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Report No. 8926-132

Material - Aluminum - 7075-T6

Evaluation of Protruding Head, Overaged Rivets

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Material - Aluminum - 7075-T6

Evaluation of Protruding Head, Overaged Rivets

Abstract:

Overaged 7075-T6 aluminum alloy rivets were sought as replacement for 2024-T31 aluminum rivets which presented production difficulties. Heat treatment of 7075-O aluminum alloy rivets by means of a 30-minute 870°F solution heat treatment, followed by water quenching and aging for 4-1/2 hours at 325°F provided 7075-T6 rivets which were 10 per cent stronger than 2024-T31 rivets, and were comparable with the 2024-T31 rivets with respect to driving characteristics. Salt spray tests of 500 hours duration with rivets stressed to 40, 50, 60 and 68 per cent of their ultimate tensile strength did not indicate incidence of stress corrosion cracking. The solution potential of the 7075-T6 was not changed by the revised heat treatment.

Reference:

1. Harvey, J. L., Parker, W. M., Turner, H. C., "Evaluation of Protruding Head, 7075-T6 Aluminum Alloy, Overaged Rivets," General Dynamics/Convair Report MP 57-555, San Diego, California, 17 April 1959 (Reference attached).
2. Harvey, J. L., Parker, W. M., Turner, H. C., "Additional Testing of Protruding Head 7075-T6 Aluminum Alloy, Overaged Rivets," General Dynamics/Convair Report MP 57-555-3, San Diego, California, 12 August 1959 (Reference attached).

ANALYSIS
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CONVAIR
A DIVISION OF THE ALUMINUM COMPANY OF AMERICA
SAN DIEGO

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PURPOSE:

1. Develop a heat treatment for 7075 aluminum alloy to produce satisfactory rivets; these rivets should have 10% greater shear strength than the presently used 2024-T31 aluminum alloy rivets and should be free of rejectable cracks according to current Manufacturing Process Specification, when driven by current shop procedures.
2. Determine susceptibility to stress corrosion cracking and the solution potential of 7075-T6 overaged rivets.

CONCLUSIONS:

1. Solution heat treating 7075 aluminum alloy protruding head rivets at 870°F + 10°F for 30 minutes and water quenching, followed by aging at 325°F + 5°F for 4-1/2 hours and cooling in still air, provided the best heat treating cycle. This heat treatment produced rivets free of rejectable cracks as outlined under Manufacturing Process Specification 46.05D.
2. With the use of the above heat treatment, ultimate shear strengths varied from 43,100 psi to 46,900 psi.
3. No significant change in solution potential was observed on rivets overaged at 325°F for 4-1/2 hours in comparison to rivets aged at the conventional age hardening cycle for 7075 aluminum alloy of 250°F for 24 hours.
4. No evidence of stress corrosion cracking was found after 500 hours in salt spray at 41% of the ultimate tensile strength.

TEST PROCEDURE:

General:

- A. All 7075-O aluminum alloy rivet wire used in this test was furnished Convair by Aluminum Company of America. Heat numbers are unknown.
- B. Rivets were manufactured and anodized by Manufacturing Rivet Crib. Driving of rivets and manufacture of test specimens was accomplished by Dept. 31 personnel. All rivet holes manufactured for this test were in accordance to dimensions outlined in Convair Specification Q-2001.
- C. Heat treating, exposure to salt spray and testing of rivets and specimens were all performed in the Materials & Processes Laboratory of Convair-San Diego. The temperature tolerances for all the heat treatments used were +10°F for solution heat treating, and +5°F for the various aging cycles.

TEST PROCEDURE: (Continued)

Universal testing machines and test jigs in the Materials and Processes Laboratory were used to obtain all mechanical properties.

Heat Treatments Used for Shear Specimens:

In order to determine the proper overaging cycle, appropriate lengths of 1/8" diameter 7075-0 rivet wire were cut. These lengths were then solution heat treated at 870°F for 30 minutes and water quenched. The aging intervals used were: (a) 1 week at room temperature; (b) 250°F for 24 hours; and (c) 325°F for 1, 3, 5, 7, 9, 11 and 12 hours. Single and double shear tests were made.

A sufficient amount of 1/8" diameter protruding head 7075-0 rivets were first solution heat treated at 870°F for 30 minutes and water quenched. These were then aged at the following intervals: (a) 250°F for 24 hours; (b) 300°F from 2 to 12 hours; (c) 325°F from 1 to 12 hours; and (d) 350°F from 2 to 6 hours. Simple shear tests were made.

Sufficient amount of 1/4" diameter 7075-0 rivets were solution heat treated at 870°F for 30 minutes and water quenched. Aging intervals used were: (a) 250°F for 24 hours; (b) 300°F from 2 to 7 hours; and (c) 325°F from 1 to 5 hours. Simple shear tests were made.

Driving Characteristics:

In order to observe the driving characteristics of overaged rivets, the following aging cycles were chosen at completion of above rivet shear tests: (a) 250°F for 24 hours; (b) 300°F for 4, 5 and 6 hours; and (c) 325°F for 2, 3, 4, 4-1/2 and 6 hours. The 1/8" diameter rivets were driven into a .125" thick 7075-T6 clad plate. Likewise, the 1/4" diameter rivets were driven into a .250" thick 7075-T6 clad plate. Initial protrusions used were 1.05 to 1.15 diameter and 1.33 diameter to be upset to 1.3 to 1.4 and 1.5 diameters, respectively. Rivets were driven by the following driving combinations: (a) rivet gun using flat sets; (b) squeezer with flat set; and (c) squeezer using cone point set.

Lap Joint Shear Specimens:

Lap joint shear specimens were made using 1/8", 5/32", 3/16" and 1/4" diameter rivets. Aging cycles used were: (a) 250°F for 24 hours; and (b) 325°F for 4, 4-1/2, 5 and 6 hours. Rivets were tandem-spaced at 4 rivet diameters apart and with a 2-diameter edge distance.

Storage Tests:

Rivets from 4 coils of 5/32" diameter rivet wire, each coil from a different heat, were solution heat treated and aged at 325°F for 4-1/2 hours, and tested for lap joint shear strength. Then from one of the coils, aging of a second group of rivets was delayed for one week, then aged and tested. From another coil a second group of rivets was stored at room temperature after aging and tested at monthly intervals

TEST PROCEDURE: (Continued)

Solution Potential Tests:

The solution potential of the overaged rivets, 325°F for 4-1/2 hours, and the normally aged rivets, 250°F for 24 hours, were compared. The rivets were immersed in a solution of 53 gm. NaCl plus 3 gm. H₂O₂ per liter. Solution potential measurements were made with an Ag:AgCl reference electrode and these were converted to solution potentials with 0.1N Calomel electrode. (See Appendix)

Stress Corrosion Tests:

The stress corrosion samples (see Figure III) were made using two .250" thick clad 7075-T6 plate sandwiched together. At the center of the panel 1/8" diameter rivets were driven. Rivets used were aged at 250°F for 24 hours, and at 325°F for 4-1/2 hours. Steel pins of 1/4" diameter were wedged between the sandwiched panels. Specimens were then subjected to the salt spray exposure test for 500 hours. Calculations of applied tension stress in the rivets are outlined in the Appendix.

Tests to Obtain Upsetting Force:

To obtain the force required to drive a 1/8" diameter rivet to a 1.3 to 1.4 diameter upset head, a steel block 1.125" thick with a .125" $\pm$.000" rivet hole was used in making tests. Lengths of rivet wire were cut so that there was an initial protrusion between 1.05 and 1.15 of rivet wire diameter.

RESULTS:

The results of the single and double shear tests on 1/8" diameter 7075-T6 rivet wire aged at different temperatures for various time cycles are found in Table I.

The results of the simple shear tests performed on 1/8" and 1/4" diameter 7075-T6 rivets are found in Tables II and III. The results for the 300°F and 325°F aging temperatures are graphically shown in Figure I and II.

Table IV contains the results of the lap joint tests performed on the protruding head rivets. Results of storage tests are also included in this table.

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RESULTS: (Continued)

The solution potential results were as follows:

Aging Temp.	Aging Time	Rivet Diam.	Electrode Potential of Rivet in NaCl-H ₂ O ₂ Solution versus Indicated Reference Electrode	
			Ag:AgCl Electrode (Measured)	0.1N Calomel Electrode (Calculated)
325°F	4-1/2 Hrs.	1/8"	-.710V	-.827V
"	"	1/4"	-.705V	-.822V
250°F	24 Hrs.	1/8"	-.715V	-.832V
"	"	1/4"	-.710V	-.827V

The above results compare favorably with the value listed in ASM Metals Handbook, 1948 Edition, Page 792 for 7075-T6 of -.81V obtained with a 0.1N Calomel reference electrode.

Examination of the stress corrosion samples (see Figure III) with a binocular microscope showed no signs of cracking after 500 hours in the salt spray exposure test.

The average force required to upset 1/8" diameter 7075-T6 rivet wire aged at 325°F for 4-1/2 hours was 2084 lbs., and 2266 lbs. for wire aged at 250°F for 24 hours.

DISCUSSION OF RESULTS:

The shear ultimate strengths obtained on the rivet wire and rivets in the un-driven condition exceeded the values quoted in ANC-5, March, 1955 Edition, Page 121 for 2024-T31 subjected to this type of testing.

During the driving tests it was observed that the best reproducible results were obtained when upsetting to a 1.3 to 1.4 rivet diameter upset head with an initial protrusion of 1.05 to 1.15 rivet diameter. Upsetting to a 1.5 rivet diameter from a 1.33 rivet diameter initial protrusion resulted in rejectable cracks in the upset head.

The overaging cycles from which upset heads consistently free of cracks were obtained were at 325°F for 4-1/2 hours and 300°F for 6 hours. Although sound bucked heads were obtained with some of the other aging cycles for one type of upsetting, this condition did not prevail for all types of upsetting methods. For example, sound bucked heads were obtained after one aging cycle when squeezer and cone point set were used; cracks were obtained in the same rivets when a rivet gun with flat sets was used. Therefore the reproducibility of driving characteristics and the shorter time for overaging greatly influenced the choice of the 4-1/2 hours at

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DISCUSSION OF RESULTS: (Continued)

325°F as the best overaging cycle. It must be pointed out again that the limits one must adhere to are a 1.05 to 1.15 initial protrusion, and a 1.3 to 1.4 upset diameter head. Rivets aged at 325°F for 4-1/2 hours with the above mentioned driving methods and rivet diameter limits will give an upset head free of rejectable type cracks.

The average ultimate lap joint shear strength of all the 7075-T6 protruding head rivets exceeded the values quoted in ANC-5, March 1955, Edition, Page 121 for 2024-T3 protruding head rivets subjected to this type of testing. Storage of rivets after heat treatment had no effect on the lap joint shear strength.

NOTE: The data from this report is written are recorded in Materials and Processes Engineering Data Book No. 986.

TEST 57-555

7075-T6 OVERAGED RIVETS
AGING TEMPERATURE 300°F.

1/8" RIVETS
A
AGED 24 HRS.
@ 250°F.

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1/4" RIVETS
A
AGED 24 HRS.
@ 250°F.

SIMPLE SHEAR STRENGTH - KSI

53

51

50

49

48

47

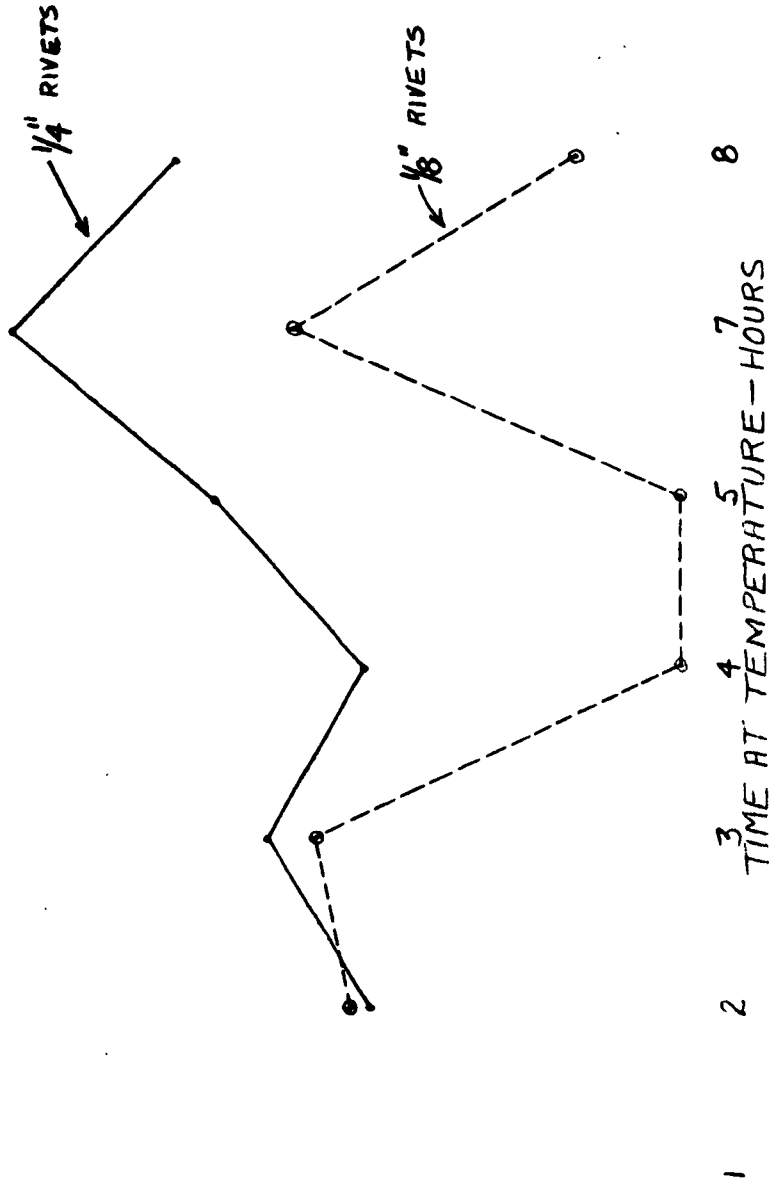
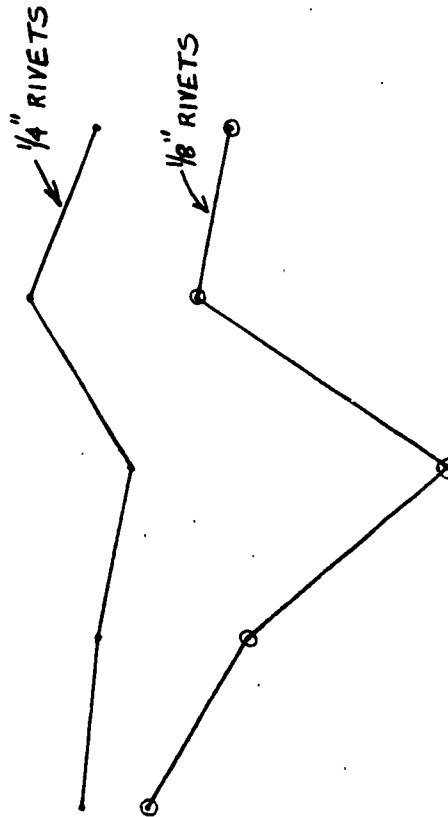


FIGURE I

TEST 57-555
7075-T6 OVERAGED RIVETS
AGING TEMPERATURE 325 °F



470

48

49

50

51

52

53

8

7

6

5

4

3

2

1

FIGURE II

TIME AT TEMPERATURE-HOURS

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1. ALL RIVETS SOLUTION HEAT TREATED 30 MIN. AT 870°F.
2. SPECIMENS 1&2: RIVETS AGED 24 HRS. AT 250°F.
3. " 3&4: " " 4 1/2 " " 325°F
4. BEFORE EXPOSURE TO SALT SPRAY, RIVETS STRESSED BY WEDGING 1/4" ROUND PINS BETWEEN PLATES ON BOTH SIDES OF RIVET AND 7 1/4" APART.

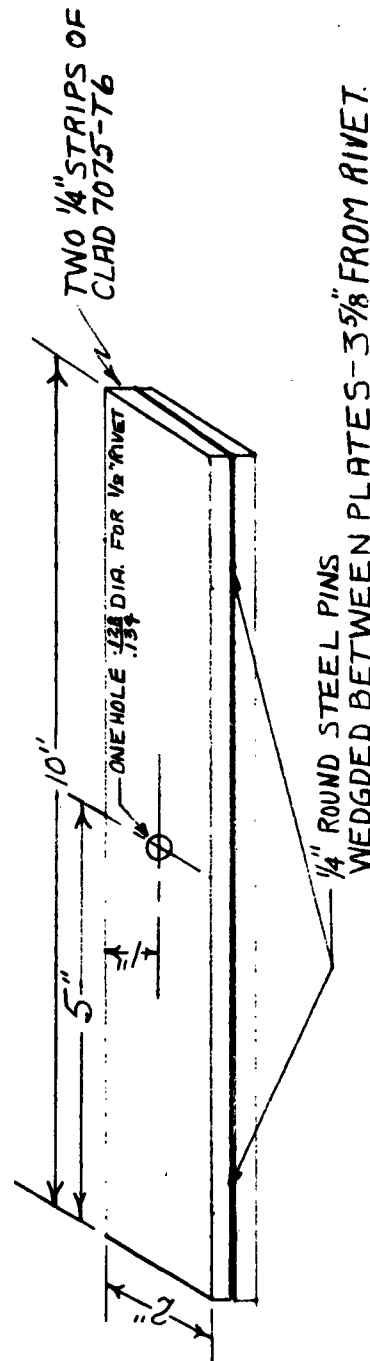


FIGURE III STRESS CORROSION SPECIMEN

TABLE I

SHEAR VALUES OF 7075-T6 RIVET WIRE		SPECIMEN SIZE	AGING		TEST RESULTS-SINGLE SHEAR - LBS.				AVERAGE VALUES PSI.
			TEMP. °F	TIME	# 1	# 2	# 3	AVERAGE	
WIRE-DOUBLE SHEAR	1/8"	↑	ROOM	1 WEEK	537.5	540	545	540.8	45,100
			250°	24 HRS.	637.5	632.5	637.5	635.8	53,000
			325°	1 HR.	532.5	535	527.5	531.7	44,300
				3 "	520	520	530	523.3	43,600
				5 "	537.5	535	530	534.2	44,600
				7 "	532.5	540	535	535.8	44,650
				9 "	542.5	532.5	532.5	535.8	44,650
				11 "	512.5	520	517.5	516.7	43,100
				12 "	537.5	530	527.5	531.7	44,300
WIRE-SINGLE SHEAR	1/8"	↑	ROOM	1 WEEK	458	466	480	468	39,000
			250°	24 HRS.	560	570	562	564	42,050
			325°	1 HR.	490	486	494	490	40,850
				3 "	488	494	490	490.7	40,920
				5 "	482	490	502	491.3	40,970
				7 "	486	492	486	488	40,700
				9 "	480	494	496	490	40,850
				11 "	478	482	488	482.7	40,250
				12 "	498	490	478	488.7	40,750

ALL SPECIMENS WERE SOLUTION HEAT TREATED AT 870°F ± 10°F. FOR 30 MINUTES, WATER QUENCHED.

TABLE II

SHEAR VALUES OF 7075-T6 RIVETS										
TYPE OF TEST	SPECIMEN SIZE	AGING		TEST RESULTS-SIMPLE SHEAR-LBS.					AVERAGE VALUES PSI.	
		TEMP. °F	TIME	#1	#2	#3	#4	#5		
RIVETS-SIMPLE SHEAR	1/8"	250°	24 HRS.	638	638	625	623	617	628	51,150
			2	577	595	590	597	598	591.4	48,200
			3	597	597	605	602	580	596.2	48,600
			4	575	578	582	538	557	566	46,100
			5	575	560	575	545	580	567	46,200
			6	590	600	585	600	595	594	48,400
			7	585	585	580	580	550	576	46,900
			7	615	605	605			608.3	49,550
			8	580	575	585			580	47,250
			9	590	580	590			586.7	47,750
			11	600	590	590			593.3	48,350
			12	580	580	585			581.7	47,900
		325°	1	620	600	635	610	620	617	50,300
			2	610	605	615	610	600	608	49,500
			3	585	600	585	600	600	594	48,900
			4	610	610	610	610	615	611	49,750
			5	605	600	605	615	620	609	49,600
			5	565	570	575			570	46,400
			7	570	570	565			568.3	46,250
			9	565	570	565			566.7	46,150
			11	540	540	550			543.3	44,250
			12	545	550	550			548.3	44,650
		350°	2	555	555	540			550	44,800
			3	540	540	540			540	44,000
			4	535	535	535			535	43,600
			5	535	525	530			530	43,200
			6	515	490	510			505	41,150

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ALL SPECIMENS WERE SOLUTION HEAT TREATED AT 870°F.±10°F. FOR 30 MINUTES, WATER QUENCHED.

ALL SPECIMENS WERE SOLUTION HEAT TREATED AT 870°F. ± 10°F. FOR 30 MINUTES, WATER QUENCHED.

TABLE III

TYPE OF TEST	SPECIMEN SIZE	AGING TEMP. °F	SHEAR VALUES OF 7075-T6 RIVETS TEST RESULTS - SIMPLE SHEAR - LBS.					AVERAGE VALUES P.S.L.	
			#1	#2	#3	#4	#5		
RIVETS - SIMPLE SHEAR	1/4"	250°	2495	2365	2345	2360	2310	2370	48,350
		300°	2387	2412	2422	2390	2445	2411	48,100
		325°	2448	2475	2405	2435	2455	2443.6	49,750
			2428	2455	2372	2428	2415	2419.6	49,300
			2417	2460	2425	2460	2490	2450.4	49,900
			2500	2500	2570	2570	2500	2516	51,250
			2500	2430	2440	2465	2465	2460	50,150
		375°	2510	2535	2545	2580	2530	2540	51,750
			2545	2520	2510	2560	2535	2534	51,600
			2545	2555	2570	2575	2465	2518	51,250
			2590	2550	2560	2550	2545	2559	52,100
			2530	2550	2550	2510	2530	2534	51,600

ALL SPECIMENS WERE SOLUTION HEAT TREATED AT 870°F ± 10°F FOR 30 MINUTES, WATER QUENCHED.

TABLE IV

UNIVERSAL HEAD 7075-T6 RIVETS IN LAP JOINTS OF CLAD 7075-T6 SHEET									
RIVET SIZE	SHEET THICKNESS	AGING		TEST ULTIMATE LOADS - LB/RIVET				AVERAGE ULTIMATE LOAD PS.L.	REJECT-ABLE CRACKS
		TEMP. °F.	TIME HOURS	#1	#2	#3	#4		
1/8"	.063"	325°	6	535	540	545		540 41,635	0
			5	645	670	652		656 50,600	0
			4	675	665	660		667 51,450	0
			4	657.5	660	657.5		658 50,750	ALL
			4 1/2	845	925	890		887 44,700	0
			4 1/2	875	910	845		877 49,200	0
			4 1/2	850	870	870		863 43,400	0
			4 1/2	900	910	905		905 45,600	0
			4 1/2	920	922	925		922 46,400	0
			4 1/2	930	945	925		933 46,900	0
			4 1/2	910	900	905		905 45,600	0
			4 1/2	925	892	895		904 45,500	0
			4 1/2	890	910	915		905 45,600	0
			4 1/2	905	893	905	925	906 45,500	0
			4 1/2	1267	1303	1270		1280 44,700	0
			24	2722	2695	2745	2740	2726 52,600	ALL
		250°	6	2165	2165	2155	2200	2171 41,850	0
		325°	5	2592	2475	2395		2471 47,600	0
			4	2657	2650	2600		2636 50,850	0
			4	2380	2492.5	2595		2489 48,000	ALL
			4 1/2	2250	2200	2250		2233 43,100	0

COIL #1
COIL #2
COIL #3
COIL #4
AGED AFTER 1 WEEK
DELAY COIL #4
AGED AND TESTED AT
SPACE COIL #3
AGED STORED 1 MONTH
THEN TESTED COIL #3
AGED STORED 2 MONTHS
THEN TESTED COIL #3
AGED STORED 3 MONTHS
THEN TESTED COIL #3

ALL RIVETS WERE SOLUTION HEAT TREATED AT 870°F. ± 10°F. FOR 30 MINUTES, WATER QUENCHED

APPENDIX

CALCULATIONS ON STRESS CORROSION SPECIMENS

The tension stress in the stress corrosion test was calculated as shown. This stress is approximately 50% of the typical ultimate tensile strength of 1/8" diameter 7075 aluminum rivet wire. This calculated stress is in addition to the residual stresses created during driving which are not known.

$$r = \frac{1}{48} \frac{PL^3}{EI}$$

$$P = \frac{48 EIr}{L^3}$$

$$= \frac{48(10.3 \times 10^6 \text{ lb./in.}^2)(.0026 \text{ in.}^4)(.125 \text{ in.})}{(7.25 \text{ in.})^3}$$

$$= 422.4 \text{ lb.}$$

r (rad. of steel pin) = .125 in.
 E (modulus of 7075-T6) = $10.3 \times 10^6 \text{ lb./in.}^2$
 I (moment of inertia of 7075-T6 plate) = .0026 in.⁴
 L (dist. between of steel pins) = 7.25 in.

therefore,

$$S = \frac{P}{A}$$

$$= \frac{422.4 \text{ lb.}}{.01297 \text{ in.}^2}$$

$$= 32,600 \text{ lb./in.}^2$$

P (tension load on rivet) = 422.4 lb.
 A (area of 1/8" diam. rivet) = .01297 in.²

CALCULATION OF SOLUTION POTENTIAL VALUES

The cell solution used contained 53 gm. NaCl plus 3 gm. H₂O₂ per liter. The reference electrode used was Ag:AgCl with a calibrated potential of -.217 volts. The Ag:AgCl electrode was calibrated against a known saturated Calomel electrode. Measured solution potentials were converted to solution potentials with an 0.1 Normal Calomel reference electrode with the formula,

$$E_T = E_+ - E_-$$

E_T is the cell potential (the electrode potential of the rivet in test solution versus 0.1N Calomel electrode).

E_+ is the anode half-cell potential with respect to a reference electrode (the electrode potential of the rivet in test solution versus Ag:AgCl electrode).

E_- is the cathode half-cell potential (0.1N Calomel versus Ag:AgCl electrode or .117 volts).

This conversion was made so that values could be compared with those in the literature which are reported with the 0.1N Calomel electrode.

ANALYSIS

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REPORT NO. 57-555-3

MODEL F106

DATE 8-12-59

Report No. 57-555-3
Additional Testing of Protruding
Head, 7075-T6 Aluminum Alloy,
Overaged Rivets - Model F106

OBJECT:

To obtain further information on the effect of prolonged storing at room temperatures on ultimate shear strength of overaged 7075-T6 protruding head rivets.

To evaluate the stress corrosion properties of overaged 7075-T6 protruding head rivets at stress levels of 50%, 60%, and 68% of typical ultimate tensile strength.

CONCLUSIONS:

Prolonged storing of overaged 7075-T6 protruding head rivets at room temperature had no effect on the ultimate shear strength.

Overaged 7075-T6 protruding head rivets when stressed at 50%, 60%, and 68% of typical ultimate tensile strength and exposed to 500 hours salt spray exposure test showed no evidence of stress corrosion cracking.

PROCEDURE:

All protruding head rivets used were solution heat treated at 870°F for 30 minutes, water quenched and aged at 325°F for 4-1/2 hours, air cooled.

Rivets, 5/32" diam., which after aging had been stored at room temperature for 10 months, were tested for lap joint shear strength in .063" clad 7075-T6 sheet.

The original stress corrosion specimens (see Report No. 57-555) were tested at a stress level of 41% of the typical ultimate tensile strength for 7075-T6. Further information was required as to the stress corrosion properties of the overaged 7075-T6 rivets at the following stress levels: 50%, 60%, and 68% of typical ultimate tensile strength.

Duplicate specimens were made similar to the one depicted in Figure III, Report No. 57-555, except that the distances between pins and rivets were changed to achieve the higher stress levels. The new distances between pin and rivet were 3-13/32", 3-3/16", and 3-1/16" for the 50%, 60%, 68% stress levels, respectively.

Specimens were then subjected to the salt spray exposure test for 500 hours. This exposure was not continuous due to breakdown of the equipment. Total down time was 212 hours; the specimens were not removed from the cabinet during this interval making a total of 712 hours that the specimens were in the salt spray cabinet.

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RESULTS:

Following are the results of the lap joint shear strength tests:*

Rivet Size	Sheet Thickness	Aging		Test Ult. Loads - lb/Rivet					Average Ultimate Load, PSI
		Temp. °F	Time Hrs.	#1	#2	#3	#4	Average	
5/32"	.063	325°	4-1/2	992	969	961	956	969.5	48,700

*For comparison values, see Table IV of Report No. 57-555.

At the completion of the salt spray exposure test, the stress corrosion specimens were examined under a binocular microscope and no stress cracking was observed.

Note: The data from which this report was written are recorded in Engineering Materials and Processes Laboratories Data Book No. 3014.