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EVALUATION OF MIG AND TIG WELDING PROCESSES FOR JOINING 2014-T6 ALUMINUM ALLOY - PHASE II

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ABSTRACT

The phase II portion of the MIG-TIG weld evaluation program consisted of six testing programs. One program, reported herein, was conducted to evaluate MIG and TIG welds for joining .250" thick, 2014-T6 aluminum alloy and to determine the optimum cleaning procedures prior to TIG welding .100" thick 2014-T6. MIG and TIG welded test panels were evaluated on the basis of transverse weld and all-weld-metal tensile tests conducted at room temperature and at $-423^{\circ}F$ ($-253^{\circ}C$). The cleaning procedures prior to TIG welding were evaluated by the number of defects observed by X-ray and dye penetrant inspection after welding.

The highest tensile strength was obtained with a 2-pass TIG weld on a stainless steel back-up bar. The optimum procedure for edge preparation prior to TIG welding was: deburr, scrape top and bottom surfaces, draw file, and prepare .030" radius on back edge.

The other five testing programs that were included in this evaluation of MIG and TIG welds have been reported separately, References 1, 2, 3, 4, and 5. These programs were conducted to study TIG spot welding, grain boundary melting, etching prior to dye penetrant inspection, weld cooling rate, and biaxial strength. The abstracts for these reports are given in Appendix 1 of this report.

1. INTRODUCTION

The Phase I portion of this testing program was initiated in April, 1964 to evaluate the mechanical properties of MIG and TIG welds in .100" thick, 2014-T6 aluminum alloy. Phase I was completed in January, 1965 (Reference 6) and it was concluded that welds made with the TIG process exhibited slightly higher mechanical properties than similar welds made with the MIG process which was currently being used for Saturn S-IVB butt welds. The TIG welding process also offered the advantages of independent control of the weld variables, greater tolerance for thickness variation in the parent metal along the weld joint, and less shrinkage and distortion due to a smaller weld bead. However, it was recognized that the TIG process was more sensitive to cleaning prior to welding.

Based on the results of Phase I, it was decided to initiate the Phase II portion of this program to further evaluate the TIG welding process. The first portion of the Phase II tests (designated Part A) was to evaluate MIG and TIG welds made on production welding fixtures. The final report for "Part A" is contained herein. The remaining portions of the Phase II tests (designated Parts B through F) studied TIG spot welding, grain boundary melting, etching, weld cooling rate, and biaxial strength. The tests for parts B through F have been reported separately, References 2, 3, 4, 5, and 6. The abstract for each report is given in Appendix 1.

2. PROCEDURE AND RESULTS

The Phase II, Part A, tests were divided into two major efforts as follows:

1. Evaluation of MIG and TIG welds for the Saturn S-IVB longitudinal cylinder joint. The test welds were prepared on the Pandjiris Fixture at Huntington Beach, California.

2. Determination of the optimum pre-weld cleaning procedures. The cleaning procedures were evaluated on the basis of X-ray and dye penetrant inspection after TIG welding.

2.1 Evaluation of MIG and TIG Welds Simulating the Longitudinal Cylinder Weld Joint

MIG and TIG welded test panels were prepared on the Pandjiris fixture using .250" thick, 2014-T6 aluminum alloy plate and 4043 weld wire. The test panels were cleaned and welded by production personnel at Huntington Beach, California. Transverse weld tensile coupons and all-weld-metal tensile coupons were machined from the welded test panels and the welds were evaluated on the basis of the tensile properties obtained at room temperature and at -423°F (-253°C).

2.1.1 Welding

Two test weld panels, 6 feet long X 8 inches wide, were prepared for each type of weld to be evaluated. Each welded panel was prepared from 2 strips, 6 feet long X 4" wide, of .250" thick 2014-T6 aluminum alloy. The abutting edges of the strips to be used for the MIG welds were machined with a 60° "V" joint as shown in Appendix 2-1, and the edges of the strips to be used for the TIG welds were machined square for a square butt joint. All test strips were cleaned per DPS 9.305, issue of 3-2-65, prior to welding and covered with plastic protective covers until they were placed into the Pandjiris fixture. The strips were cleaned within 24 hours prior to welding.

All test panels were welded by production personnel on the Pandjiris fixture at A3 location. A series of test welds were made to determine the best parameters for each type of TIG weld. (The MIG weld parameters were those currently in use for production hardware). Based on the weld appearance and the transverse weld tensile strength, the "optimum" parameters selected are given in Table 1. These were used for all welds reported herein. The double repair welds were made as follows:

1. Make a normal weld.
2. Shave weld bead penetration and reinforcement flush with parent metal.
3. Reweld
4. Shave flush
5. Reweld

In order to get sufficient drop-through on the underbead side of the weld, it was necessary to use considerably more heat for the welds made on the copper back-up bar than for welds made on a stainless steel bar. This additional heat caused the back-up bar to heat up ahead of the weld and thus reduced the chilling effect of the bar. No other significant welding difficulties were encountered.

After welding, all test panels were X-ray and dye penetrant inspected per DPS 10.320, issue of 3-9-65 and DPS 4.701, issue of 7-30-64. All welds passed the dye penetrant inspection, but six defects observed on the radiographs were rejectable per the Saturn S-IVB inspection standards. Four of the defects were in a single-pass, TIG welded panel made on a copper back-up bar, and the other two were in a similar panel which had a simulated double repair. These defect areas appeared as small, round, dark spots on the radiograph - indicating that they were areas of lower density than the surrounding weld metal. They appeared to be similar to the defects observed in the Phase I portion of this MIG-TIG weld evaluation program, but their origin and composition were not determined. The defect areas were avoided when the tensile specimens were subsequently prepared from the welded panels.

2.1.2 Tensile Testing

The MIG and TIG welds were evaluated on the basis of tensile properties. Transverse weld and all weld metal tensile specimens as shown in Appendix 2-2 were prepared from each welded panel. The specimens were tensile tested at room temperature and at -423°F (-253°C). The results given in Tables 2, 3, 4, and 5 indicate that the highest tensile properties were obtained from 2-pass TIG welds made on a stainless steel back-up bar.

2.1.3 Metallography

Transverse weld specimens cut from each of the test weld panels were polished and etched with Keller's reagent. A typical cross-section of each weld is shown in Figures 1 and 2. The MIG welds were considerably wider than the TIG welds but no other significant differences were observed. Note: the

Table 1

Welding Parameters Used for Simulated Longitudinal Cylinder Weld Test Panels

Type of Weld (1)	Back-up Bar (2)	Passes	Amps	Volts	Travel Speed in/min.	Wire Feed Speed in/min.
MIG (1-pass)	Stainless Steel	1 pass	250	37	24	--
MIG (1-pass + double repair)	Stainless Steel	1st pass 2nd pass 3rd pass	250 255 260	37 39 40	24 24 24	-- -- --
TIG (2-pass)	Stainless Steel	1st pass 2nd pass	250 250	10.5 14.0	14 18	0 34
TIG (2-pass)	Copper	1st pass 2nd pass	335 250	10.5 14.0	12 18	0 34
TIG (1-pass)	Copper	1 pass	335	13.0	10	38
TIG (1-pass + double repair)	Copper	1st pass 2nd pass 3rd pass	335 335 335	13.0 13.0 13.0	10 10 10	38 38 38

Notes:

	MIG Welds	TIG Welds
(1) Shielding Gas	75% Helium 25% Argon (60 cfh)	100% Helium (60 cfh)
(2) Back-up Bar Groove Size	5/16" wide .060" deep (curved)	5/16" wide .040 deep (curved)

Table 2

Transverse Weld Tensile Strength of .250" Thick, 2014-T6 Aluminum Alloy at Room Temperature

Type of Weld	Back-up Bar	Yield Strength, KSI	Ultimate Strength, KSI	% Elongation in 1"
MIG (1-pass)	Stainless Steel	25.9 25.6 25.3 28.1 25.1	44.4 43.3 43.7 44.6 44.7	7 7 7 7 7
MIG (1-pass + double repair)	Stainless Steel	23.6 23.7 21.7 21.9 23.2	40.2 40.0 37.8 39.0 40.1	7 7 7 7 7
TIG (2-pass)	Stainless Steel	34.8 34.7 33.5 34.2 34.7	51.9 55.9 54.5 55.3 54.7	5 6 6 6 6
TIG (2-pass)	Copper	32.6 33.7 32.8 33.5 32.5	52.2 51.4 53.9 52.1 54.1	5 5 7 5 8
TIG (1-pass)	Copper	30.7 31.2 32.0 31.9 31.1 31.8	51.8 48.5 51.0 42.5 48.5 52.4	6 4 4 2 4 7
TIG (1-pass + double repair)	Copper	28.7 29.1 30.1 29.1 29.3	49.9 50.1 50.5 48.6 50.6	6 6 6 5 5

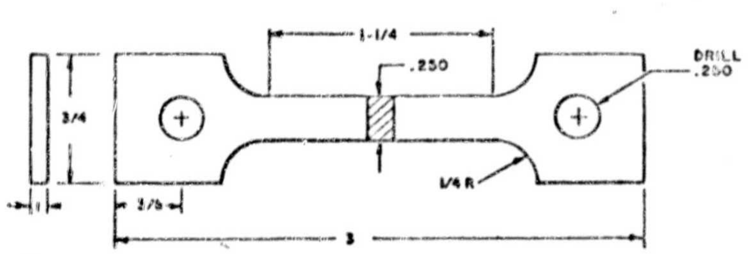

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Table 3

Transverse Weld Tensile Strength of .250" Thick, 2014-T6 Aluminum Alloy at -423°F (-253°C)

Type of Weld	Back-up Bar	Yield Strength, KSI	Ultimate Strength, KSI	% Elongation in 1"
MIG (1-pass)	Stainless Steel	34.0	57.1	2
		35.3	56.3	2
		32.2	57.0	2
		37.3	55.9	2
		36.7	54.4	2
MIG (1-pass + double repair)	Stainless Steel	22.0	51.0	2
		(1)	49.5	3
		31.0	52.4	2
		27.7	53.2	3
		29.5	48.3	2
TIG (2-pass)	Stainless Steel	----	64.9	2
		45.9	67.7	2
		45.4	68.4	2
		52.3	63.3	2
		50.8	60.9	2
TIG (2-pass)	Copper	46.6	63.2	2
		43.9	66.4	2
		(1)	58.8	2
		38.8	60.1	3
		41.5	65.0	2
TIG (1-pass)	Copper	48.0	58.9	2
		(1)	60.9	3
		43.1	59.0	3
		37.9	63.0	2
		38.7	61.7	3
TIG (1-pass + double repair)	Copper	40.0	60.5	3
		(1)	57.0	3
		31.8	58.2	3
		34.1	57.8	3
		33.0	61.9	3

Note: (1) The tensile load-strain curve was not valid.

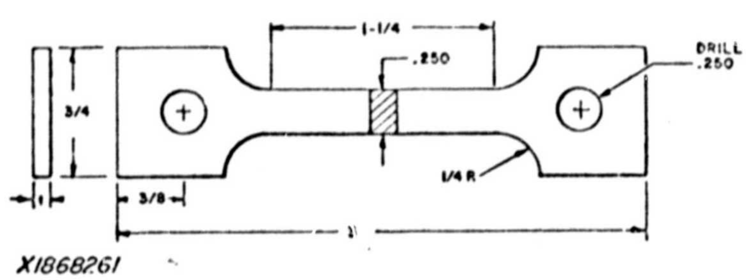
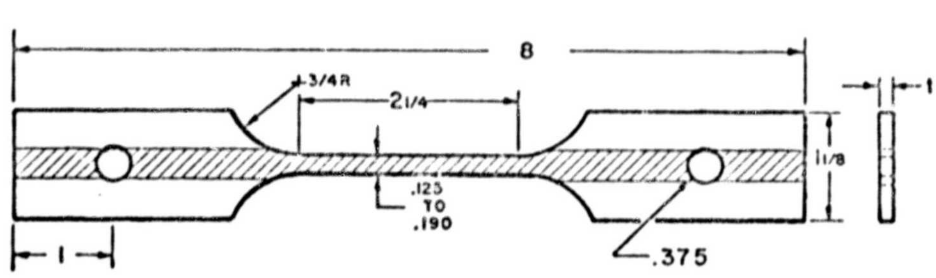


Table 4

All-Weld-Metal Tensile Strength of .250" Thick, 2014-T6 Aluminum Alloy at Room Temperature

Type of Weld	Back-up Bar	Yield Strength, KSI	Ultimate Strength, KSI	% Elongation in 2"
MIG (1-pass)	Stainless Steel	21.2	37.5	5
		22.1	35.4	4
		21.9	36.1	4
		23.1	36.8	5
MIG (1-pass + double repair)	Stainless Steel	16.8	32.4	5
		18.1	33.2	5
		18.3	32.6	5
		18.8	32.8	5
TIG (2-pass)	Stainless Steel	29.1	49.2	10
		30.4	48.8	10
		29.6	49.5	10
		30.2	47.8	9
TIG (2-pass)	Copper	27.4	48.0	9
		27.5	48.3	9
		26.9	49.3	10
		27.7	49.1	9
TIG (1-pass)	Copper	25.4	44.0	6
		26.3	43.5	8
		26.3	44.5	8
		26.2	43.3	7
TIG (1-pass + double repair)	Copper	22.9	44.1	10
		23.8	44.4	11
		23.9	42.5	9
		23.7	43.4	9

ALL WELD METAL TENSILE SPECIMEN



DLP 13.820-TFS57

MIG Weld

(1-pass)

Stainless Steel
Back-up Bar

Photo Number: M21594

Magn. 3X

Keller's Etchant

MIG Weld

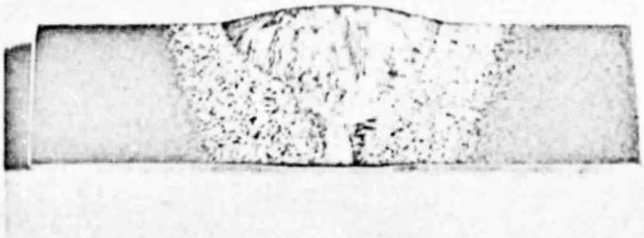
(1-pass + double repair)

Stainless Steel
Back-up Bar

hoto Number: M21595

Magn. 3X

Keller's Etchant



TIG Weld

(2-pass)

Stainless Steel
Back-up Bar

Photo Number: M21593

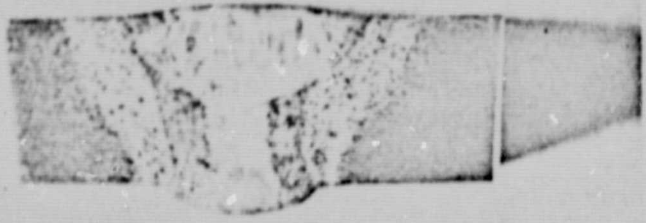
Magn. 3X

Weld Bead Penetration has
Been Machined Off

Keller's Etchant

FIGURE 1

Cross Section of MIG and TIG Welds in
.250" Thick, 2014-T6 Aluminum Alloy



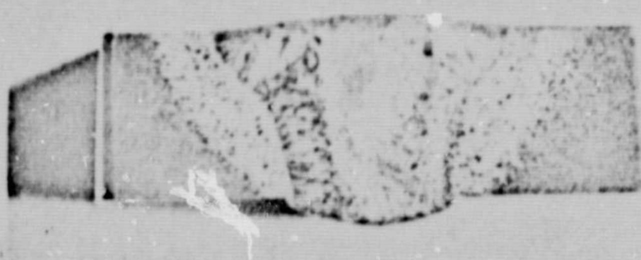
TIG Weld
(2-pass)

Copper Back-up Bar

Photo Number: M21592

Magn. 3X

Keller's Etchant



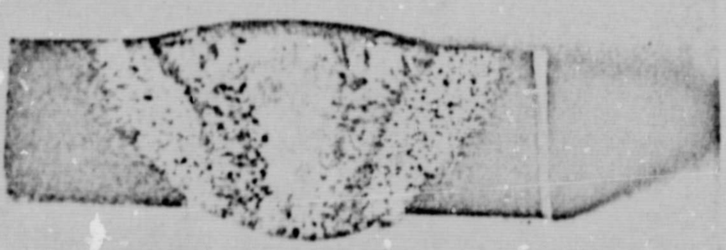
TIG Weld
(1-pass)

Copper Back-up Bar

Photo Number: M21596

Magn. 3X

Keller's Etchant



TIG Weld
(1-pass + double repair)

Copper Back-up Bar

Photo Number: M21591

Magn. 3X

Keller's Etchant

FIGURE 2

Cross Section of TIG Welds in
.250" Thick 2014-T6 Aluminum Alloy

Table 5

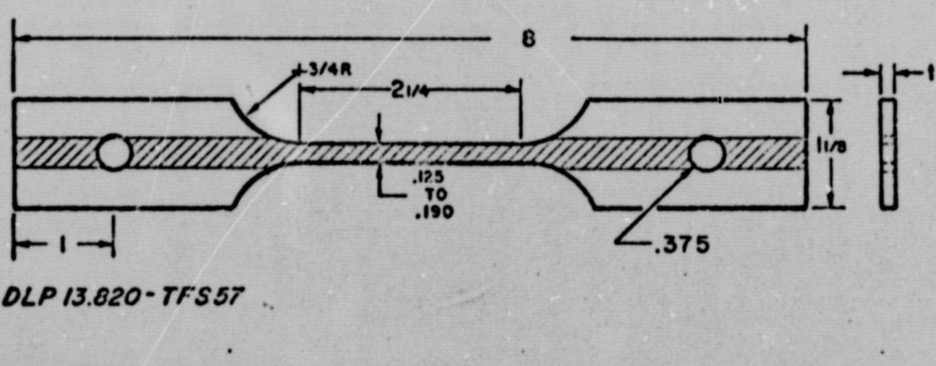
All-Weld-Metal Tensile Strength of .250" Thick, 2014-T6 Aluminum Alloy at -423°F (-253°C)

Type of Weld	Back-up Bar	Yield Strength, KSI	Ultimate Strength, KSI	% Elongation in 2"
MIG (1-pass)	Stainless Steel	41.5 41.8 42.9 42.7 43.2	45.1 43.8 49.2 48.8 50.5	0.5 (2) 1.4 (2) --- 0.9 (2) ---
TIG (2-pass)	Stainless Steel	49.5 47.6 46.5 (1)	58.2 59.8 58.7 58.9	1 1 1 1
TIG (2-pass)	Copper	44.6 44.5 44.9 44.8	58.3 55.0 59.4 57.7	1 1 1 1
TIG (1-pass)	Copper	44.2 41.4 43.4 42.9	54.6 54.5 53.3 49.8	1 1 1 1
TIG (1-pass + double repair)	Copper	37.9 38.7 24.6 37.7	51.9 52.2 52.9 51.2	2 2 2 1

Notes: (1) The tensile load-strain curve was not valid.

(2) These values were obtained from the tensile load-strain curve. All others were determined by fit-back.

ALL WELD METAL TENSILE SPECIMEN



DLP 13.820-TFS57

Table 6

Parameters Used to Prepare TIG Welds for
Pre-Weld Cleaning Evaluation Tests

VARIABLES	BACK-UP BAR GROOVE DEPTH	
	.025"	.040"
Volts	11.5	11.8
Current, Amps	170	190
Travel Speed (in/min)	13	13
Shielding Gas		
Type	Helium	Helium
Flow, CFH	125	120
Filler Wire		
Alloy	4043	4043
Feed Rate, IPM	35	60
Diameter, in.	.062	.062
Back-up Bar	Copper	Copper
Groove Width, in.	.250	.250
Power Supply	Sciaky	Sciaky
Torch	Sciaky, SW6	Sciaky, SW6
Seam Tracker	Sciaky, probe type	Sciaky, probe type
Electrode Diameter	1/8"	1/8"
Configuration	Taper to .070"	Taper to .070"
(.2% Thorium)		

FOLDOUT FRAME 1

Table 7

TIG Weld Defect Summary

.100" Thick, 2014-T6 Aluminum Alloy, Butt, Fusion Welded on a Coppe

PRE-WELD CLEANING PROCEDURE	COPPER BACKup BAR GROOVE DEPTH IN INCHES	TOTAL INCHES OF WELD (THREE PANELS)	DYE PENETRANT DEFECTS AFTER SHAVING
CONTROL PANELS			
Sawed Edge Only			
1. Sawed edge only, no deburr, no etch, no scrape, no draw file, no back radius.	0.025"	144	82
2. Sawed edge only, no deburr, no etch, no scrape, no draw file, no back radius.	0.040"	210	69
3. Sawed edge only, no deburr, no etch, no scrape, no draw file, no back radius.	0.040"	210	172
TEST PANELS			
Sawed			
4. Sawed edge, deburred, draw file, back radius, no etch, no scrape.	0.040"	210	8
Sawed and Etched			
5. Sawed edge, etched twice in 24 hour period, no deburr, no scrape, no draw file, no back radius.	0.025"	144	136
6. Sawed edge, etched twice in 24 hour period, no deburr, no scrape, no draw file, no back radius.	0.040"	210	67
7. Sawed edge, deburred, etched once, 6 hour delay, draw file, back radius. no scrape.	0.040"	120	62
8. Sawed edge, deburred, etched once, 6 hour delay, wire brush top and bottom, draw file, back radius, no scrape.	0.040"	210	30
Sawed and Scraped			
9. Sawed edge, deburred, scraped top and bottom, draw filed, back radius, no etch.	0.025"	144	5
10. Sawed edge, deburred, scraped top and bottom, draw filed, back radius, no etch.	0.040"	210	1

ble 7

efect Summary

FOLDOUT FRAME 2

tt, Fusion Welded on a Copper Back-up Bar

TAL INCHES OF WELD REE PANELS)	DYE PENETRANT DEFECTS AFTER SHAVING	X-RAY DEFECTS AFTER SHAVING	TOTAL WELD DEFECTS AFTER SHAVING	TOTAL DEFECTS PER INCH OF WELD
144	82	159	241	1.68
210	69	90	158	0.76
210	172	126	298	1.49
210	8	5	13	0.067
144	136	128	264	1.83
210	67	53	120	0.57
120	62	16	78	0.38
210	30	8	38	0.181
144	5	6	11	0.076
210	1	0	1	0.0048

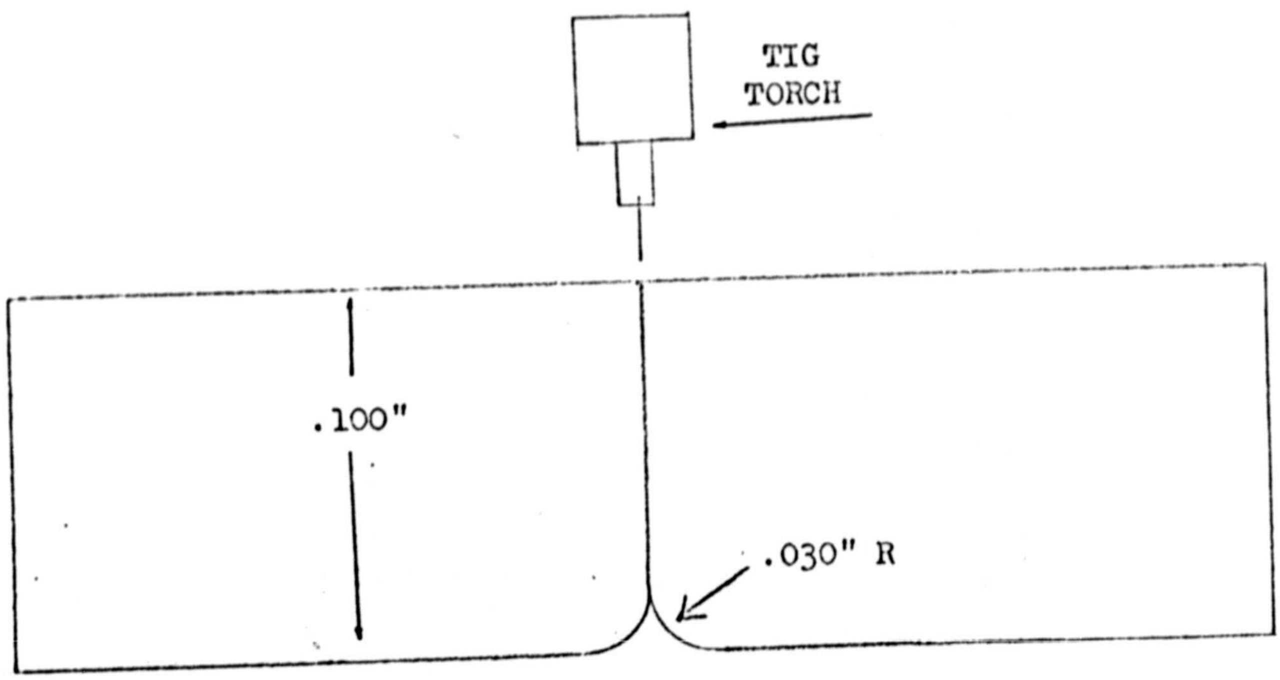


FIGURE 3

Square Butt Joint Showing Back-Radius

penetration side of the 2-pass TIG weld made on a stainless steel bar has been shaved off.

2.2 Determination of Optimum Pre-Weld Cleaning Procedures

During the Phase I portion of this MIG-TIG weld evaluation program, it was noted that the TIG welds had an excessive number of defects which were probably due to the pre-weld cleaning procedure. In addition, an attempt to manufacture a Saturn S-IVB common bulkhead using the TIG welding procedure was unsuccessful because of excessive defects in the welds. Therefore, a series of tests was conducted in the laboratory to determine the optimum pre-weld cleaning and joint preparation procedures for TIG welding .100" thick, 2014-T6 aluminum alloy.

Three weld panels were prepared for each cleaning procedure to be evaluated. The panels were prepared in the Welding Laboratory using the parameters given in Table 6. After welding, the weld bead penetration and reinforcement were shaved off per Saturn S-IVB common bulkhead production procedure. Then, each weld was X-ray and dye penetrant inspected per DPS 10.320 and DPS 4.701. The pre-weld cleaning procedures evaluated and the number of defects observed are given in Table 7. The etching technique referenced in Table 7 was the Passajel 101 and British Etch method per DPS 9.305. The back radius was .030" ± .010", Figure 3.

The most significant improvement in weld quality was due to a .030" radius on the back edge of the abutting surfaces, Figure 3. Other procedures that reduced the number of defects in the weld are listed below:

1. Deburr, draw file and back radius - compare test 4 with tests 1, 2, and 3 (Table 7).

2. Eliminate etching procedure - compare tests 4 and 7 (Table 7).

3. Scrape top and bottom surfaces - compare tests 4 and 10.

4. Use .040" deep groove in back-up bar - compare tests 9 and 10; also tests 5 and 6.

Based on the results given in Table 7, the optimum pre-weld cleaning procedure selected for TIG welding .100" thick, 2014-T6 aluminum alloy was:

1. Saw or machine edge (dependent on specific joint).

2. Deburr

3. Scrape top and bottom surfaces.

4. Draw file abutting surfaces.

5. Back radius (nominal .030" radius on back edge for 0.100" thick material).

3. CONCLUSIONS

3.1 TIG welds in 1/4" thick, 2014-T6 aluminum alloy exhibited significantly higher tensile properties than MIG welds for the welding conditions and test temperatures studied.

3.2 The highest tensile strength was obtained with a 2-pass TIG weld on a stainless steel back-up bar.

3.3 At $-423^{\circ}F$ all welds exhibited similar elongation. At room temperature the elongation of the weld metal was significantly higher for TIG welds than for MIG welds.

3.4 The optimum procedure for preparation of the abutting edges prior to TIG welding .100" thick, 2014-T6 aluminum alloy was:

1. Deburr
2. Scrape top and bottom surfaces.
3. Draw file abutting surfaces.
4. .030" radius on back edge.

4. REFERENCES

1. Babiracki, E. G., TIG Spot Weld Repair and Bracket Attachment, Report No. SM-49156, Douglas Aircraft Company, February 4, 1966.

2. Hocker, R. G., Grain Boundary Melting and Cracking in MIG Welded 2014 Aluminum Extrusions, Report No. SM-49152, Douglas Aircraft Company, November 30, 1965.

3. Hocker, R. G., and S. H. Vander Weide, Evaluation of Etching 2014-T6 Aluminum Weldments Prior to Dye Penetrant Inspection, Report No. SM-48405, Douglas Aircraft Company, July 2, 1965.

4. Tucker, M. S., A. Phillips and V. Kerlins, The Influence of Cooling Rate on the Strength and Microstructure of 2014 Aluminum Alloy Welds, Report No. SM-49167, Douglas Aircraft Company, March 1, 1966.

5. Rawe, R. A., Biaxial Strength of MIG and TIG Welded 2014-T6 at 70°, -320°, and -423°F, Report No. DAC 62102, Douglas Aircraft Company, May, 1968.

6. Davis, R. J., R. N. Hooker and E. F. Kaluza, Evaluation of MIG and TIG Welding Processes For Joining 2014-T6 Aluminum Alloy - Phase I, Report No. SM-48383, Douglas Aircraft Company, January 21, 1965.

DATA

Douglas Aircraft Company Technical Record Book No. 4450.

APPENDIX 1

ABSTRACTS FROM DOUGLAS AIRCRAFT COMPANY REPORTS FOR PARTS B, C, D, E, AND F OF THIS MIG-TIG-WELD EVALUATION PROGRAM, PHASE II

APPENDIX 1-1

ABSTRACT FROM DACo REPORT SM-49156,
TIG Spot Weld Repair and Bracket Attachment, Ref. 1
(Part B - Portion of MIG-TIG Evaluation, Phase II)

This report covers an investigation initiated to develop the Tungsten Inert Gas (TIG) spot welding process for the repair of localized weld defects in aluminum (Phase I) and for the joining of clip attachments on Saturn S-IVB stages (Phase II). The feasibility of the Phase I process was demonstrated but the methods developed in the investigation could not be released for use in production because of the lack of equipment reliability and the occurrence of shrinkage cracks in the repaired nuggets. Phase II results indicate that, with some additional evaluation, the TIG spot welding process may be used successfully for securing clip attachments.

APPENDIX 1-2

ABSTRACT FROM DACo REPORT SM-49152,
Grain Boundary Melting and Cracking in MIG Welded 2014 Aluminum Extrusions, Ref. 2
(Part C - Portion of MIG-TIG Evaluation, Phase II)

Crack indications have been observed in the heat-affected zone of aluminum weldments for Saturn tankage when inspected with dye penetrant. This problem has been particularly noticeable in weldments containing extruded ring sections where extremely coarse-grained regions prevail. Several experimental MIG weldments were made on the production, S-IVB, LOX fixture using extrusions with large, medium, and fine grain sizes. A metallographic analysis of these weldments revealed cracks caused by thermal stresses and by arc-plasma impingement (melting of the surface grain boundaries in the weld heat-affected zone). It was found that these cracks could be prevented by minimizing arc-plasma impingement. A 0.1% oxygen addition to the argon shielding gas was found effective in minimizing impingement and surface cracking of the extrusions. Recent Saturn, S-IVB, production experience has verified that this technique eliminates arc impingement and minimizes grain-boundary cracking.

APPENDIX 1-3

ABSTRACT FROM DACo REPORT SM-48405,

Evaluation of Etching 2014-T6 Aluminum Weldments
Prior to Dye-Penetrant Inspection, Ref. 3

(Part D - Portion of MIG-TIG Evaluation, Phase II)

Surface defects in aluminum welds for Saturn tankage sometimes escape detection when inspected with dye penetrant. Smeared metal caused by wire brushing can cover weld flaws and prevent detection during dye-penetrant inspection. A caustic etch can be used to remove this smeared metal and expose the underlying flaws.

Several commercial etchants were evaluated and Turco 4366-NAA was selected for production use. Etching procedures were established. It was shown that Turco 4366-NAA is not detrimental to the strength or microstructure of 2014-T6 weldments. MIG, arc-plasma, impingement cracks revealed by etching are discussed. Arc-plasma impingement appears not to affect uniaxial, tensile strength or tension-tension fatigue strength of as-welded 2014-T6 weldments.

APPENDIX 1-4

ABSTRACT FROM DACo REPORT SM-49167,

The Influence of Cooling Rates on the Strength and Microstructure of 2014 Aluminum Alloy Welds, Ref. 4

(Part E - Portion of MIG-TIG Evaluation, Phase II)

This study was conducted to determine the influence of weld cooling rates on the strength and microstructure of 2014 aluminum alloy welds. Weld cooling rates were measured for welds made with copper and titanium back-up bars and without back-up bars.

It was found that the most rapid weld cooling rates occurred when the two-pass, square-butt, TIG welds were chilled with a copper back-up bar. Rapid weld cooling rates were characterized by high mechanical properties, low peak temperatures in the heat-affected zone, narrow heat-affected zones, large degrees of dendritic structure in the central zone of a weld, segregation of manganese, small numbers of non-symmetrical "holes" in the heat-affected zone, and plate-like and script-like phases of similar cross-sectional areas.

Light and electron microscopy were used to examine weld microstructure. Electron microscopy and selected area electron diffraction analyses provided clues to the identification of one phase. A script-like phase consisted of elemental silicon and $CuAl_2$. An unidentified plate-like phase was found to crack along planes perpendicular to the tensile loading direction.

Examinations were also made to determine the morphology and identity of phases in MIG and TIG 2014 aluminum alloy welds that were made in another study. In the TIG welds, the previously identified script-like phase was again observed. In general, TIG welds fractured in the matrix, whereas MIG welds fractured intercellularly.

APPENDIX 1-5

ABSTRACT FROM DACo REPORT DAC 62102

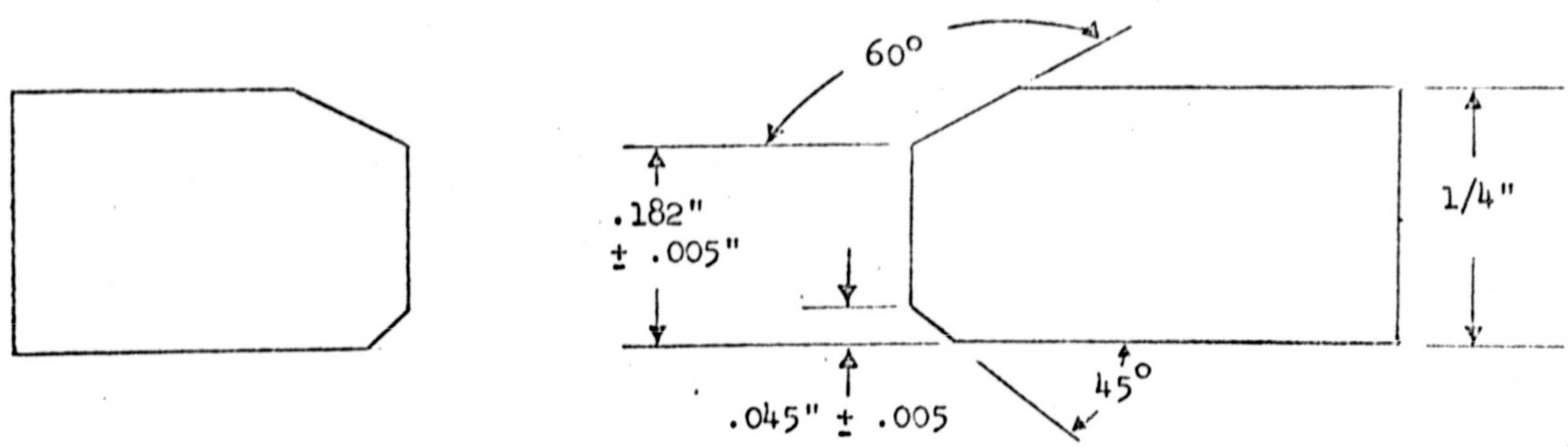
Biaxial Strength of MIG and TIG Welded 2014-T6 at 70°, -320°, and -423°F, Ref. 5

(Part F - Portion of MIG-TIG Evaluation, Phase II)

A test program was conducted to develop biaxial strength allowables for MIG and TIG welds in 2014-T6 aluminum. Welded cylinders, 16-in. in diameter and 60-in. long, were fabricated using procedures simulating actual production methods used for Saturn S-IVB domes and common bulkheads. Certain of the specimens were subjected to a thermal curing cycle. The cylinders, each having two diametrically opposite longitudinal welds, were tested to failure at 70°, -320° and -423°F by combined internal pressurization and applied axial loading producing biaxial stress states of either 2-to-1 (axial-to-hoop) or 1-to-1 (axial-to-hoop). Under all test conditions the TIG-welded specimens exhibited greater biaxial strength than the MIG-welded specimens.

APPENDIX 2-1

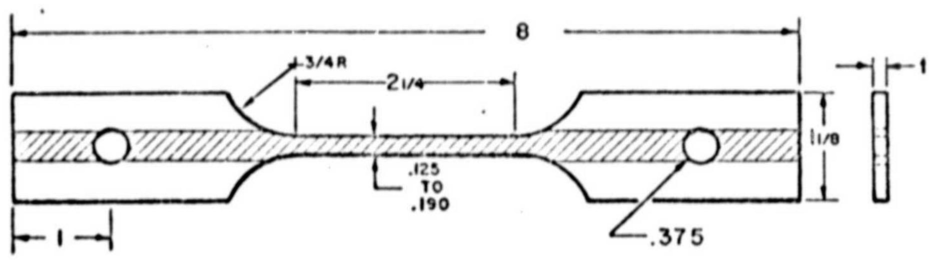
60° "V" JOINT USED FOR .250" THICK MIG WELDS



APPENDIX 2-2

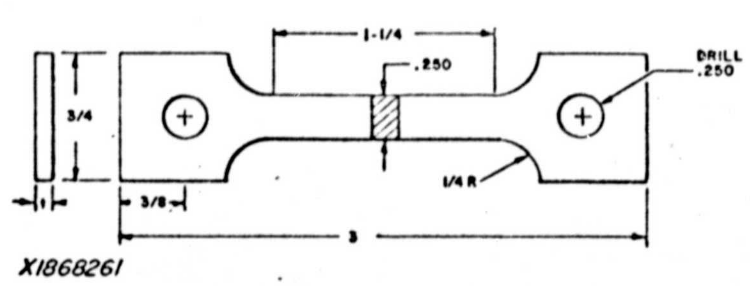
TENSILE SPECIMENS

ALL WELD METAL TENSILE SPECIMEN



DLP 13.820-TFS57

TRANSVERSE WELD TENSILE SPECIMEN



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