



HAL
open science

CORROSION RESISTANCE OF ALUMINUM-LITHIUM ALLOYS

F. Lin, Y. Moji, W. Quist, D. Badger

► **To cite this version:**

F. Lin, Y. Moji, W. Quist, D. Badger. CORROSION RESISTANCE OF ALUMINUM-LITHIUM ALLOYS. Journal de Physique Colloques, 1987, 48 (C3), pp.C3-905-C3-911. 10.1051/jphyscol:19873105 . jpa-00226539

HAL Id: jpa-00226539

<https://hal.science/jpa-00226539>

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

CORROSION RESISTANCE OF ALUMINUM-LITHIUM ALLOYS

F.S. LIN, Y. MOJI, W.E. QUIST and D.V. BADGER

*The Boeing Commercial Airplane Company, P.O. Box 3707,
Seattle, WA 98124-2207, U.S.A.*

ABSTRACT: The effects of corrosive environments on aluminum-lithium-copper-(magnesium) alloys have been studied as they relate to the commercial airplane industry. It has been found that, in general, the alloys 2090 and 2091 exhibit equal or improved corrosion performance compared to the 2024 and 7075 alloys they are likely to replace. Cladding and coating systems have been shown to compare favorably with conventional alloys.

BACKGROUND: Aluminum alloys containing around 2% lithium are being developed for the aerospace industry to take advantage of the low densities that are possible. If these alloys have properties equivalent or superior to conventional aerospace alloys, density reductions can be translated into greater efficiency of the final vehicle. Equivalency in mechanical properties is required for gage for gage substitution, and for the 2090 and 2091 alloys this has been achieved to a relatively close degree. However, for use in the commercial airplane industry any new alloy needs to also have excellent corrosion resistance because it will be exposed to many extremes of temperature and atmosphere over a lifetime that may exceed 30 years. In addition to the requirement for good basic corrosion resistance, finishing and cladding systems need to be developed for aluminum-lithium alloys.

INTRODUCTION: Corrosion properties of Al-Li alloys exposed in various environments have been extensively investigated by several researchers to determine the resistance to pitting, intergranular corrosion, exfoliation and stress corrosion cracking. Areas of research covered the effect of chemistry (1-3), aging (4, 5) and grain structure (6) on corrosion properties. This work showed that the corrosion resistance of some Al-Li alloys did appear capable of reaching the desired goals for aerospace applications.

In general aluminum-lithium alloys will be either clad with a non-lithium alloy to provide galvanic protection and a superior surface appearance, or will be protected by a series of finishing operations to ensure long term reliability. The corrosion studies leading to the choice of cladding and finishing systems will be addressed in this paper.

MATERIALS: Both bare and clad alloys of 2090, 2091, 2024-T3 and 7075-T6 were used in the present study. The 2024 and 7075 alloys were used to generate baseline data for comparison purposes. All 2090 had an unrecrystallized grain structure and was tested in both under-aged (T8S2) and near peak-aged (T8S7) tempers. The 2091 had a recrystallized structure and was tested in both naturally aged (T3) and artificially aged (T8, 275°F/12hrs) conditions. The chemical compositions of the clad Al-Li alloys are listed in Table 1.

EXPERIMENTAL PROCEDURES:

- (1) Measurement of Electrochemical Potential and Protective Current of Alclad Sheet: The electrolyte and test method used for potential measurement were based on ASTM G69. In addition, some samples were measured in a 3.5% NaCl solution with pH values of 3.5, 6.5 and 11. A Saturated Calomel Electrode (SCE) was used as a reference.

The output of protective current was measured by connecting alclad and bare samples, one inch apart in a corrosion cell in which the 3.5% NaCl solution was used as the electrolyte. Current density was taken when samples had been immersed in the solution for 45 minutes.

TABLE 1. COMPOSITIONS OF THE CORE AND THE CLADDING FOR 2090 AND 2091 ALCLAD SHEET

ALLOY NO.	GAUGE (inches)	CLADDING Thickness (inches x 10 ³)	Alloy/Temper	Alloy Element (wt. %)							
				Li	Cu	Mg	Zr	Fe	Si	Zn	Al
1	0.06	4.2	7072 Clad	0.10	0.50	-	-	0.20	0.04	0.60	Base
			2090-T8S2	1.96	2.65	-	0.11	0.05	0.05	0.04	Base
2	0.08	4.5	7072 Clad	0.02	0.17	0.03	0.01	0.29	0.08	0.88	Base
			2090-T8S2	1.81	2.65	-	0.08	0.05	0.04	0.01	Base
3	0.16	9.3	7072 Clad	0.001	-	-	-	0.23	0.06	1.0	Base
			2090-T8S2	1.99	2.69	-	0.11	0.05	0.05	-	Base
4	0.08	4.6	7072 Clad	0.15	0.55	0.03	0.01	0.25	0.04	0.67	Base
			2090-T8S7	1.83	2.60	-	0.07	0.05	0.03	0.01	Base
5	0.08	4.9	1145 Clad	0.02	0.27	0.04	0.01	0.45	0.07	0.11	Base
			2090-T8S2	1.77	2.65	-	0.07	0.04	0.03	0.01	Base
6	0.08	4.5	1145 Clad	0.11	0.45	0.02	-	0.35	0.04	0.02	Base
			2090-T8S7	1.77	2.66	-	0.08	0.05	0.04	0.01	Base
7	0.06	2.8	1230 Clad	0.11	0.23	0.33	0.01	0.36	0.06	-	Base
			2091-T3	1.84	1.74	1.55	0.09	0.04	0.03	-	Base

- (2) Finishing Process: Chemical conversion coating and chromic acid anodizing processes are normally used as primary finishing processes. For the former process, specimens were deoxidized, Alodine 1200S was applied, followed by primer and top coat. For the chromic acid anodizing process, specimens were deoxidized, anodized and then coated with primer and top coat.
- (3) Corrosion Test Specimens and Methods:
- Plate products: A rectangular sample with dimensions of 3 inches X 5 inches with six titanium fasteners installed.
 - Sheet Products: Three types of samples were used to evaluate corrosion resistance. Type I was an aluminum sample (4 inches x 5 inches) coupled to a smaller passivated stainless steel plate, with four aluminum rivets. This was used for galvanic and stress corrosion. Type II was a scribed panel specimen. Type III was an aluminum sample with a variety of installed fasteners, (Figure 1). It was scribed diagonally to penetrate through the coatings. Type II and III specimens were used to evaluate filiform corrosion.
- (4) Corrosion Test and Evaluation of Results: All filiform corrosion samples were exposed to 12N hydrochloric acid vapor at 75°F for 1 hour followed by a 60 days test in an environment of 85% relative humidity at 95°F. Type I specimens were tested in neutral salt spray, others in acidified salt spray for 60 and 30 days, respectively. In addition, some samples were exposed

to a sea coast environment at a test site on Whidbey Island in the northwest U.S.A. in order to determine a correlation with the results of laboratory accelerated tests.

All samples were visually examined and rated for corrosion density and distance of migration of corrosion. A rating number was assigned, corresponding to corrosion property, such that corrosion resistance increases with increasing number from 0 to 10.

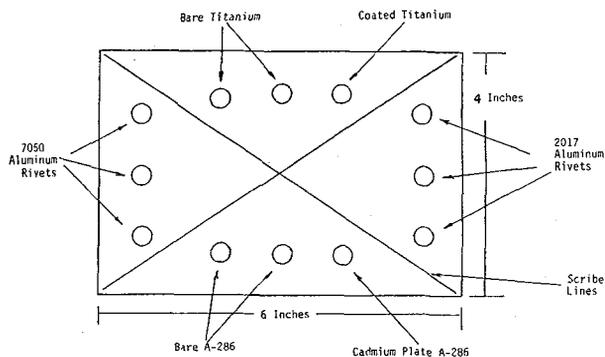


Figure 1. Type III Filiform Corrosion Specimen for Sheet Products

- (5) Stress corrosion testing: Sheet specimens of 2091 & 2024 alloys were loaded in tension and tested per ASTM G44 for 30 days by alternate immersion in 3.5% NaCl solution. Specimens were examined for cracking and corrosion pits.

RESULTS AND DISCUSSION:

Electrochemical Potential of Alclad Sheet: The cladding alloys used in sheet products have to meet several criteria: (1) to provide superior corrosion resistance with respect to the core material, (2) to protect the core galvanically, and (3) to retain a good surface appearance during atmospheric weathering. In order to achieve these goals, the cladding alloy must be sufficiently anodic to the core and inherently resistant to weathering. Thus pure aluminum is a better cladding material than an alloy if it can provide adequate anodic protection.

The potential of the alloy measured using the ASTM G69 method may not be representative of the actual potential of the alloy exposed to a service environment. Therefore, a 3.5% NaCl solution with three different pH values (3.5, 6.5 and 11) was also employed to measure the potential of alclad sheet. The solution with pH value of 11 was included because Al-Li alloys in contact with neutral salt water increase the pH value of salt water up to 11 under certain conditions (3). This is associated with the formation of lithium hydroxide.

Results of electrochemical potential measurement are listed in Table 2 and these are discussed as follows: -

- (1) Effect of electrolyte: An electrochemical potential difference between the core and the cladding existed regardless of the electrolytes used. This implies that galvanic protection of the core is effective in a NaCl solution with pH values ranging from 3.5 to 11.
- (2) Cladding thickness and copper diffusion: The potential of the cladding alloy depends on both its thickness and prior thermal treatment as these determine the amount of copper that diffuses to the surface. (Copper is the only element in 2090 and 2091 alloys that can shift the potential in a cathodic direction). The potential of the cladding on Alloy 2, was more

TABLE 2. ELECTROCHEMICAL POTENTIAL DIFFERENCE AND OUTPUT OF CURRENT BETWEEN THE CORE AND THE AND THE CLADDING OF 2090, 2091, 2024 AND 7075 SHEET

Alloy No.	Alloy/Tempor Alclad Alloy	Gauge (inches)	Cladding Thickness (inch X10 ³)	3.5% NaCl, pH=6.5			3.5% NaCl, pH=3.5		3.5% NaCl, pH=11		NaCl +H ₂ O ₂	
				Potential (-MV)		Current (μA)	ΔE(-MV)	Current (μA)	ΔE(-MV)	Current (μA)		ΔE(-MV)
				Alclad /Core	ΔE							
1	2090-T8S2 7072	0.06	4.2	735 679	56	376	57	56	90	-	93	
2	2090-T8S2 7072	0.08	4.5	860 675	185	96	190	28	75	128	-	
3	2090-T8S2 7072	0.16	9.3	859 679	180	480	169	112	117	-	213	
4	2090-T8S7 7072	0.08	4.6	770 730	40	60	5	24	25	300	-	
5	2090-T8S2 1145	0.08	4.9	780 675	105	88	75	24	25	40	-	
6	2090-T8S7 1145	0.08	4.5	750 730	20	36	5	28	50	132	-	
7	2091-T3 1230	0.06	2.8	-	-	-	-	-	-	-	105	
8	2024-T3 1230	0.06	1.6	749 632	119	60	119	196	58	-	124	
9	2024-T3 1230	0.16	4.4	768 632	136	44	128	80	154	-	138	
10	7075-T6 7072	0.06	1.6	826 776	50	36	41	156	115	-	114	
11	7075-T6 7072	0.16	5.4	826 776	50	48	59	148	147	-	120	

anodic than that on Alloy 1 (Table 2, 3.5% NaCl with pH=6.5). This must be due to different thermal treatments because they have essentially the same cladding thickness. On the other hand, the difference in potential of the cladding between Alloys 1 and 3 is due to the cladding thickness.

- (3) Cladding alloys: As expected, 2090-T8S2 clad with 1145 (alloy 5) had a smaller potential difference between the core and the cladding than the alloy clad with 7072 (Alloy 2). These two alloys were chosen for comparison because they had a similar amount of copper diffusing to the surface of the cladding. The potential and current measurements suggested that 7072 cladding alloy was too active for 2090-T8S2 in several cases and that 1145 is a better candidate. This was born out by subsequent corrosion testing. For 2090-T8S7, both 1145 and 7072 (Alloys 4 and 6) provided a similar level of galvanic protection.

Cladding alloy 1145 provided sufficient anodic protection for 2091-T3, when tested per ASTM G69, because it exhibited a potential difference similar to those of clad 2024 and clad 7075. Recent data have also shown that it is still a good cladding alloy for 2091-T8.

- (4) Effect of aging: The potential difference between the core and the cladding diminishes with increasing aging time and/or temperature. This is due to precipitation in the core alloy so that the potential of the core shifts toward the anodic direction. For example, the potential of , 2090-T8S7, was 45 mV greater than that of 2090-T8S2.

Output of Protective Current of Alclad Sheets: Electrochemical potential measurements described in the previous section can only be used to predict a tendency for the cladding to protect the core thermodynamically. It does not take into consideration electrode kinetic reactions which actually determine the output of protective current generated between the core and the cladding.

The protective current generated between the core and the cladding in salt water with three different pH values is listed in Table 2. The output current in neutral salt water for 2024 and for 7075 alclad sheet was similar even though the former had double the potential difference of the latter. As cited earlier, this is due to different electrode kinetic reactions between the two alloys in which activation polarization is a key factor.

Protective current generated between the core, 2090-T8S7, and the 7072 or 1145 cladding alloys was similar to that of alclad 7075-T6 though the former alloys had a smaller potential difference between the core and the cladding. The current measurement combined with the lower corrosion rate of 2090 (with respect to 7075) indicates that both pure aluminum and 7072 can provide an adequate anodic protection for a core of 2090-T8S7 in a neutral salt water.

Corrosion Resistance of the Finished Samples: Corrosion protection of aluminum alloy aircraft components can be achieved by use of high quality coatings. The effectiveness of a finish system depends on the coating substance, the physical and chemical properties of the coating and the surface preparation of the substrate prior to coating.

In order to establish a reliable finishing system for the Al-Li alloys, several combinations of surface treatments and coating systems were tested in the present study, (Tables 3 and 4). Corrosion testing results were as follows:

TABLE 3 CORROSION PERFORMANCE OF 2090 PLATE WITH FINISHING SYSTEMS

SURFACE TREATMENT	FINISHES*	ACIDIFIED SALT SPRAY (30 Days)				FILIFORM CORROSION Test				WHIDBEY ISLAND (12 Months)			
		2024 -T351	2090 -T8P2	7075 -T651	2090 -T8P7	2024 -T351	2090 -T8P2	7075 -T651	2090 -T8P7	2024 -T351	2090 -T8P2	7075 -T651	2090 -T8P7
CHROMIC ACID ANODIZE	PRIMER I	8	7	2	5	8	7	5	8	9	6	6	7
	PRIMER II	8	6	5	7	9	9	7	8	9	8	10	10
	PRIMER III	8	7	2	3	9	7	8	10	9	8	6	8
	PRIMER + TOP COAT (BODY)	7	6	4	6	9	8	7	9	9	4	6	9
	PRIMER + TOPCOAT (LOWER WING)	9	8	4	6	9	8	8	10	9	7	10	9
	PRIMER + TOPCOAT (UPPER WING)	9	8			10	10			9	8		
AVERAGE PERFORMANCE		8	7	4	5	9	8	7	9	9	7	7	8

Corrosion Rating per ASTM D1654....10 = No Corrosion
0 = Heavy Corrosion

-T8P7 = Peak Aged
-T8P2 = Under Aged

* Primer I - Inhibited Epoxy, II - Inhibited Epoxy (Fuel Tank), III Urethane Compatible
Topcoat (Body) - Epoxy Enamel (Lower Wing) - High Flex. Urethane, (Upper Wing) - Corogard (Copolymer PVC/PVA with Aluminum)

TABLE 4 CORROSION RATIO FOR FINISHED 2091 ALLOY
(SAMPLE RATING DIVIDED BY CONTROL RATING)

SURFACE TREATMENT	PRIMER*	TOPCOAT**	Salt Spray (60 Days) Type I Specimen		Filiform (60 Days) Type II Specimen		Filiform (60 Days) Type III Specimen	
			2091-T3 2024-T3	2091-T8 2024-T3	2091-T3 2024-T3	2091-T8 2024-T3	2091-T3 2024-T3	2091-T8 2024-T3
ALODINE 1200S	I		1.3	1.3				
	I	I	1.2	1.2	1.1	1.1	1.1	0.9
	III		1.3	1.3				
	III	II	1.0	1.0	1.2	1.1	1.2	1.1
CHROMIC ACID ANODIZE + DILUTE CHROMATE SEAL	I		1.0	1.0				
	I	I	1.4	1.4	1.3	1.3	1.6	1.5
	III		1.3	1.1				
	III	III	1.2	1.4	1.3	1.3	1.3	1.1
	II		1.0	1.0				

* See Table 3

** Topcoat - I - Epoxy Enamel
II - Decorative Enamel (High-Flex)
III - Exterior Enamel (General Purpose)

- (1) 2090 Plate: Since 2090-T8P2 may replace 2024-T3 alloy in some aerospace applications the corrosion of the two materials was compared (Table 3). For salt spray and sea coast test environments, corrosion performance of 2090-T8P2 was slightly inferior to that of 2024-T3 regardless of primers used. In the filiform corrosion testing, 2090-T8P2 was still slightly inferior to 2024-T3 except for two cases in which the alloy was coated with (a) Primer II, and (b) Primer plus topcoat (upper wing). However, in just about all cases the finished 2090-T8P7 had a better corrosion resistance than 7075-T6.
- (2) 2091 Sheet: Table 4 displays corrosion performance of the finished 2024-T3, 2091-T3 and -T8. Note that each alloy was coated with a different combination of surface treatment, primer and topcoat. The results are expressed in terms of the ratio of corrosion resistance of 2091 to 2024. For samples tested by three methods, both 2091-T3 and -T8 had a better or equivalent corrosion resistance to 2024-T3, except for one case in which 2091-T8 was finished with Alodine 1200S + Primer I + Topcoat I.
- (3) Laboratory Corrosion Test Environment vs Sea Coast: A consistent correlation was established between two different test environments as displayed in Table 3. If the coated alloy performed better in the sea coast environment, it also performed better in the laboratory test environments.
- (4) Stress corrosion testing of 2091-T3 showed that this alloy was basically equivalent to 2024-T3, however, when either of these alloys is exposed to an adhesive bonding cycle it suffers a large drop in stress corrosion resistance. Similarly, artificially aged 2091-T8 (12 hrs at 275°F) and 2024-T3 & 2091-T3 aged for 168 hours at 212°F both showed similar losses in corrosion resistance, Table 5.

TABLE 5 STRESS CORROSION RESISTANCE OF 2091 AND 2024 BARE SHEET

ALLOY	AGING CONDITION	LT THRESHOLD STRESS (ksi)	COMMENTS
2024	T3	35	Passed
	T3+250°F/4hrs*	15	Severe IG
	T3+212°F/168hrs	15	"
2091	T3	35	Passed
	T3+250°F/4hrs*	15	Pitting
	T3+275°F/12hrs*	15	Cracking
	T3+212°F.168hrs	15	"

3.5% NaCl - Alternate immersion.

* Equivalent to an extended bonding cycle.
* -T8 condition. (Aged 12 hrs at 275°F)

CONCLUSIONS

1. The finished 2090-T8S2, 2091-T3 and -T8 have equivalent or better corrosion performance than that of the corresponding baseline alloys.
2. In neutral salt water, both 1145 and 7072 clad on 2090-T8S7 generate the same output of current between the core and the cladding as alclad 7075-T6.
3. 1230 is the preferred cladding alloy for 2091.
4. 2091-T3 alloy exhibits similar stress corrosion resistance to 2024-T3, but both alloys showed degradation in properties when artificially aged.

ACKNOWLEDGEMENTS

The authors wish to thank L. C. Fordyce, D. T. Lovell, Jr. and T. G. Wickerath for technical help during the course of this work.

REFERENCES

1. P. L. Plane, J. A. Gray and C.J.E. Smith, Aluminum-Lithium Alloys III, eds. C. Baker, P. J. Gregson, S. J. Harris and C. J. Peel, 1985, P. 273.
2. A. K. Vasudevan, P. R. Ziman, S. C. Jha and T. H. Sanders, Jr., *ibid*, P. 303
3. N. J. H. Holroyd, A. Gray, G. M. Scamans and R. Hermann, *ibid*, P. 310
4. B. A. Baumert and R. E. Ricker, *ibid*, P. 282.
5. J. G. Rinker, M. Marek and T. H. Sanders, Jr. Aluminum-Lithium Alloys II, 1983, P. 597
6. G. Le Roy and P. Meyer, Development of Aluminum-Lithium Alloys at Cegedur Pechiney, WESTEC 1986