Properties of Aluminum-Lithium Alloy – A New Aerospace Alloy

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ABSTRACT

The current aspiration for more efficient aircraft has spur to move towards further lighter material and Aluminum-Lithium has the potential to be an alternative. On one hand, the addition of lithium in aluminum provides desired properties like increase in elastic modulus, excellent fatigue and cryogenic toughness and decrease in density but on the other hand, it also generates few undesirable properties along with the problems to develop in few of these alloys. This paper brings out the basics of Aluminum-lithium alloy. Through this paper, these undesirable properties, thermal stability, anisotropy and corrosion resistance of the aluminum-lithium alloys are discussed. This paper studies and analyses the few important properties of Al-Li alloy, so as to find the best suitable alloy for its vast application in aerospace industry.

Keywords: *Density, Elastic Modulus, Corrosion resistance, Thermal stability, Anisotropy*

1. INTRODUCTION

Lithium being the lightest known metal, with it atomic number three is an excellent alloying element with aluminum, and perfect when reducing weight is the prime focus. There is 3% decrease in the density of the alloy with every 1% addition of lithium to aluminum, resulting a room for decrease of the net weight.

Addition of lithium to aluminum also increases the elastic modulus of the alloy. With every, 1% addition of lithium to aluminum, there is 6% increase in the elastic modulus. This is because lithium results in precipitating hardening in aluminum. This increases the stiffness of the alloy. Lithium is among few elements, which exceed solid solubility of 1% in aluminum. Hence, although lithium has the tendency to burn when exposed to excessive heat or at the time of alloying but it is relatively easy to alloy with aluminum.

As the density has also reduced, with preserving the basics desired properties, less amount of material is needed and hence the total weight can be reduced, which is the main goal of an Aerospace Industry. But reduction of certain undesirable properties generated should also needs attention and needs to be dealt properly.

2. BASICS ABOUT THE ALUMINUM-LITHIUM ALLOYS

Development in the field of Aluminum-lithium alloy for its commercial use began in 1970s as replacement of conventional airframe alloys. This was developed by adding lithium to aluminum-copper, aluminum-magnesium and aluminum-copper-magnesium alloys. There are three generations of aluminum-lithium alloy produced with each time improving the desired quality from the previous one.

Alloying with lithium reduces structural mass by three methods. First, displacement- A lithium atom is lighter than aluminum atom so each lithium atom displaces one aluminum atom from crystal lattice maintaining lattice structure. Second, strain hardening- introduction of another type of atom into crystal strains the lattice. This makes material much stronger. Third, precipitation hardening- when properly aged, lithium forms metastable Al_3Li phase with coherent crystal structure. These precipitations strengthen the metal by impending dislocation motion during deformation. Some of the important alloy, keeping aircraft material in view, that have emerged are alloy 2090, 2091, 8090 and Weldalite. Composition and some of the mechanical properties of these alloys are stated below.

Table 1: Composition of various Al-Li alloys

Alloy	Cu	Li	Zr	Others
2090	2.7	2.2	0.12	-
2091	2.1	2.0	0.1	-
8090	1.3	2.45	0.12	0.95 Mg
Weldalite	5.4	1.3	0.14	0.4 Ag
049				0.4 Mg

Table 2: Mechanical Properties of various Al-Li alloys

Alloy	Density (g/cm)	Ductility (El %)	Elastic Modulus (GPa)	Tensile Strength (MPa)	Longitudinal K_{Ic} (MPa $m^{1/2}$)	Melting Temperature (^oC)
2090	2.59	3-6	76	500	44	580-660
2091	2.58	6	75	550	>130	560-670
8090	2.55	4-5	77	480	75	600-655

Weldalite2195, has utilized NASA for U.S. space shuttle tank. Reduced density and high strength was the basic requirement, which this alloy provided. Fuel and oxidizer tank of SpaceX Falcon9 launch vehicle also used Aluminum-Lithium alloys.

Even though it provides advantage of weight reduction and eventually less fuel consumption by aircraft, it has not been able to fully dominate the Aerospace industry due to some of the issues. However, because of the impactful benefits provided by aluminum-lithium alloy, research will continue to reduce undesirable properties, and eventually will be utilized by aircraft industry.

3. STUDY OF PROPERTIES OF ALUMINUM-LITHIUM ALLOY

3.1 Thermal Stability

Thermal stability, the ability of material to maintain its mechanical properties when aged, is one such problem with this alloy. Keeping Aerospace at center, it highly undesirable for the material properties to fluctuate, as there is always a fluctuating temperature.

Lithium is soluble in aluminum a solid solution is formed. However, this solid solution is supersaturated and can easily decompose into a second phase (Al_3Li) when work-hardened. When this solution decomposes, the properties of these alloys changes. The graph in the Fig1 it is shows the variation of Yield strength, ultimate strength and ductility in percentage elongation change with time in alloy 1464 aging at 850C. It is seen that yield and ultimate strength increases with percentage elongation; there is decrease in ductility at low temperature aging. With low temperature aging, while the ductility decreases due to decomposition into precipitation hardening phase. Hence this type of low temperature ageing can easily occur to the parts, which becomes warm too easily.

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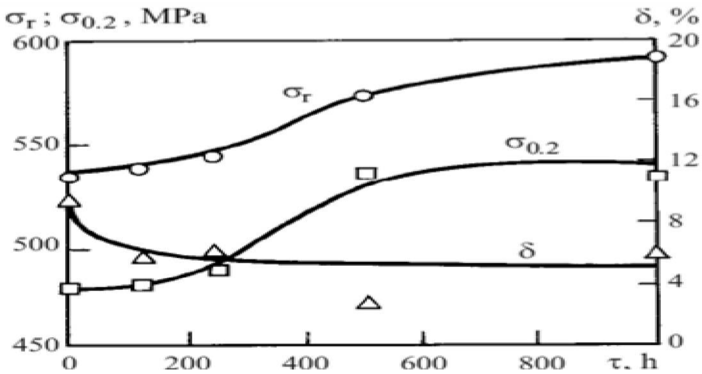


Fig1: Ultimate rupture strength, yield strength and %EL of 1464 when aged at 85^{0}C

Components near engine and components heated due to friction will easily cause ageing. A Russian scientist Zarkharov presented few potential methods to increase thermal stability of aluminum-lithium alloy. First, by decreasing the content of lithium. By this there is reduction in super saturation of lithium in solid solution. It is beneficial because it results in the solid solution having more stability and less decomposition into second phase. The content of lithium cannot be decreased drastically because it again lessen the properties like elastic modulus, density etc. for which it is used. Another method is by heat treatment of the alloys. If supersaturated lithium is taken out of solid solution during manufacturing, then it cannot decompose during the use of material. Since less decomposition into the second phase can occur during use, the mechanical properties will change less and thermal stability is increased.

3.2. Anisotropy

Another issue with the alloy is anisotropy. Anisotropy is the variation of mechanical properties of a material along the different orientation. Since highly anisotropic materials are unpredictable, it will be of less importance for the industries.

Morrison and Allen Experiment

This experiment was performed on two different aluminum-lithium alloys, namely 2090-T8E41 and 8090-T8771, and anisotropic behaviors were observed. 2024-T351 and 7075-T651 were also tested comparison as it is widely used in commercial planes. Material obtained was rolled. The 8090-T8771 was 12.5mm hick, while the 2090-T8E41 was 15mm plate. Microstructure is shown in figure 2.

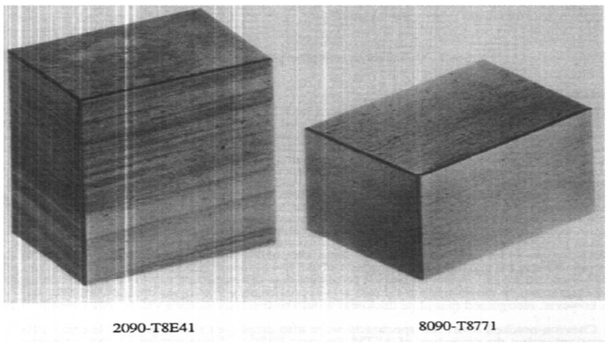
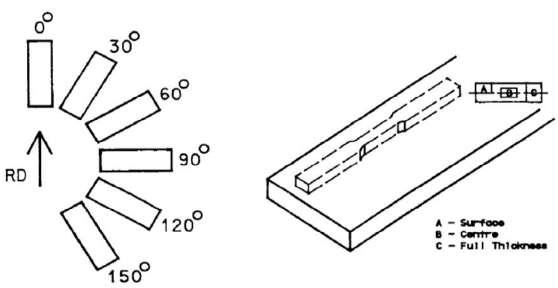


Fig 2: Microstructure of Al-Li alloys at 35x Magnification



For tensile test, dogbone tensile pieces 5mm thick, 12mm wide, 5mm wide at gauge length and 25 mm long were cut out of the received plates. Two pieces were cut at each direction in relation to the rolling direction, starting at the longitudinal (0^0) and moving clockwise at intervals of 30^0, as shown in figure 3 below. Then the standard procedures were carried out at room temperature.

Fig 3: Specimen for Tensile Test, Cut With Respect To Rolling Direction

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Fracture toughness tests were done using chevron-notched specimen and tested according to ASTM standard E1304. Fracture toughness specimens were cut in the same orientation as the tensile pieces and four pieces in each direction were tested. They were 13mm square by 26mm long, done by cutting out all except a triangle-shaped area that connected the specimen. Procedure followed is represented in the figure 4 below.

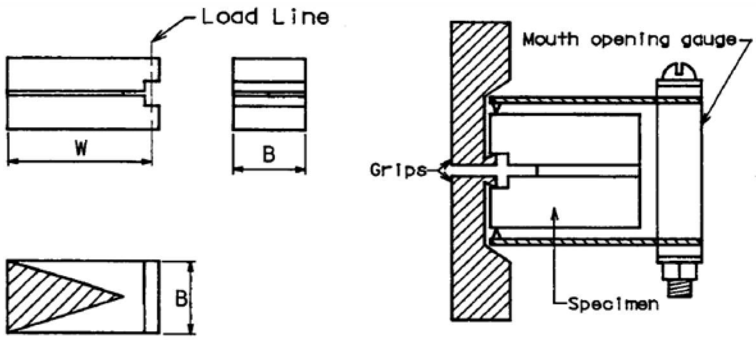

Fig 4: Profile of Fracture Toughness Specimen and Testing Apparatus

RESULT AND DISCUSSION OF MORRISON AND ALLEN EXPERIMENT

Table 3: Composition of 8090 and 2090 Al-Li alloy tested in Morrison and Allen

Material	Li	Cu	Mg	Fe	Si	Zr	Na
8090-T8771 12.5 mm plate	2.35	1.2	0.64	0.05	0.03	0.11	0.0005
2090-T8E41 15 mm plate (nom.)	1.9 - 2.6	2.4 - 3.0	≤0.25	≤0.12	≤0.10	0.08 - 0.15	-

Table 4: Mechanical properties of 8090 and 2090 Al-Li alloy tested on Morrison and Allen

Material		0.2% Proof Stress MPa	UTS MPa	Elongation %	Toughness K_Q MPa√m
8090-T8771 12.5 mm plate	Longitudinal	508	555	5	31 (L-T)
	Transverse	479	548	8	28 (T-L)
2090-T8E41 15 mm plate	Longitudinal	559	595	5	-
	Transverse	586	617	7	-

Figure 5 shows the graph of the result from Morrison and Allen tensile test for both 8090-T8771 and 2090-T8E41 alloys. For both alloys, the yield strength and ultimate rupture strength dipped at 60^0 and 120^0 from rolling direction. Overall 2090-T8E41 alloys were less anisotropic than the 8090-T8771.

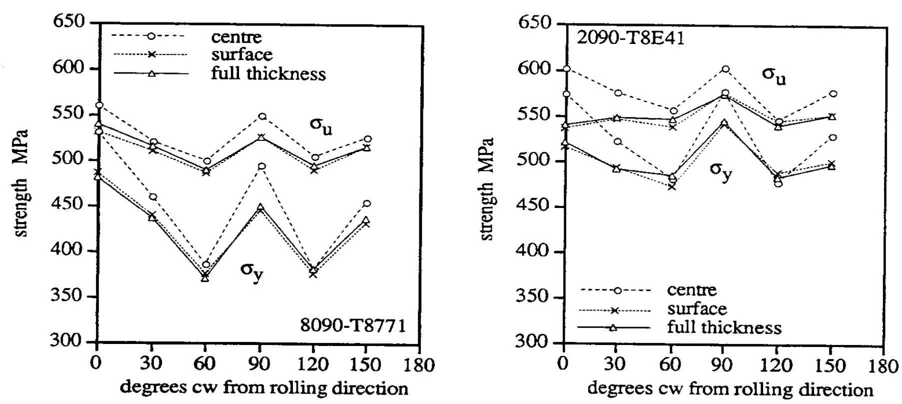

Fig 5: Ultimate Tensile (u) and Yield Strength (y) of 2090 and 8090 Al-Li alloy as Function of Orientation

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There were also variations in percentage elongation with variation in rolling direction. The longitudinal experiences the least elongation and the transverse direction had the second least ductility. The 60^0 and 120^0 direction had the most elongation, which corresponds to their reduced strength as was stated above in tensile test, represented in figure 6.

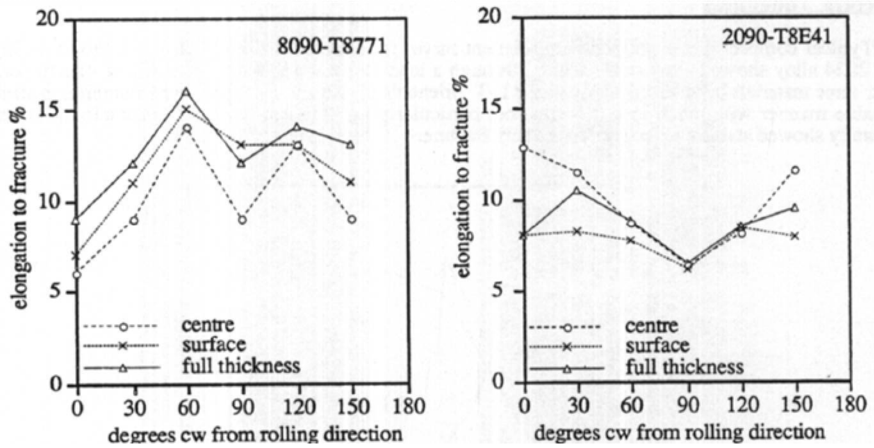

Fig 6: Percentage Elongation of 8090 and 2090 Al-Li Alloy as Function of Orientation

The experiment also gave the variation of fracture toughness shown in figure7. The 8090 alloys had higher fracture toughness than 2090 alloy but 80980 toughness values had much larger span then 2090 alloy. This means that 2090 alloy is less anisotropic in fracture toughness than the 8090 alloys.

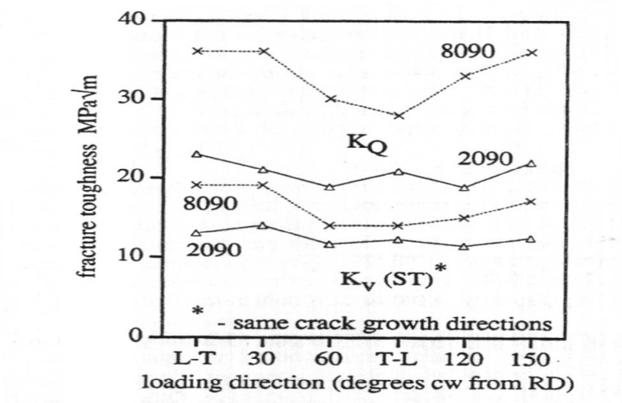

Fig 7: Fracture Toughness Values of 8090 and 2090 Al-Li Alloy as a Function of Orientation

The experiment illustrated the anisotropy in second generation Al-Li alloy. Hence anisotropic is another issue that needs to be eradicated. Comparing the two alloys may give the source of the anisotropy. The most drastic difference is composition, as 2090 has less lithium and more copper as shown in table above. Another source of anisotropy is heat treatment. The 2090 alloy was water quenched after solution treatment, while the 8090 alloys were not. Also, the 2090 alloy was aged for less time. These differences result in different grain sizes and crystallographic texture, which are factors of anisotropy.

3.3 Corrosion Resistance

Thompson Experiment

Corrosion resistance is one of the most desired properties of an aircraft material since it travels in varying environment with varying temperature and moisture level. Aluminum-lithium alloys 2090-T8E41 and 8090-T851 were tested. Plates received were 3 in. by 6 in. Then the plates were machined to $1/10^{th}$ and ½ thickness resulting in a step formation. After machining plates were degreased with solvent, etched in sodium hydroxide for 5 minutes, rinsed in water and dried with compressed air.

Shipboard Exposure

Corrosion test were performed on two different aircraft carrier and environment. The U.S. constellation was traveling in the Western Pacific and Indian Ocean from February through

September 1991. This included the monsoon season in that area. The U.S.S. John F Kennedy was in the Mediterranean Sea for eight months. Weather reports measuring temperature and relative humidity were collected on both ships.

The Aluminum-lithium alloy in this case never corroded to above moderate exfoliation. Overall the specimen on U.S.S Constellation had more corrosion than those on Kennedy shown in the figure 8. Hence effect of different weather condition can be studied from the above observation. While comparing within different alloy, second generation aluminum-lithium alloy material had less corrosion than non-lithium 7075 alloy in T641 temper.

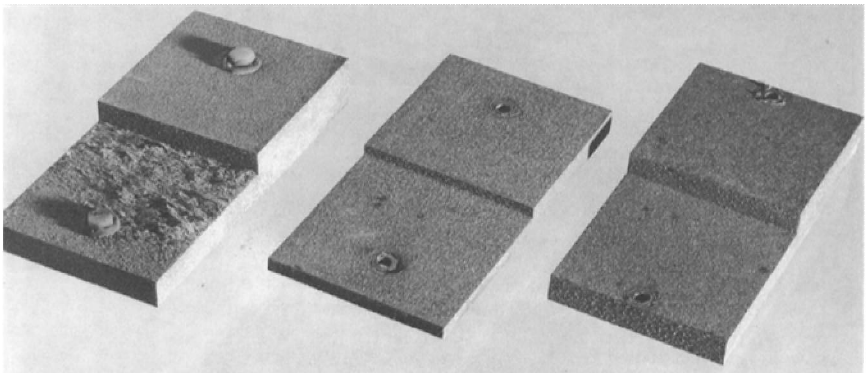

Fig 8: 7075-T651 (left), 2090-T8E41 (middle) and 7075-T7351(right) after tests on board the U.S.S. Constellation

Laboratory Test

EXCO Test: This is the quickest method. Here the alloy is submerged in nitric acid for 48 hours. A coat of beeswax was put on the edges in order to isolate the test just on the surface. Material gave very poor performance in this test. This test resulted in very severe exfoliation corrosion. This test gives no information about the corrosion resistance, as no difference between specimens could be identified.

MASTMAASIS Test: In this test solution of acetic acid and sodium chloride is intermittently sprayed on material. The cycle was 50 minutes of spray, 2 hours of drying and 3 hours of soak in solution, which was carried for 4 weeks. This test did not result in severe exfoliation corrosion except 7075-T651. Testing resulted in pitting of alloy, depth of which increased further in the next few weeks.

SO_2 Salt Fog: This method is more suitable as it imitate the shipboard experiment, Sulfur dioxide representing exhaust from fuel burnt and salt water representing ocean water spray. In this test also alloy 7075-T651 suffered severe exfoliation corrosion whereas 7075-T7351 experienced only slight exfoliation, but neither experienced corrosion more than pitting.

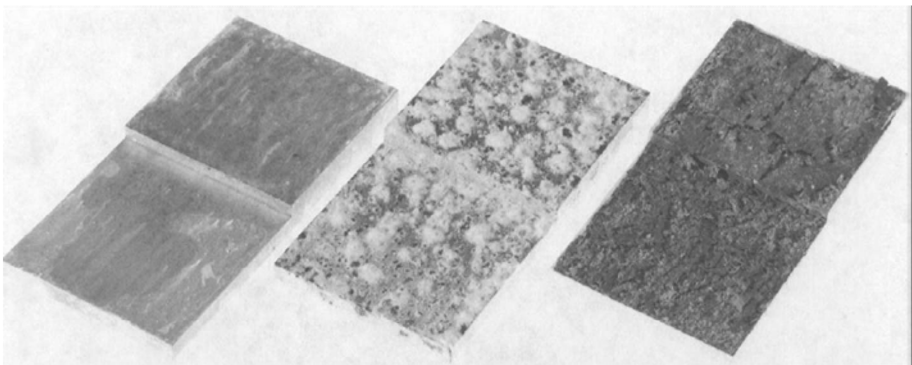

Fig 9: 2090-T8E41 after salt fog (left), EXCO (middle) and SO_2 Salt Fog (right)

Table 5: Results from corrosion tests. N- No attack, P- pitting, EA- Slight Exfoliation, EB- Moderate Exfoliation, EC- Severe Exfoliation, ED- Very severe Exfoliation

Alloy	Plane	Constellation	Kennedy	EXCO	MAST	SO_2
7075-	T/10	EA	N-P	ED	ED	ED
T651	T/2	EC	EB	ED	ED	ED
7075-	T/10	P	P	EA	P	EA
T7351	T/2	P	P	EA	P	EA
2020-	T/10	P-EA	N-P	ED	P	P
T651	T/2	P-EA	N-P	ED	P	P
2090-	T/10	P	P	ED	P	P
T8E41	T/2	P	P	ED	P	P
8090-	T/10	P-EA	b	ED	P	P
T851	T/2	P-EA		ED	P	P

From the Thompson test which almost generates the same environment as faced by the aircraft i.e. saline environment, it was observed that second generation Al-Li alloy are reasonably less susceptible to corrosion. There development of these alloys can be considered when only corrosion resistance is the prime focus.

4. CONCLUSION

Researches on aluminum-lithium have been continuing for over last few years. The alloys have a great potential in aerospace industry but strict regulations hold back their commercial use. The first and second generation alloys had substantial issues but the third generation alloys were revised and have fewer mechanical property issues.

Because of the benefits and cost saving possible with use of aluminum-lithium alloys, research and development will continue. If the improvement of few properties or eradication of some problem is to be made, aluminum-lithium alloys could replace conventional alloys completely. This will be a vast contribution to aerospace industry.

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