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ARTICLE

Effects of Cerium and Zirconium Microalloying Addition on the Microstructures and Tensile Properties of Novel Al-Cu-Li Alloys

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Abstract: Effects of Ce and Zr additions (combinative addition and single addition) on the microstructures and tensile properties of novel Al-5.8wt%Cu-1.3wt%Li alloys with an elevated Cu/Li ratio were investigated comparatively by a microscopy method and tensile test. The microstructural observation shows that the intermetallic dispersoid in the case of combinative addition of Ce and Zr is more significantly refined from coarse polygonal shape to fine irregular particles compared to that in the case of single addition of Ce or Zr. Due to the refinement and the modification of intermetallic dispersoid, the corresponding fracture mode changes from brittle intergranular fracture to ductile transgranular fracture during tension. In addition, microstructural analysis reveals that the addition of Ce promotes the precipitation of the T_1 phase which is the predominant strengthening phase in Al-Cu-Li alloy. In comparison to Ce containing Al-Cu-Li alloy, Ce+Zr-containing Al-Cu-Li alloy raises the degree of supersaturation of Cu in matrix due to less Cu atoms being trapped in finer AlCuCe dispersoid after solution treatment. Thus it is found that the ultimate tensile strength (UTS) and yield strength (YS) for the later alloy are increased by 19.6% and 16.1%, respectively. And the elongation (El) is similar, owing to decreasing of the phase size, changing of precipitation type to T_1 phase only and further grain refinement.

Key words: Al-Cu-Li alloy; cerium; precipitation; dispersoid; microstructure

Al-Li alloys with elevated Cu/Li weight ratio have received considerable interest from both industrial and scientific communities because of their attractive high specific strength, large elastic modulus, small anisotropy, excellent resistivity to damage and good weldability [1,2]. In past several decades, a number of researchers have paid attention to the microstructure and the mechanical properties of Al-Cu-Li alloys with trace amounts of Zr and Ce[2-5].

Upon homogenization, the decomposition of super-saturated Al-Zr solid solution occurs by the nucleation of Al_3Zr precipitates with a metastable cubic $L1_2$ structure, which is thermally stable at high homologous temperatures. Thus Al_3Zr dispersoid has an effort to control the recrystallization of the alloy during following thermal-mechanical processing. Fine and coworkers[6] suggested that even greater stability could be achieved by decreasing the lattice parameter mismatch between Al_3Zr and the α-Al solid solution. Through ternary additions of transition metals (TM) such as Ti, V, or Hf, $Al_3(Zr_{1-x}TM_x)$ precipitates are formed, exhibiting reduced coarsening rates compared with binary Al_3Zr precipitates, because of a reduced matrix/ precipitate lattice parameter mismatch [7]. In addition, Van Dalen [8] and Booth-Morrison[9] reported that additions of Zr and Sc improved coarsening resistance of Al_3(Sc, Zr) precipitates compared with Al_3Sc.

The use of rare earth Ce as a micro-alloying element in Al and also as a transition metal has been studied for several years. The Ce addition was reported to affect the ductility and the fracture toughness of 8090 alloy sheets

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rich in impurities of Fe, Si and alkali metals [10]. Once the Cu level was up to 5.8% in the present alloy system, the probable Ce containing precipitates observed in such a system might be $\tau_1(Al_8Cu_4Ce)$ phase [11]. Ce addition in the Al alloys usually has the following three effects: (i) Hindering the diffusion of the major elements in experimental alloys and finally retarding the coarsening of primary strengthening phases [10]. (ii) Forming primary AlCuCe phase which acted as nucleating agents for remainder liquid solidified to α (Al) and combined with Ce atoms segregated at the solidification front of the dendrites so as to increase the region of compositional supercooling and finally reduce the arm spacing of secondary dendrites[12], e.g. grain size varied with the Ce content in Al-Cu-Mg-Mn-Ag alloys[13] and the dendritic structure could be refined, the morphology of precipitates changed from spherical to needle shape when Ce content varied from 0.1% to 0.4% (mass fraction) in 7055Al alloy [14]. In addition, Lai *et al*.[15] also found that addition of Ce could remarkably refine the as cast grains and eutectic microstructure. (iii) Forming τ_1 dispersoids during homogenization and thermal mechanical process. These types of particles took high antirecrystallized effect in the alloy during following heat treatment[16]. Furthermore, it is deduced that high dispersity of these particles also caused a noticeable thermal stability upon aging at a high temperature.

However, the systematical and comparative study on the synergistic effect of Ce and Zr microalloying additions on the coarse dispersoid (μm scale size) and predominant strengthening precipitate (nm scale size) microstructure and properties of novel Al-Cu-Li alloys alloyed with a large amount of copper (5.8 wt%) is not available. The purpose of this work is to study the relationship between the mechanical behavior and the microstructure characteristics of novel Al-Cu-Li alloys with different cerium and zirconium additives, to understand the microalloying mechanisms of Ce and Zr additions in these alloys.

1 Experiment

The chemical compositions of the investigated alloys are listed in Table 1.

Master alloys of Al-Zr, Al-Ce and Al-Cu and pure elements of Ag, Mg, Li and Al were melted in a vacuum induction melting furnace under a controlled atmosphere of argon gas, using high pure graphite crucible. Lithium addition was made by plunging Li wrapped in aluminium foil. Casting was carried out under argon. Ingots with size of 150 mm× 100 mm × 22 mm were homogenized using three-step homogenization cycle at 400 °C/8 h + 470 °C/8 h + 510 °C/8 h in a salt bath. After homogenization treatment, the ingots underwent a two step hot rolling following by a one-step cold rolling to got 2 mm-thick sheets.

Tensile specimens were cut along the rolling direction of the cold rolled sheet. They were firstly solution treated at 520 °C for 1 h and then quenched in water prior to artificial aging treatment at 180 °C. The homogenized and solution treated specimens were observed by electronic microscopy. The grain structure of solution treatment was evaluated on Leica DMILM optical microscope (OM). A Quanta-200 environmental scanning electron microscope (SEM) was used for evaluating the microstructural features of the alloy. The wave length-dispersive X-ray spectrometer (WDS) microanalysis of the intermediate phases in arbitrarily selected area was performed on JEOL JXA-8230 electron microprobe analysis (EPMA) instrument. The TEM samples were taken from the tested specimens whereas thin foils were prepared by jet electro polishing in a 75% methanol and 25% nitric acid solution cooled down to approximately –30 °C. TEM observation was carried out by TecnaiG^2 20 ST microscope.

2 Results

2.1 Microstructure after homogenization

Fig.1 shows SEM images for the homogenization microstructures of the alloys with various contents of Ce and Zr, which demonstrates a substantial difference of microstructure in the size and the morphology of discontinuous intermetallic dispersoid. Fig.1a shows the micrograph of Al-Cu-Li alloy with the addition of 0.14 wt% Zr only (alloy A). It is clearly seen that the coarse particle is presented in the form of polygonal shape and the transverse size of coarse particle is up to about 10 μm. Fig.1b represents the microstructure of Al-Cu-Li alloy with the addition of 0.20 wt% Ce (alloy B). It is obvious that the average transverse size of intermetallic particle decreases to less than 6 μm. Combination additions of 0.20 wt% Ce and 0.13 wt% Zr to Al-Cu-Li alloy (alloy C) can refine intermetallic dispersoid significantly. It is found that the transverse size of the particle decreases to about 2 μm. Moreover, the coarse polygonal shape structure transforms into the small "skeleton" particles and the discontinuous irregular particle morphology.

The WDS composition analysis of intermetallic dispersoid and matrix is shown in the right part of Fig.1. Fig.1a reveals that a higher level of Zr is found within the coarse second phase after homogenization. Fig.1b presents that the predominant second phase is AlCuCe phase. Fig.1c shows that the modified particle is AlCuCe phase with small content of Zr.

Table 1 Chemical compositions of the alloys (wt%)

Alloy	Li	Cu	Ag	Mg	Ce	Zr	Al
A	1.28	5.91	0.39	0.37	-	0.14	Bal.
B	1.34	5.82	0.41	0.39	0.19	-	Bal.
C	1.31	5.87	0.41	0.43	0.2	0.13	Bal.