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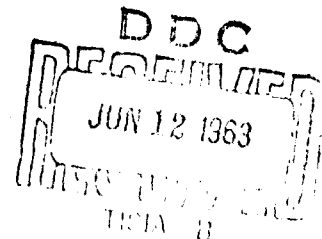
Report No. 3926-160

Material - Titanium - Ti 6Al-4V, Commercially Pure (A-70)

Seam Weld Strengths

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REPORT NO.

Report No. 8926-160

Material - Titanium - Ti 6Al-4V, Commercially Pure (A-70)

Seam Weld Strengths

Abstract:

Seam welds were made by the electric resistance, roller welding practice in a variety of welding combinations comprised of 0.012" thick rigidized commercially pure, 0.025" thick commercially pure, and 0.025", 0.032" and 0.040" thick Ti 6Al-4V alloys. Tension testing revealed that in all cases, except that one in which 0.040" thick Ti 6Al-4V comprised the thinnest weld joint member, failures occurred in the parent metal; in the exception noted the failure took place in the heat affected zone adjacent to the weld. The efficiency of the weld joints was thus found to be 100 per cent, except in the case of 0.040" thick Ti 6Al-4V where it was found to be 92 per cent.

Reference: Stier, H. H., Turner, H. C., Sutherland, W. M.,
"Seam Welds with Ti 6Al-4V Titanium Sheet,"
General Dynamics/Convair Report MP 56-115,
San Diego, California, 27 December 1956.
(Reference attached).

ANALYSIS**PREPARED BY** Stier/Turner**CHECKED BY** W. M. Sutherland**REVISED BY****CONVAIR**A DIVISION OF GENERAL DYNAMICS CORPORATION
SAN DIEGO**PAGE 1****REPORT NO.** 56-115**MODEL** F-100A**DATE** 12-27-56**REPORT NO. 56-115
SEAM WELDS WITH Ti-6Al-4V
TITANIUM SHEET****OBJECT:**

1. To establish satisfactory machine settings for seam welding various combinations of sheets of A-70 and Ti-6Al-4V titanium.
2. To determine the shear strength of various seam-welded combinations of A-70 and Ti-6Al-4V sheet.

PURPOSE:

To establish procedures, obtain design values and provide data with which military approval may be obtained so that Ti-6Al-4V material may be substituted for A-110-AT material in Convair's planes.

CONCLUSIONS:

The Ti-6Al-4V titanium sheet in the annealed condition is suitable to replace A-110-AT with respect to its seam-welding characteristics; viz.,

- (i) the new material can be seam welded with existing Plant II equipment,
- (ii) the strength of the welded joints is equal to (or exceeds) that found in A-110-AT.

DESCRIPTION OF SPECIMENS:

Chemical composition and mechanical properties of the titanium sheet used in this test are recorded in Table I.

The following combinations of A-70 and Ti-6Al-4V sheet were seam-welded:

- (a) .025 AV to .032 AV
- (b) .025 AV to .025 P
- (c) .025 AV to .025 AV to .025 AV
- (d) .025 AV to .025 AV to .012 R
- (e) .025 AV to .012 P to .012 R
- (f) .025 AV to .012 R to .012 P
- (g) .032 AV to .040 AV to .012 R
- (h) .012 R to .025 AV to .012 R
- (i) .012 R to .012 R to .025 AV to .032 AV
- (k) .025 AV to .025 AV
- (l) .032 AV to .032 AV
- (m) .040 AV to .040 AV

(Note: In the table above, the number represents thickness of sheet, AV represents Ti-6Al-4V plain sheet, P represents A-70 plain sheet, R represents A-70 rigidized sheet.)

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SAN DIEGO**PAGE 2****REPORT NO.** 56-115**MODEL** F-106A**DATE** 12-27-56**TEST PROCEDURE:**

Prior to welding, the titanium panels were prepared as follows:

1. Vapor degrease (solvent 1050-55, MPS 64-03)
2. Alkaline cleaner (Clean 1010-10, MPS 61.01, 150°-180°F.)
3. Hot water
4. Titanium etch (CVAC-AQ1, 1010-95, 1.5-3.0%
CVAC-AQ1, 1010-80, 25-35%, MPS 63.03)
5. Cold water
6. Oakite etch (clean 1010-100, MPS 61.03)
7. Hot water
8. Vapor degrease (see step 1.)

Various machine settings on a Precision Seam Welder, 150 KVA, in Plant II were tried until a satisfactory weld was produced; viz., peel tests and microscopic examination revealed

1. Continuous fused zone penetration into the outer sheets of not less than 20% of the original sheet thickness at any point over an area whose major axis is 80% of the interface weld diameter (approximately 50% nugget overlap).
2. No interface nugget expulsion.
3. Freedom from surface burns (straw or blue color at edge of weld acceptable).

Specimens for testing in shear were welded when penetration requirements had been met using a given machine setting.

Tension-shear coupons were mill-cut from seam-welded panels. The panels were welded from two pieces of 3" x 6" material (with the grain direction parallel to the 6-inch length) plus 1" x 6" strips (grain direction parallel to the 6-inch length). (See Figure 1.) In addition, separate panels were welded from rigidized material which had the grain direction of the rigidized sheet perpendicular to the 6-inch length. In this manner the combinations including rigidized A-70 could be tested with the rigidizing parallel to the load (as well as with rigidizing normal to the load).

In this report the side of the rigidized sheet on which the sinusoidal configurations appear as ridges will be called the top surface; the opposite side of the sheet (where the sinusoidal configurations appear as depressions) will be known as the bottom surface of the sheet. (See Figure 2.)

Combinations including rigidized A-70 were placed between the welding electrodes with the rigidized sheet above the plain sheets and, further, with the top surface of the rigidized sheet in contact with the welding electrode. Exceptions to this arrangement were made in the following combinations:

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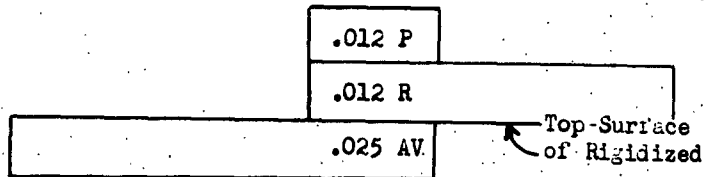
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TEST PROCEDURE. (Cont'd.)

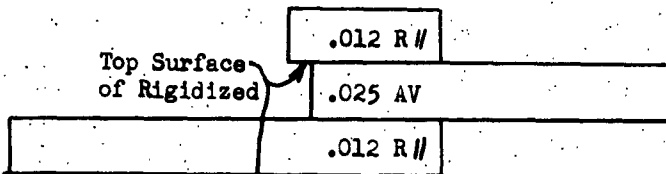
- (f) .025 AV to .012 R to .012 P
- (h) .012 R to .025 AV to .012 R
- (i) .012 R to .012 R to .025 AV to .032 AV

The orientation of sheets in these combinations is shown in cross section:

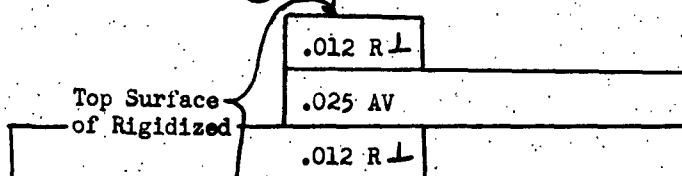
(f) - I & II



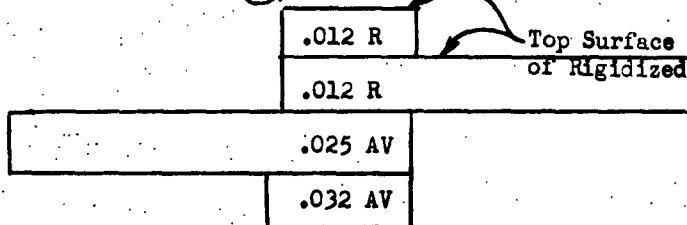
(h) - I



(h) - II



(i) - I & II



(Note: .012 R // has the rigidizing parallel to the load and
 .012 R ⊥ has the rigidizing perpendicular to the load.)

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Shear specimens were pulled in a Tinius Olsen tensile machine at a crosshead speed of 0.2 in. per min. until failure.

DISCUSSION OF PROCEDURE:

Future tests of this nature should employ 4" x 8" instead of 3" x 6" material. This will permit gripping shear coupons securely in the tensile machine and, further, enough material will be available for 5 coupons per panel.

Sheet combinations which included rigidized A-70 were tack-welded at 3 points along the overlap. This was necessary to prevent arcing. The tacks were so placed and the seam so welded that the seam covered up the tacks. The tack-welds had no observable effect on weld strength except in one specimen where the tack lay outside the seam weld, in which case the weld strength was greatly reduced.

RESULTS AND DISCUSSION:

Seam-weld machine settings and corresponding tension-shear values are given in Table II and III.

Failures in the parent metal during testing indicates a weld-joint efficiency of 100%, that is, the weld is as strong as the parent metal.

The efficiency of all welds using rigidized A-70 material may be assumed to be 100% since the few random failures in the heat-affected zone (HAZ) showed strengths equal to that of the parent metal.

Welds with .025 AV, .025 P, and .032 AV showed 100% efficiency with all failures occurring in parent metal.

The welded combination of .040 AV to .040 AV showed 92% efficiency with all failures occurring in the heat-affected zone.

A comparison between physical properties of parent metal and breaking strength of seam-welded metal is given for 6Al-4V and A-70:

<u>Material</u>	<u>Ult. Strength (Parent)</u>	<u>Ult. Strength (Weld)</u>	<u>Efficiency</u>
.012 R	(not tested)	87,000 psi (ave.)	100%
.025 P	100,400 psi (ave.)	105,100 psi (ave.)	100%
.025 AV	134,900 psi (ave.)	138,000 psi (ave.)	100%
.032 AV	137,100 psi (ave.)	136,300 psi (ave.)	100%
.040 AV	141,700 psi (ave.)	130,700 psi (ave.)	92%

A similar comparison of values for A-110-AT taken from report 9354 is given:

<u>Gauge</u>	<u>Ult. Strength (Parent)</u>	<u>Ult. Strength (Weld)</u>	<u>Efficiency</u>
.032	127,000 psi (ave.)	130,000 psi (ave.)	100%

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SAN DIEGO**PAGE** 5**REPORT NO.** 56-115**MODEL** F-106A**DATE** 12-27-56**RESULTS AND DISCUSSION. (Cont'd.)**

Microscopic examination of all welds showed sound nuggets and penetration from 60% to 90% into the outer sheets. The combination of .025 R to .025 AV showed a coarse mixture of the respective microstructures at the interface within the nugget area.

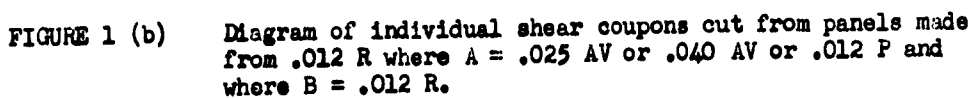
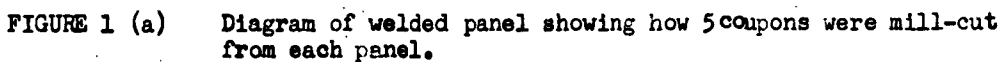
Values for shear test no's. (e) - I - 2, (h) - I - 2, and (k) - 4 were omitted from the Table III for the following reason:

- e-I-2, the tensile machine operator damaged the specimen when clamping specimen into the grips of the tensile machine.
- h-I-2, a tack weld lay outside the seam weld and acted as a local stress-raiser.
- k-4, the specimen failed in the metal held within the jaw of the testing machine.

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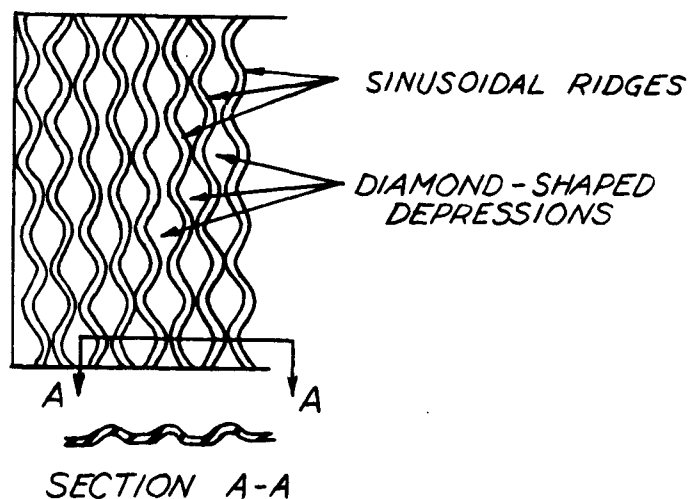


FIGURE 2 - TOP VIEW OF RIGIDIZED SHEET

NOTE: In this report the side of the rigidized sheet on which the sinusoidal configurations appear as ridges is called the top surface.

TABLE I. MECHANICAL PROPERTIES & CHEMICAL COMPOSITION OF SPOT WELDED MATERIALS

[illegible]

TABLE II. MACHINE SETTINGS FOR WELDING Ti-6Al-4V
ON PRECISION SEAM WELDER (MACH. #1, PLANT II) SERIAL NO. 251649

[illegible]

TABLE III. RESULTS OF TENSION SHEAR TESTS
ON SEAM-WELDED Ti-6Al-4V SPECIMENS

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Identif.	Gauge & Mat'l. Welded	Interfacial Tested	Thickness of Welded Sheet (in.)	Area (in ²)	Load (lb.)	Ultimate Strength (psi)	Ave. Ultimate Strength (psi)	Location of Failure
(a) - 1	.025 Ti-6Al-4V	(1) (1)	(1) = .025	.0180	2530	141,600	141,600	Parent of .025 Ti
- 2	"	"	"	"	2515	139,500	139,500	"
- 3	"	"	"	"	2530	140,000	140,000	"
- 4	"	"	"	"	2580	142,800	142,800	"
- 5	"	"	"	"	2535	140,800	140,800	"
(b) - 1	.025 Ti-6Al-4V	(1) (1)	(1) = .025	.01875	1915	105,800	105,800	Parent of .025 Ti
- 2	"	"	"	"	1960	105,600	105,600	"
- 3	"	"	"	"	1955	105,200	105,200	"
- 4	"	"	"	"	1990	106,700	106,700	"
- 5	"	"	"	"	1965	105,200	105,200	"
(c) - 1	.025 Ti-6Al-4V	(1) (1)	(1) = .025	.01577	1790	140,800	140,800	Parent of .025 Ti
- 2	"	"	"	.01577	1725	138,400	138,400	"
- 3	"	"	"	.025	1760	141,000	141,000	"
- 4	"	"	"	.025	1790	142,300	142,300	"
(d) - 1	.025 Ti-6Al-4V	(1) (1)	(1) = .0115	.00570	505	87,200	87,200	Parent of .012 Ti
- 2	"	"	"	.00579	500	86,400	86,400	"
- 3	"	"	"	.00576	500	86,900	86,900	"
- 4	"	"	"	.00578	500	86,600	86,600	"
(e) - 1	.025 Ti-6Al-4V	"	"	.00560	507	90,500	90,500	Parent of .012 Ti
- 2	"	"	"	.00573	516	90,000	90,000	"
- 3	"	"	"	.00571	501	87,700	87,700	"
- 4	"	"	"	.00586	525	89,500	89,500	"

KEY:
 .012 Ti = liquidized sheet of Ti-70
 with grain direction parallel
 to PULL direction.
 .012 Ti = liquidized sheet of Ti-70
 with grain direction perpendicular
 to PULL direction.
 AV = Ti-6Al-4V plain
 .025 Ti = Ti-75-A plain



TABLE III. (CON'T.)

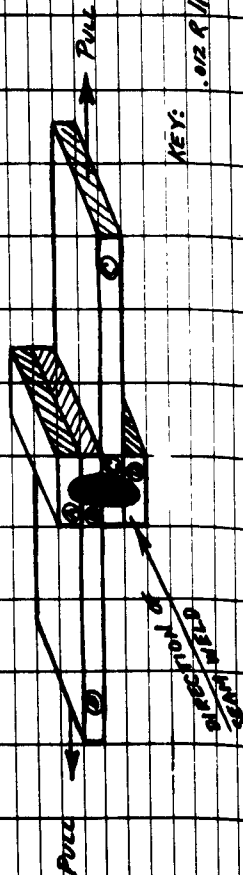
Identif.	Gauge & Mpt'l.	Interface Tested	Thickness of Rivet Steel (in.)	Load of Rivet (pounds)	Ultimate Strength (psi)	Avg. Ultimate Strength (psi)	Location of Failure
(a)-I-1	.012R1 .012P .012AV	(a) (b)	.0081	505	81,300	81,300	Failure at .012R
-2	" " "	"	.0081	460	79,600	79,600	"
-3	" " "	"	.0081	525	81,300	81,300	"
-4	" " "	"	.0081	570	81,300	81,300	"
(a)-II-1	.012R1 " "	"	.0081	470	81,300	81,300	Failure at .012R
-2	" " "	"	.0081	460	79,600	79,600	"
-3	" " "	"	.0081	490	81,300	81,300	"
-4	" " "	"	.0081	460	79,600	79,600	Failure at .012R
(b)-I-1	.012R1 .012P .012AV	(b) (c)	.0081	505	81,300	81,300	Failure at .012R
-2	" " "	"	.0081	460	79,600	79,600	"
-3	" " "	"	.0081	525	81,300	81,300	"
-4	" " "	"	.0081	570	81,300	81,300	"
(b)-II-1	.012R1 " "	"	.0081	470	81,300	81,300	Failure at .012R
-2	" " "	"	.0081	460	79,600	79,600	"
-3	" " "	"	.0081	490	81,300	81,300	"
-4	" " "	"	.0081	460	79,600	79,600	Failure at .012R
(c)-I-1	.012R1 .012P .012AV	(c) (d)	.0081	505	81,300	81,300	Failure at .012R
-2	" " "	"	.0081	460	79,600	79,600	"
-3	" " "	"	.0081	525	81,300	81,300	"
-4	" " "	"	.0081	570	81,300	81,300	"
(c)-II-1	.012R1 " "	"	.0081	470	81,300	81,300	Failure at .012R
-2	" " "	"	.0081	460	79,600	79,600	"
-3	" " "	"	.0081	490	81,300	81,300	"
-4	" " "	"	.0081	460	79,600	79,600	Failure at .012R



TABLE III. (CONT.)

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Identit	Gauge & Mat'l.	Interface	Thickness of	Area	Load	Ultimate	Ave. Min.	Location
		Tested	Failure Sheet	(in ²)	(pounds)	Strength (psi)	Strength (psi)	of Failure
(A)-I-1	.012R/.025AV/.02RL	①	①	.00571	500	85,200	84,700	HAZ of .012R
-2	"	"	"	.00573	468	82,600	"	"
-3	"	"	"	.00571	475	82,600	"	"
-4	"	"	"	.00594	525	87,400	"	"
(A)-I-1	.012RL	"	"	.00579	550	92,000	91,900	Parent of .012R
-2	"	"	"	.00570	545	92,000	"	"
-3	"	"	"	.00570	536	92,000	"	"
-4	"	"	"	.00580	533	92,000	"	"
-5	"	"	"	.00573	525	92,000	"	HAZ of .012R
(A)-I-1	.012R/.025AV/.02RL	①	①	.00571	524	87,200	87,100	Parent of .012R
-2	"	"	"	"	512	85,200	"	"
-3	"	"	"	"	511	85,100	"	"
-4	"	"	"	"	489	87,400	"	"
-5	"	"	"	"	505	87,200	"	"
(A)-II-1	.012RL/.02RL	"	"	.00595	550	89,200	88,300	"
-2	"	"	"	.00594	530	89,200	"	"
-3	"	"	"	.00574	480	85,200	"	"
-4	"	"	"	.00644	540	89,400	"	"



KEY:

.012 R/L = rigidized sheet of RC-70 with grain direction parallel to PULL direction

.012 R/L = rigidized sheet of RC-70 with grain direction perpendicular to PULL direction

AV = 71.6 H/4Y plain

CONVARS
BANK BUREAU

TABLE III. (CON'T.)

Identif.	Gauge & Mat'l.	Interface Tested	Thickness of Failing Sheet (in.)	Load of Failure (pounds)	Ultimate Strength (psi)	Ave. Ultimate Strength (psi)	Location of Failure
(A) - 1	.025AV .025AV	(A) (B)	.026"	2640	157,200	136,000	Airport
- 2	" "	"	"	2675	157,200	"	"
- 3	" "	"	"	2645	157,200	"	"
- 4	" "	"	"	1940	157,200	"	"
- 5	" "	"	"	2650	157,200	"	"
(A) - 1	.032AV .032AV	"	.036"	3670	156,000	136,000	Parent
- 2	" "	"	"	3690	156,000	"	"
- 3	" "	"	"	3625	156,000	136,000	"
- 4	" "	"	"	3710	157,500	"	"
- 5	" "	"	"	3700	157,500	"	"
(Am) - 1	.040AV .040AV	"	.050"	4900	130,500	130,500	HAZ
- 2	" "	"	"	4916	131,000	"	"
- 3	" "	"	"	4900	130,500	130,700	"
- 4	" "	"	"	4920	131,200	"	"
- 5	" "	"	"	4870	130,500	"	"

See Gripped Metal