. R. Stoner, "Determination of the Weldability and Thermal Stability of Refractory Metal Alloys", Seventh Quarterly Report, Westinghouse Astronuclear Laboratory, WANL-PR-(P)-007, NASA-CR-54434.

3. D. R. Stoner and G. G. Lessmann, "Operation of 10^{-10} Torr Vacuum Heat Treating Furnaces in Routine Processing", Transactions of the Eighth Annual Conference on Vacuum Metallurgy, American Vacuum Society, June, 1965.

4. G. G. Lessmann and D. R. Stoner, "Determination of the Weldability and Thermal Stability of Refractory Metals Alloys", Fifth Quarterly Progress Report, Westinghouse Astronuclear Laboratory, WANL-PR-(P)-005, NASA-CR-54232.

5. G. G. Lessmann and D. R. Stoner, "Determination of the Weldability and Thermal Stability of Refractory Metal Alloys", Ninth Quarterly Progress Report, Westinghouse Astronuclear Laboratory, WANL-PR-(P)-009, NASA-CR-54923.

6. G. G. Lessmann and D. R. Stoner, "Determination of the Weldability and Thermal Stability of Refractory Metal Alloys", Third Quarterly Progress Report, Westinghouse Astronuclear Laboratory, WANL-PR-(P)-003, NASA-CR-54088.

7. G. G. Lessmann and D. R. Stoner, "Determination of the Weldability and Thermal Stability of Refractory Metal Alloys", Eighth Quarterly Progress Report, Westinghouse Astronuclear Laboratory, WANL-PR-(P)-008, NASA-CR-54723.

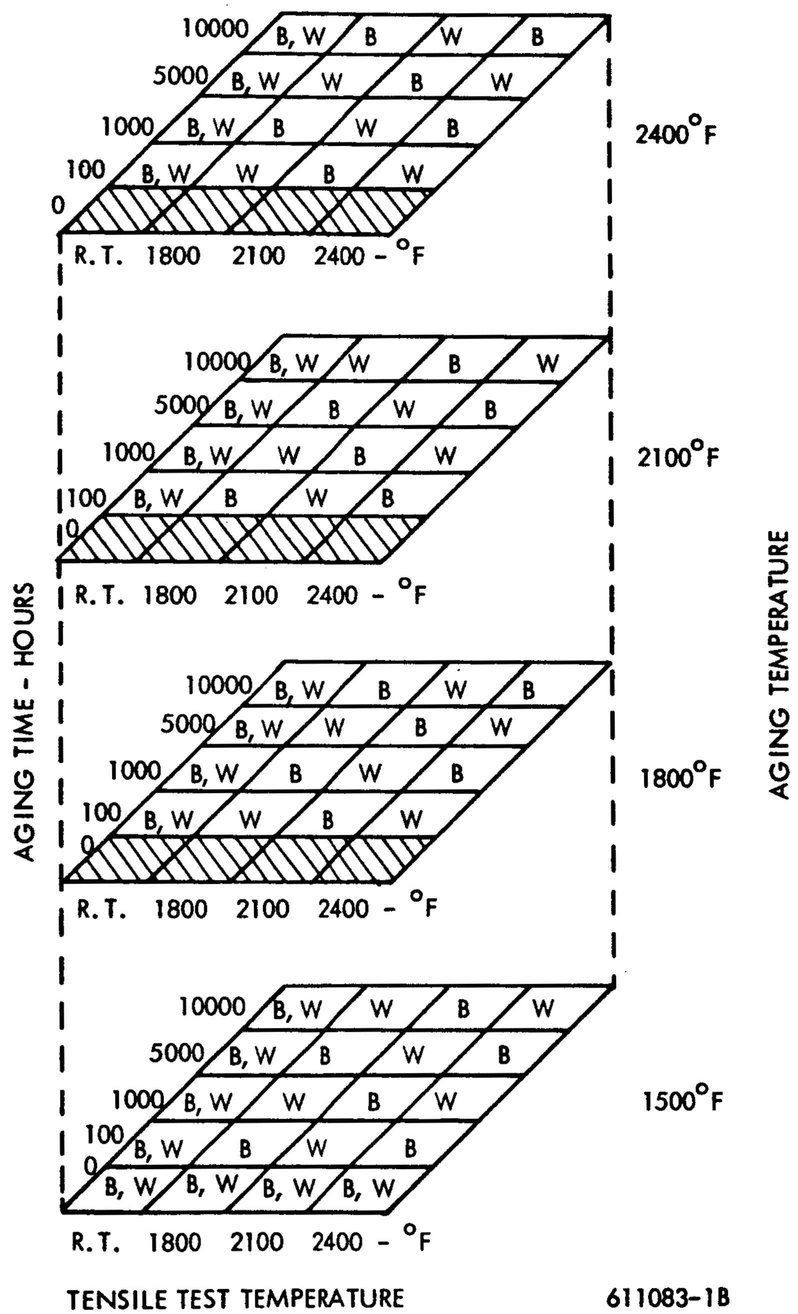
FIGURE 1 - Ultra-High Vacuum (10^{-10} Torr) Heat Treating Laboratory for 10,000 Hour Aging Study

Alloy	Aging Time, Hours(1)			
	100	1000	5000(2)	10,000
B-66	X	X	X	--
D-43	X	X	--	X
D-43Y	X	X	--	--
Cb-752	X	X	--	--
SCb-291	X	X	--	--
C-129Y	X	X	--	--
Ta-10W	X	X	--	--
AS-55	--	--	--	--
FS-85	X	X	X	X
T-111	X	X	X	X
T-222	X	X	X	X

(1) Each age indicated at 1500°F, 1800°F, 2100°F, and 2400°F.

(2) Furnace load run simultaneous with 10,000 Hr. run.

FIGURE 2 - Aging Schedule for Long Time Thermal Stability Study



B = BASE METAL SPECIMEN
W = WELD METAL SPECIMEN
\\\ = DUPLICATE CONDITION, NOT RETESTED

FIGURE 3 - Typical Tensile Test Schedule for Aged Specimens

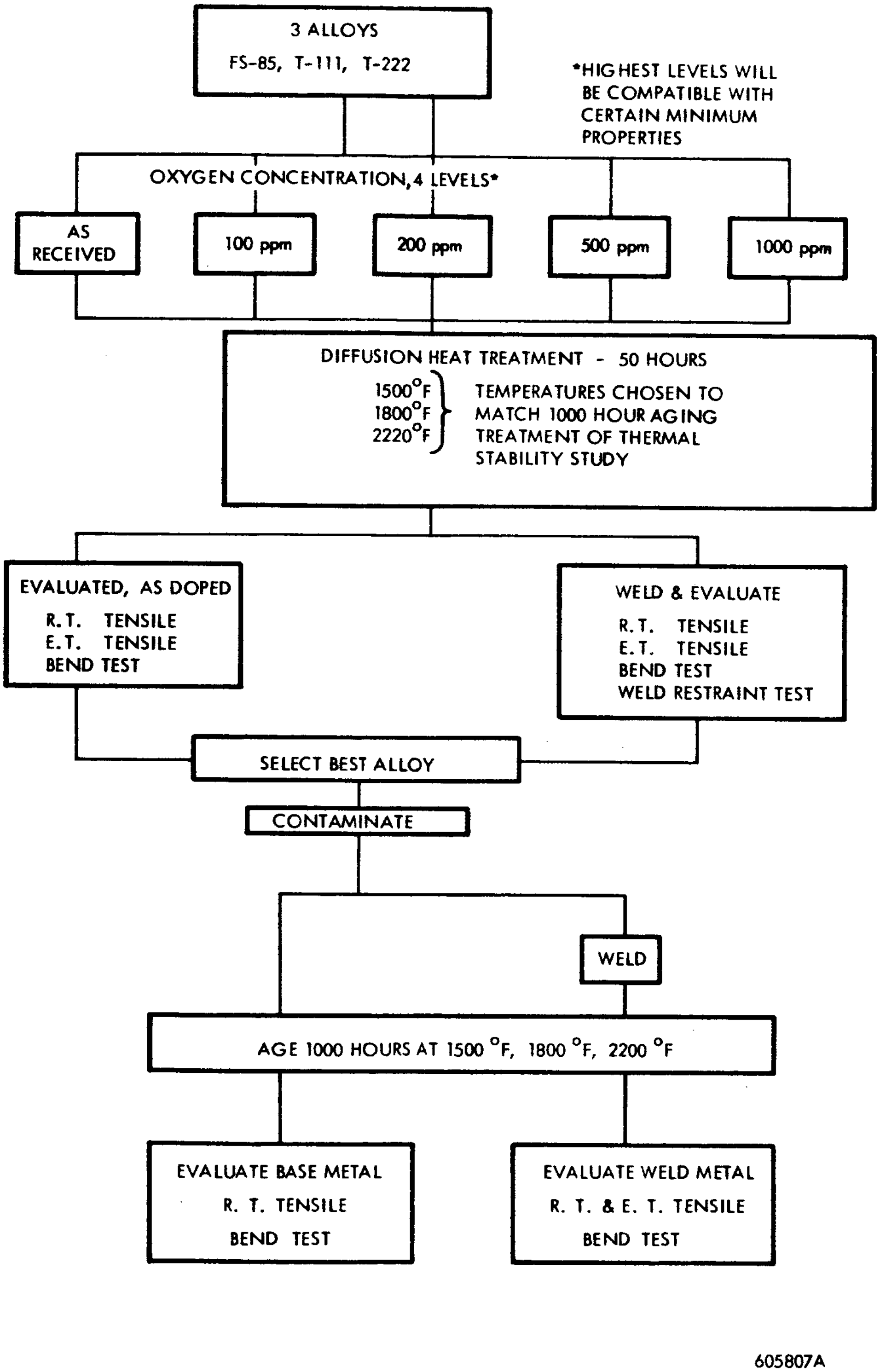
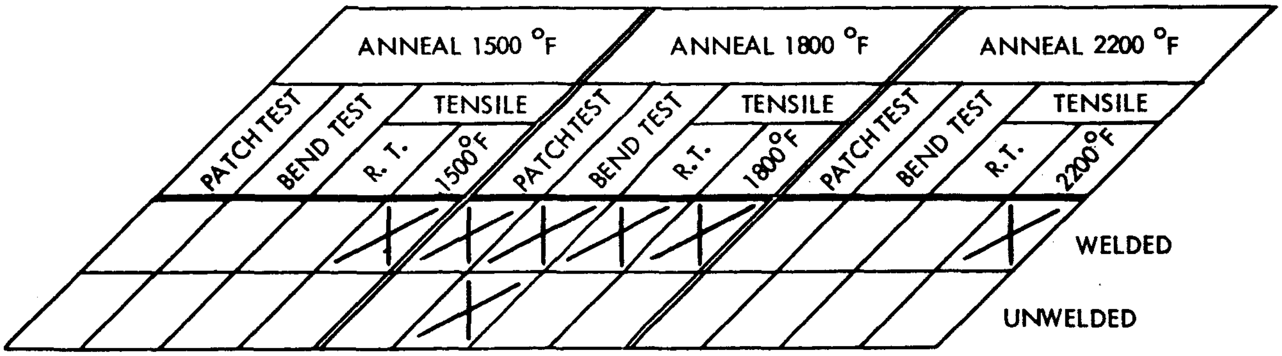
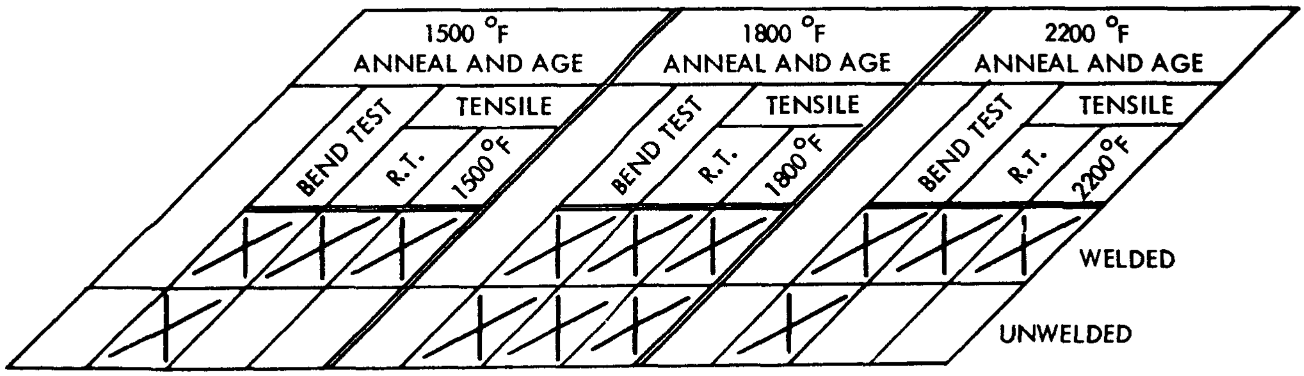


FIGURE 4 - Program Outline for Contaminated Alloy Weldability Evaluation
NOTE: Bead-on-Plate Welds Used on this Program



TASK I 3 ALLOYS X 5 OXYGEN LEVELS
AS RECEIVED
100 PPM
200 PPM
500 PPM
1000 PPM



TASK II I ALLOY X 5 OXYGEN LEVELS
AS RECEIVED
100 PPM
200 PPM
500 PPM
1000 PPM

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FIGURE 5 - Detailed Outline of Specimen Requirements for Oxidation Program

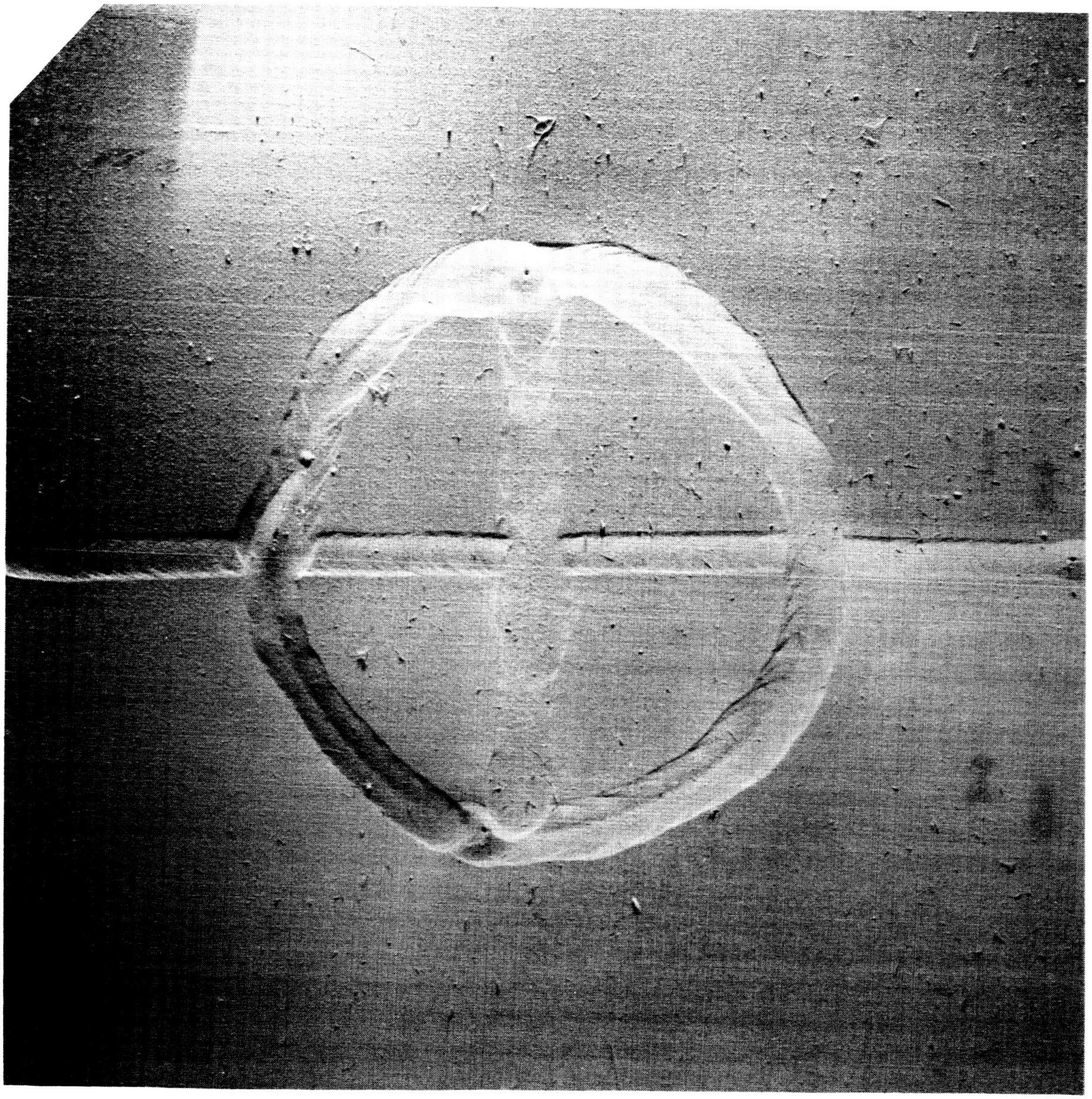

FIGURE 6 - Weld Restraint Patch Test

TABLE 1 - Alloys Included in the Weldability and Thermal Stability Evaluations

Alloy	Nominal Composition Weight Percent
AS-55	Cb-5W-1Zr-0.2Y-0.06C
B-66	Cb-5Mo-5V-1Zr
C-129Y	Cb-10W-10Hf+Y
Cb-752	Cb-10W-2.5Zr
D-43	Cb-10W-1Zr-0.1C
FS-85	Cb-27Ta-10W-1Zr
SCb-291	Cb-10W-10Ta
D-43+Y	Cb-10W-1Zr-0.1C+Y
T-111	Ta-8W-2Hf
T-222	Ta-9.6W-2.4Hf-0.01C
Ta-10W	Ta-10W
W-25Re	W-25Re
W	Unalloyed
Sylvania "A"*	W-0.5Hf-0.02C

* NOTE: All alloys from arc-cast and/or electron beam melted material except Sylvania "A"

TABLE 2 - Optimized Weld Conditions for 0.035 Inch Sheet

Alloy	Process	Parameters (1)	One Hour Post Weld Anneal Temp., °F	Weld Width Top/Bottom (inches)	BDBTT, °F(2)	
					Long. Bends	Trans. Bends
Ta-10W	TIG	7.5-1/4-118	None	.190/.180	<-320	<-320
	EB	15-1/2-4.5	None	.049/.034	<-320	<-320
T-111	TIG	15-3/8-115	2400°F	.195/.189	<-320	<-320
	EB	15-1/2-3.8	2400°F	.038/.027	<-320	<-320
T-222	TIG	30-1/4-190	2400°F	.180/.159	<-320	<-320
	EB	15-1/2-3.8	2400°F	.039/.026	<-320	<-320
B-66	TIG	15-3/8-86	None	.190/.180	0	+75
	EB	25-3/16-3.2	1900°F	.036/.024	-225	-175
C-129Y	TIG	30-3/8-110	2400°F	.180/.130	-200	-225
	EB	50-1/2-4.1	2200°F	.040/.026	-250	-250
Cb-752	TIG	30-3/8-87	2200°F	.129/.090	-75	0
	EB	15-3/16-3.3	2400°F	.036/.017	-200	-200
D-43	TIG	30-3/8-114	2400°F	.159/.143	+100	0(3)
	EB	50-1/2-4.4	2400°F	.040/.027	-225	-225
D-43Y	TIG	15-3/8-83	2400°F	.165/.150	-175	-250
	EB	50-1/2-4.0	2400°F	.036/.022	-250	<-300
FS-85	TIG	15-3/8-90	2400°F	.204/.195	-175	-175
	EB	50-3/16-4.4	2200°F	.038/.026	-200	-200
SCb-291	TIG	15-1/4-83	2200°F	.160/.150	-275	-275
	EB	50-1/2-4.4	None	.038/.027	<-320	-250

(1) For TIG Welds: Speed (ipm) - Clamp Spacing (in.) - Amperes
For EB Welds: Speed (ipm) - Clamp Spacing (in.) - Milliamperes
(All EB welds with 60~, 0.050 inch longitudinal deflection and 150 KV beam voltage)

(2) BDBTT ≈ Bend Ductile Brittle Transition Temperature at 1t Bend Radius Except FS-85 EB Welds at 2t Bend Radius.

(3) Probable Value (Determined Value <-125°F)

TABLE 3 - Summary of Bend Ductile-to-Brittle Transition Temperatures for Aged Specimens.*

Alloy & Specimen Type	Before Aging	100 Hour Ages 1500°F	1700°F	1800°F	2100°F	2400°F
	Bend Ductile-to-Brittle Transition Temperature (°F)					
B-66						
Arc Weld-Longitudinal	0	+300	+75	0	+25	0
Arc Weld-Transverse	+75	+150	+200	+100	-100	+50
EB Weld-Longitudinal	-225	-200	-150	-200	-225	-125
EB Weld-Transverse	-175	-200	-175	-175	-125	0
Base Metal-Longitudinal	-300	<-200	---	<-320	-225	+75
Base Metal-Transverse	-275	<-200	---	-250	-200	0
C-129Y						
Arc Weld-Longitudinal	-200	-125	-100	-25	-150	-125
Arc Weld-Transverse	-225	-200	-100	-175	-175	-250
EB Weld-Longitudinal	-250	-225	-200	-250	-225	-225
EB Weld-Transverse	-250	-225	-225	-250	-275	-225
Base Metal-Longitudinal	<-320	-320	---	-250	<-320	-250
Base Metal-Transverse	<-320	-320	---	-250	<-320	-250
Cb-752						
Arc Weld-Longitudinal	-75	+25	+25	0	-75	-125
Arc Weld-Transverse	0	-100	-25	-50	-75	-100
EB Weld-Longitudinal	-200	-200	-100	-175	-150	-175
EB Weld-Transverse	-200	-175	-150	-75	-150	-175
Base Metal-Longitudinal	---	<-320	---	<-320	<-320	-250
Base Metal-Transverse	---	-200	---	-175	-250	-250
D-43						
Arc Weld-Longitudinal	+100	0	+75	-100	-125	-75
Arc Weld-Transverse	0	0	0	-200	-250	-250
EB Weld-Longitudinal	-225	-125	-200	-250	-250	-250
EB Weld-Transverse	-225	-175	-225	-225	-250	-225
Base Metal-Longitudinal	-175	-200	---	-250	-275	-250
Base Metal-Transverse	-200	-100	---	-250	-250	-225

*All data based on welds prepared using optimum welding conditions and post-weld anneals. Base metal annealed with same anneal as TIG welds.

TABLE 3 - Summary of Bend Ductile-to-Brittle Transition Temperatures for Aged Specimens.* (Continued)

Alloy & Specimen Type	Before Aging	100 Hour Ages				
		1500°F	1700°F	1800°F	2100°F	2400°F
	Bend Ductile-to-Brittle Transition Temperature (°F)					
D-43Y						
Arc Weld-Longitudinal	-175	---	---	---	---	---
Arc Weld-Transverse	-250	---	---	---	---	---
EB Weld-Longitudinal	-250	---	---	---	---	---
EB Weld-Transverse	<-320	---	---	---	---	---
Base Metal-Longitudinal	<-320	<-320	---	<-320	<-320	<-320
Base Metal-Transverse	<-320	<-320	---	<-320	<-320	<-320
FS-85						
Arc Weld-Longitudinal	-175	-75	-200	25	-25	-150
Arc Weld-Transverse	-175	+25	-175	0	0	-100
EB Weld-Longitudinal	-200	-225	-100	-100	-125	-225
EB Weld-Transverse	-200	-200	-125	+100	-75	-200
Base Metal-Longitudinal	-250	-250	---	-250	-250	-200
Base Metal-Transverse	-225	-250	---	-250	-250	-200
SCb-291						
Arc Weld-Longitudinal	-275	-250	-250	-250	-225	-250
Arc Weld-Transverse	-275	-250	-250	<-320	<-320	-250
EB Weld-Longitudinal	<-320	-250	<-320	-250	-250	-250
EB Weld-Transverse	-250	<-320	-250	<-320	<-320	<-320
Base Metal-Longitudinal	---	<-320	---	<-320	<-320	-250
Base Metal-Transverse	---	-250	---	<-320	<-320	<-320
Ta-10W						
Arc Weld-Longitudinal	<-320	<-320	<-320	<-320	<-320	<-320
Arc Weld-Transverse	<-320	<-320	<-320	<-320	<-320	<-320
EB Weld-Longitudinal	<-320	<-320	<-320	<-320	<-320	<-320
EB Weld-Transverse	<-320	<-320	<-320	<-320	<-320	<-320
Base Metal-Longitudinal	<-320	<-320	---	<-320	<-320	<-320
Base Metal-Transverse	<-320	<-320	---	<-320	<-320	<-320

*All data based on welds prepared using optimum welding conditions and post-weld anneals. Base metal annealed with same anneal as TIG welds.

TABLE 3 - Summary of Bend Ductile-to-Brittle Transition Temperatures for Aged Specimens. * (Continued)

Alloy & Specimen Type	Before Aging	100 Hour Ages				
		1500°F	1700°F	1800°F	2100°F	2400°F
	Bend Ductile-to-Brittle Transition Temperature (°F)					
T-111						
Arc Weld-Longitudinal	<-320	<-320	-250	<-320	-250	<-320
Arc Weld-Transverse	<-320	<-320	<-320	<-320	-225	<-320
EB Weld-Longitudinal	<-320	<-320	<-320	<-320	<-320	<-320
EB Weld-Transverse	<-320	<-320	<-320	<-320	<-320	<-320
Base Metal-Longitudinal	<-320	<-320	---	<-320	<-320	<-320
Base Metal-Transverse	<-320	<-320	---	<-320	<-320	<-320
T-222						
Arc Weld-Longitudinal	<-320	<-320	<-320	<-320	>-150	-225
Arc Weld-Transverse	<-320	<-320	<-320	-250	-100	-200
EB Weld-Longitudinal	<-320	<-320	<-320	<-320	<-320	<-320
EB Weld-Transverse	<-320	<-320	<-320	<-320	<-320	<-320
Base Metal-Longitudinal	<-320	<-320	---	<-320	<-320	<-320
Base Metal-Transverse	<-320	<-320	---	<-320	<-320	<-320

*All data based on welds prepared using optimum welding conditions and post-weld anneals. Base metal annealed with same anneal as TIG welds.

TABLE 4. PHASE I SPECIMEN INDEX

Alloy	Target O_2	Prefix No	Diffusion Annealing Temperature: 1500°F	1800°F		2200°F
FS-85	As-Rec'd	C3CU	1500-3	WR-7 BD-5 RT-1	WR-8 WBD-6 1800-2	2200-4
	100	C3C5	1500-3 (90)	WR-7 (95) BD-6 (100) RT-1 (120)	WR-8 (100) WBD-5 (110) 1800-2 (105)	2200-4 (100)
	200	C3C2	1500-1 (185)	WR-7 (160) BD-5 (175) RT-3 (195)	WR-8 (190) WBD-6 (195) 1800-2 (190)	2200-4 (195)
	500	C3C1	1500-1 (500)	WR-7 (560) BD-5 (620) RT-4 (505)	WR-8 (530) WBD-6 (490) 1800-3 (540)	2200-2 (490)
	1000	C3C4	1500-4 (790)	WR-7 (1110)[a] BD-5 (830) RT-1 (810)	WR-8 (810) WBD-6 (610) 1800-2 (990)	2200-3 (780)[b]
T-111	As-Rec'd	T1CU	1500-1	WR-7 BD-6 RT-3	WR-8 WBD-5 1800-4	2200-2
	70	T1C4	1500-2 (70)	WR-7 (8 5) BD-5 (75) RT-1 (85)	WR-8 (80) WBD-6 (65) 1800-3 (70)	2200-4 (85)
	140	T1C3	1500-4 (170)	WR-7 (180) BD-6 (175) RT-1 (175)	WR-8 (180) WBD-5 (190) 1800-2 (185)	2200-3 (170)
	350	T1C1	1500-2 (340)	WR-7 (315) BD-6 (350) RT-3 (315)	WR-8 (325) WBD-5 (340) 1800-4 (330)	2200-1 (340)
	700	T1C2	1500-1 (770)	WR-7 (770) BD-5 (740) RT-2 (770)	WR-8 (810)[a] WBD-6 (775) 1800-3 (770)	2200-4 (770)
T-222	As-Rec'd	T3CU	1500-1	WR-7 BD-5 RT-2	WR-8 WBD-6 1800-4	2200-3
	70	T3C4	1500-2 (175)	WR-7 (75) BD-5 (75) RT-1 (90)	WR-8 (95) WBD-6 (75) 1800-3 (85)	2200-4 (75)
	140	T3C3	1500-1 (195)	WR-7 (160) BD-6 (175) RT-2 (160)	WR-8 (170) WBD-5 (150) 1800-3 (165)	2200-4 (185)
	350	T3C1	1500-4 (300)	WR-7 (335) BD-6 (330) RT-2 (285)	WR-8 (290) WBD-5 (325) 1800-3 (350)	2200-1 (345)
	700	T3C2	1500-3 (940)	WR-7 (970)[a] BD-5 (910) RT-2 (840)[c]	WR-8 (940) WBD-6 (920) 1800-1 (840)[c]	2200-4 (880)

Key:

XX — X — XXX

Specimen Type

Specimen No.

Oxygen addition, wt gain after 50-hour diff. anneal

a. Wt gain as contaminated
b. Specimen improperly welded (no test)
c. Specimen fractured during machining (no test).

WR weld restraint patch tests two required for one test
BD bend ductility test (base metal)
WBD weld bend ductility test
RT, 1500, 1800, 2200 - tensile tests at

TABLE 5. WELD RESTRAINT PATCH TEST INSPECTION RESULTS

Alloy	Specimen No.	Oxygen Level (ppm)	Inspection Results: Visual As Welded	Dye Penetrant	Radiography
	C3C5-7/8	100	Acceptable	Acceptable	Acceptable
FS-85	C3C2-7/8	200	Acceptable	Acceptable	Acceptable
	C3C4-7/8	1000	Acceptable	Acceptable	Acceptable
	T1C4-7/8	70	Acceptable	Acceptable	Acceptable
T-111	T1C3-7/8	140	Acceptable	Acceptable	Acceptable
	T1C2-7/8	700	Acceptable	Acceptable	Acceptable
	T3C4-7/8	70	Acceptable	Acceptable	Acceptable
T-222	T3C3-7/8	140	Acceptable	Acceptable	Acceptable
	T3C2-7/8	700	Not Welded(1)	--	--

(1) Butt weld burned through. Could not be repaired.