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특집 : **Aluminium Fillers for Electronic Packaging**

Aluminium Based Brazing Fillers for High Temperature Electronic Packaging Applications

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Abstract: In high temperature aircraft electronics, aluminium based brazing filler is the prime choice today. Aluminium and its alloys have compatible properties like weight minimization, thermal conductivity, heat dissipation, high temperature precipitation hardening etc. suitable for the aerospace industry. However, the selection of brazing filler for high temperature electronics requires high temperature joint strength properties which is crucial for the aerospace. Thus the selection of proper brazing alloy material, the composition and brazing method play an important role in deciding the final reliability of aircraft electronic components. The composition of these aluminium alloys dependent on the addition of the various elements in the aluminium matrix. The complex shapes of aluminium structures like enclosures, heat dissipaters, chassis for electronic circuitry, in avionics are designed from numerous individual components and joined thereafter. In various aircraft applications, the poor strength caused by the casting and shrinkage defects is undesirable. In this report the effect of various additional elements on Al based alloys and brazing fillers have been discussed.

Keywords: Aluminium alloys, brazing, strength, electronics, porosity

1. Introduction

Aluminium based fillers are playing a great role not only in automotive but also aerospace applications. The various attracting properties obtained from the aluminium alloys are high specific strength, available in plenty, highly oxidation and corrosion resistant, high thermal and electrical conductivities.1,2) Aluminium alloys are a clean source free from unwanted health hazard and toxicity in brazing technology, and economically very cheap. A high specific strength accounts for the weight reduction drastically as compared to steel, which is beneficial to improve the fuel efficiency and reduces carbon emissions.3) The various parts of the aircraft or automotive requires joining by braze welding or simply brazing. Generally the filler metals are designed to join the various similar or dissimilar components of metals together. To achieve a proper bonding and strength, the filler metal should have lower temperature than the base metals. Though the after brazing properties depends mostly on the composition of the filler metals, the processing methods like heat treatment or casting operations, hot or cold working affects properties the aluminium and its alloys. There are various reports on the joining properties of aluminium alloys by filler metals like alloying, precipitation, modification of the various phases like IMCs or Si by adding other elements or impurities like nano ceramic oxides which are crucial for final brazed joint properties.4,5) The refinement or modification of the various IMCs, for example $CuAl_2$ in Al-2XXX series alloy is crucial for the mechanical properties in various engineering applications. In aerospace, proper aging results in the formation of the GP zones resulting in hardening of the alloy, while in automotive application presence of $CuAl_2$ is deteriorating to the joint strength properties.6,7) Some researchers have attempted to refine $CuAl_2$ and other IMCs to disperse uniformly in the aluminium matrix. An uniform dispersion of these IMC will help in the uniform brazed joint properties. Al-Cu alloys are mostly suitable in aerospace and have been extensively studied, while Al-Si alloys have been extensively studied as a brazing filler for automotive components with further additions of alloying elements.8,9) Therefore, while designing the Al based filler, the role of each alloying elements is vital, the properties are modified accordingly for the specific application. The alloying elements are of various kinds like they can be either a major or minor elements, a modifier for improving

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the IMCs or other non-uniform phase for a uniform distribution and properties. In this report, the effects of various alloying elements, modifiers, rare earth elements and nano-oxide ceramics etc. Al based brazing filler alloys for microstructural, mechanical and brazing performance are reviewed.

2. Classification of Al Alloys

There are three major categories of aluminium alloys used in aerospace, though the heat-treatable alloys have promising strength for structural applications.

2.1. Cast Alloys

The castings are available in form of sand casting, pressure casting, gravity die castings, e.g. Al-Si, Al-Mg alloys. According to the AAA (Aluminium Association of America), Tables 1 and 2 gives the basis of nomenclature of wrought and cast aluminum alloys in the four-digit system.

2.2. Wrought Aluminium Alloys

Wrought aluminium includes in the form of forged, sectioned, extruded sheets, plate, foils and drawings.

Table 1. Nomenclature of cast aluminium alloys[1,10-12)]

Alloy		Description
1XX.X	→	Pure Al
2XX.X	→	Cu
3XX.X	→	Si, Cu/Mg
4XX.X	→	Si
5XX.X	→	Mg
7XX.X	→	Zn
8XX.X	→	Sn
9XX.X	→	Others
6XX.X	→	Not assigned

Table 2. Nomenclature of Wrought aluminium alloys[1,10-12)]

Alloy		Description
1XXX	→	Pure Al
2XXX	→	Cu
3XXX	→	Mn
4XXX	→	Si
5XXX	→	Mg
6XXX	→	Mg and Si
7XXX	→	Zn
8XXX	→	Others
9XXX	→	Not assigned

Table 3. Temper Designation of aluminium alloys.[1,10-12)]

Symbol		Treatment Name
F	→	As fabricated
O	→	Annealed
H	→	Strain hardened (Wrought only)
W	→	Solution Treatment
T	→	Thermal Treatment other than F,O,H
T4	→	Solution Treatment
T6	→	Solution Treatment and Aging

2.3. Heat Treatable Aluminium Alloys

Heat treatable alloys are usually those alloys in which a sufficient amount of strengthening can be obtained by heat treatment procedures (Table 3).[11,12)]

Some of the important heat treatable alloys are as follows:

(1) Al-Cu systems with strengthening phase $CuAl_2$
(2) Al-Cu-Mg systems (magnesium enhances precipitation)
(3) Al-Mg-Si systems with strengthening phase Mg_2Si
(4) Al-Zn-Mg systems with strengthening phase $MgZn_2$

2.4. Non-Heat treatable Aluminium alloys

These alloys do not respond to heat treatment and further strengthening cannot be achieved due to the presence of a homogeneous solid solution with or without non-coherent precipitate(s) and show low strength and high ductility. For example, pure Aluminium (1100), Al-Mn (3003), Al-Mn-Mg, and Al-Si alloys.[10-12)] They are mainly used as sheet, bar, plates, wire, extrusion, and can be easily bent, formed and welded and have excellent corrosion resistance.

2.5. Conditions for Age Hardening[10-12)]

The main basic requirement of age hardening alloy system is that the solid solubility limit should decrease with decrease in temperature

Presence of coherent precipitates.

3. Alloying Additions in Al Based Alloys and Fillers

The important alloy systems are Al-Cu, Al-Si, and Al-Mg, with other minor allying components with Ni, Ti, B, rare earth elements and nanoceramic additives.

3.1. Aluminium-Copper based

The addition of copper in aluminium alloy affects the strength and hardness of aluminum in both heat treated as well as non-heat treated conditions. The addition of copper

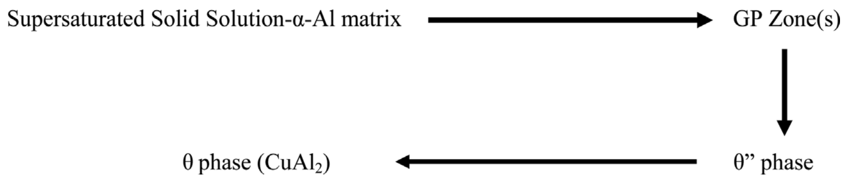

Fig. 1. Transformation sequence of GP zones in Al-Cu alloys.[1,10-12]

is most common due to the precipitation strengthening of the alloy.[10] Hardening due to copper is induced by the in situ production of Guinier Preston (GP) zones, and its transformation into a transient phase θ''. The solubility of copper in aluminium increases with increasing temperature up to the eutectic temperature of about 540°C.[1,11,12] If the alloy at this temperature is quenched rapidly, the slow precipitation of θ phase will be prevented and a highly supersaturated solid solution of copper is obtained.[10,11] However, ageing of this supersaturated solid solution at room temperature will cause the copper atoms to segregate by diffusion to form copper-rich zones called Guinier-Preston GP(1) θ zones. The difference in atomic size of copper and aluminium strains the lattice. Around above 100°C, further copper segregation produces GP(2) θ'' zones, sometimes known as θ'' phase (Fig. 1).

Ageing for sufficiently longer times may also lead to degradation in strength and hardness related to Ostwald ripening effect of the precipitates resulting in poor strength. Therefore, ageing is an important factor in developing an aluminium based alloys.[12]

3.2. Aluminium-Silicon based

Silicon is the most important element used in aluminum alloy castings. Addition of silicon provides excellent castability, high fluidity, and low shrinkage in various cast components. Silicon has very low solubility in aluminum and precipitates out as pure Si which is hard enough to increase the abrasion and corrosion resistance. However, the machinability is poor with the addition of silicon in aluminum alloy castings.[1-3]

3.3. Aluminium-Magnesium based

The solubility of Mg in Al is around 1.9 wt% at room temperature. In Al-Mg alloys with high Mg content greater than 3 wt%, solid solution is supersaturated with Mg solute atoms.[13] The precipitation sequence of Mg as an equilibrium β-phase (Mg_5Al_8) which increases the strength is given by as follows (Fig. 2).

Addition of Zn in Al-Mg alloys has been found to increase the corrosion rate, for example, in high-strength Al-Zn-Mg alloys, Al-Mg-Si and Al-Mg alloys with Mg greater than 3 wt%.[13]

3.4. Aluminium-Nickel based

In Al 2XXX alloy series, Cu interacts with Ni to form Cu-Ni aluminides. These aluminides are stable at elevated temperatures and cannot be further dissolved in solid solution during heat treatment. As a consequence, a definite proportion of Cu is present in IMC phases are absent in the precipitation of $CuAl_2$ phases during overaging.[14,15] Thus, the contribution of $CuAl_2$ to precipitation hardening mechanism decreases and high temperature strength increases.

3.5. Aluminium-Titanium and Boron based

Titanium is used in the Al 4XXX series alloy due to its grain refining action. It acts as a potential grain refiner in common Al-Si alloys. The solubility of Ti in liquid Al is around 0.12 & 0.15%.[16] An enormous addition of Ti is deleterious to casting process and induces porosities during solidification due to the precipitation of Ti-Al IMCs. Jaradeh and his co-workers examined the effect of Ti additions on the microstructure of DC-cast aluminium alloys and found that the useful range of Ti for better grain refinement is around 0.015%, while larger Ti additions up to 0.15% causes grain coarsening.[17] It has been also reported that the refining action of Ti is also accelerated if it is coupled with Boron. TiB_2 acts as additional refiners than that of $TiAl_3$ alone.[18]

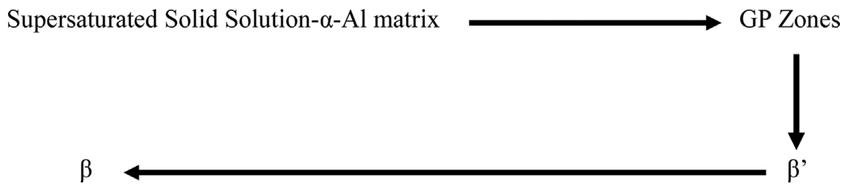

Fig. 2. Precipitation sequence in Al-Mg alloy.[13]

3.6. Aluminium-Manganese based

Manganese is also an important component in the Al 3XXX series that contributes to uniform deformation and used extensively in architectural applications. However, it has been established already that an addition of Mn up to 0.7~1.2 wt% Al6XXX and Al 7XXX series improved both yield and ultimate tensile strength significantly without a considerable reduction in ductility. The addition of Mn interacts with aluminium to form $A1_6Mn$ dispersoid which is incoherent with respect to the matrix and hinders the dislocation motion and hence increase strength and ductility.[19-22]

3.7. Aluminium with Rare earth elements

Nie and his co-workers studied the effect of a number of rare earth additions in Al-Zn-Mg alloy (La, Ce, Nd, Y, Gd, Sc and Er). They found that the optimum content of the rare earth element for improved properties should be above 0.1 wt% except Er.[23] Nogita et al also studied a series of rare earth elements in Al-Si alloys, e.g., La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.[24] They reported that that all the rare earth elements caused a depression of the eutectic temperature. However, only Eu causes a change in eutectic silicon morphology to a fibrous one.

3.8. Aluminium with Nano-metallic and Nano-oxide ceramic additives

In the last few decades, nano-ceramic particles have been exploited to refine IMCs and produce the uniform microstructure for improved mechanical and lightweight applications. High energy nanoparticles if added in an optimum concentration, may improve the properties and microstructure remarkably. Various reports have already shown that the use of ceramic nanoparticles in an optimum concentration in metal matrix nanocomposites has been found to depress the melting point of the matrix due to the refinement in the microstructure caused by the highly reactive nano additives.[25-28]

4. Conclusion

Alloying elements provide the improved microstructure of aluminium and decides the final properties of the alloy. Microstructural modifications are usually brought about by the precipitates causing an enhancement of the strength and durability at high temperatures. The addition of copper triggers the formation of GP zones from the supersaturated solid solution during aging after heat treatment suitable for aerospace. Silicon provides mostly fluidity and castability and suitable for automotive applications. Magnesium too forms precipitates and increase strengthening of the alloy. Ti and B improves the grain refinement and hence provide additional strengthening. Nickel, though expensive used in minute concentration produces aluminides with copper and aluminium for high temperature stability. Addition of Mn improves the yield strength and ultimate tensile strength, though a reduction in ductility is also observed. Recently, various reports have shown a beneficial effect of the addition of rare earth elements and nano ceramic oxides to refine the grain size as well as the various IMC and Si morphology. It can be suggested from this review that an alloying of the aluminium alloys affects the various properties, therefore the selection of alloying element should be exercised depending on its role and suitability for the particular brazing application.

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