LITHIUM ALUMINIUM ALLOYS –The New Generation Aerospace Alloys

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Increasing payload and fuel efficiency of aircrafts has become a major issue for the aerospace industry, which has boosted the development of more advanced materials with high specific properties. Among the candidate materials is the new generation of low density Li-Al alloys. These low- density alloys are attractive to the aerospace industry, since structural weight reduction is a very efficient means of improving aircraft performance.

The marriage of Li to Al offers the promise of substantially reducing the weight of aerospace alloys, since each 1 wt.% Li added to Al reduces density by 3% and increase in elastic modulus. Al-Li alloys use in aircraft applications, where the weight savings effected by using these low-density alloys greatly reduce the vehicle fuel costs and increases performance. In contrast to new materials systems such as fiber-reinforced composites, low density Al alloys do not require large capital investments by the aircraft producer in new fabricating facilities. This cost savings can more than offset the greater performance increment, which composites may offer, resulting in Al-Li alloys being substantially more cost effective than composites in some applications. Fatigue crack growth resistance in Al-Li alloys generally is very high; this is important in damage-tolerant structures such as lower wing surfaces.

PROPERTIES

Li is the lightest metallic element and each 1% of Li reduces alloy density by about 3% and increases modulus by about 6%

- 7-10% Lower density.
- 10-15% Higher Modulus.
- Excellent fatigue and cryogenic toughness properties.
- Higher stiffness.
- Superior fatigue crack growth resistance.
- Reduced ductility
- Low fracture toughness

APPLICATIONS

1) Aircraft parts such as leading and trailing edges, access covers, seat tracks and wing skins.
2) Military Applications: - Certain types of military aircrafts parts like main wing box, center fuselage, control surfaces are made by Al-Li alloys. Al-Li alloys are used as substitute for conventional Al alloys in helicopters, rockets and satellite systems.
3) Space Applications: - Of all the benefits offered, by the use of Al-Li alloys, weight savings is the most critical in space applications. Al-Li alloy is a candidate material for the cryogenic tankage of booster systems. These alloys are used in cryogenic applications for example, liquid oxygen and hydrogen fuel tanks for aerospace vehicles.

Manufacturing of Al-Li alloys

- Ingot Metallurgy.
- Rapid Solidification Metallurgy Technique.

Commercial Al-Li Alloys

1) Weldalite 049

   Composition (wt%)- 5.4Cu, 1.3Li, 0.4Ag, 0.4Mg, 0.14 Zr, bal. Al
2) Alloy 2090

   Composition (wt%)- 2.7 Cu, 2.2 Li, 0.12 Zr, bal. Al
3) Alloy 2091

   Composition (wt%)- 2.1 Cu, 2.0 Li, 0.10 Zr, bal Al
4) Alloy 8090

   Composition (wt%)- 2.45 Li, 0.12 Zr, 1.3 Cu, 0.95 Mg, bal Al

Physical Properties of Al-Li alloys

Property	**2090**	**2091**	**8090**
Density, g/cm^3	2.59	2.58	2.55
Melting range, ^{0}C	560-650	560-670	600-655
Elastic modulus, GPa	76	75	77
Poisson’s ratio	0.34		
Thermal conductivity at 25^{0}C, W/m-k	84-92.3	84	93.5
Specific heat at 100^{0}C, J/kg-k	1203	860	930

Physical Metallurgy

Li is the lightest metallic element and each 1% Li reduces the alloy density by about 3% and increases modulus by about 5%. Li in small amounts allow the precipitation strengthening of Al when a homogeneous distribution of coherent, spherical δ' (Al_3Li) precipitate is formed during heat treatment. Like other age-hardened Al alloys, Al-Li alloys achieve precipitation strengthening by thermal aging after a solution heat treatment. The precipitate structure is sensitive to a number of variables, including, but not limited to, the quenching rate following the solution heat treatment, the degree of cold deformation prior to aging, and the aging temperature and time.

The age hardening of Al-Li alloys involves the continuous precipitation of δ' (Al_3Li) from a supersaturated solution. The Al and Li in the δ' precipitates are positioned at specific locations. The eight shared corner sites are occupied by Li, and six shared faces are occupied by Al. Al-Li base alloys are microstructurally unique. The major strengthening precipitate (δ') when homogeneously precipitated, remains coherent even after extensive aging. The 8090 type Al-Li alloy display a microstructure consisting of metastable phases such as δ' (Al_3Li), S' (Al_2CuMg), T_1 (Al_2CuLi) and β' (Al_3Zr) within the grains. In addition several other constituent phases such as T_2 (Al_6CuLi_3), δ (AlLi) and impurity phases occur at grain boundaries. Another important microstructural feature is the presence of a δ'-PFZ near the high angle grain boundaries.

Precipitation Behaviour of 8090 alloy

The precipitation behaviour of 8090 alloy under artificial aging is explained as:

1) Precipitation of δ' (Al_3Li) and δ (AlLi) phases: -

The metastable δ' phase nucleates during quenching or aging may be on the grain boundaries or homogenously due to its misfit with alpha solid solution. The δ' phase formation takes place via GP (Gunier-Prestner zone) zones by the following reaction.

$$\alpha\ (\text{sss}) \longrightarrow \text{GP zones}' \longrightarrow \delta\ (Al_3Li) \longrightarrow \delta\ (AlLi)$$

As aging proceeds, more and more precipitation of new δ' phases along with coarsening of existing δ' phase nuclei increase strength significantly. After continuing aging, or increase in aging temperature, δ phase nucleates heterogeneously on high angle grain boundaries or already existing δ' phase along with dissolution of δ' phase. The formation of δ phase may be accompanied by δ' PFZ near the grain boundaries.

2) There is coprecipitation of T_1 (Al_2CuLi) and T_2 [$Al_6Cu(LiMg)_3$] phases along with δ' (Al_3Li) phases during aging. They heterogeneously precipitate mainly upto peak strength conditions and thus significantly contribute to the strength. In the 8090 alloy, changes of θ' ($CuAl_2$) phase formation

are least owing to low Cu: Li ratio. The precipitation reaction of T_1 and T_2 phase is

$$\alpha\ ss \longrightarrow \alpha + \delta' + T_2 \longrightarrow +T_2$$

$$\alpha\ ss \longrightarrow \alpha + \delta' + T_1 \longrightarrow +T_1$$

The coprecipitation of S' (Al_2CuMg) phase along with δ' phase and T_1 is important reaction. The precipitation of S' phase is very sluggish and require somewhat more aging time or temperature. S' phase also nucleates as narrow laths heterogeneously along dislocations or subboundaries. Following is precipitation reaction for S phase

$$\alpha\ ss \longrightarrow \text{GP zones} \longrightarrow S'' \longrightarrow S' \longrightarrow S\ (Al_2CuMg)$$

EXPLOSION POTENTIAL WITH

- **Water** - Any operation that generates molten Al-Li poses an explosion hazard in the presence of water; the melting range for Al-Li alloys is between 500 and 600^0C. A number of variables affect the explosion potential, including the Li content of the alloy, the depth and containment of the water, the metal temperature and the size (diameter) and velocity of the molten metal stream being introduced to the water.

- **Salt Bath** - Al-Li alloys may cause severe exothermic reactions or explosions if heat-treated in salt baths under conditions in which melting or incipient melting occurs.

- **Fire** - Finely divided Al-Li dust in sufficient concentration is explosive in the presence of an ignition source. The finer the dust, the greater the chance of ignition and the more severe the explosion. Al-Li fires, like those involving conventional Al alloys, can generate H_2 gas in the presence of water, and this may be explosive in the presence of an ignition source.

References

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