INFLUENCE OF SMALL ADDITIONS OF Be AND Zn ON THE STRUCTURE-PROPERTY RELATIONSHIPS IN AN Al-Li-Cu-Mg BASE 8090 ALLOY

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ABSTRACT: The independent and combined effects of small additions of Be (~ 0.08 and 0.15wt%) and Zn (~ 0.60wt%) on the aging of an Al-Li-Cu-Mg base alloy of 8090 composition have been investigated by transmission electron microscopy (TEM), scanning electron microscopy (SEM) and tensile tests. The results demonstrate that the nature of the phase precipitates present in the matrix and at the grain boundary substantiate the structure-property correlations in these materials.

KEYWORDS: *Al-Li-Cu-Mg alloy, Be additions, Zn additions, precipitation, coarsening, Be-rich insolubles, tensile properties.*

INTRODUCTION:

The desirable influence of suitable trace alloy additions (when present in amounts ≤0.1at%) on the nucleation frequency and the stability of strengthening precipitates in various Al alloys has been extensively studied and reviewed [1,2]. Recent studies have shown that elements like Be and Zn, when present in amounts higher than 0.1at%, bring about significant changes in the microstructure of Al-Cu-Mg [3,4] and Al-Li-Cu-Mg base alloys [5-7]. For example, 0.1wt% (i.e. about 0.3 at%) Be additions to an Al-2.5Cu-1.2Mg alloy are found to greatly increase the nucleation of the S (Al_2CuMg) phase by providing heterogeneous nucleation sites in the form of widespread dislocation loops and numerous small Be precipitates which form during artificial aging [4]. 0.15wt% Be additions to an Al-Li-Cu-Mg base 8090 alloy have also been shown to increase the homogeneity of the S precipitates upon aging and to considerably increase the strength of the alloy [5]. However, it is to be considered that the maximum solid solubility of Be in Al is about 0.08wt% at the eutectic temperature of 645°C [8]. Also, the use of an increased homogenization temperature of 590°C for the as-cast 8090 alloy in an effort to obtain the maximum amount of Be in the solid solution [5] is not a viable process [9], and it is, therefore, of practical interest to determine the influence of Be varying in the range of 0.08 to 0.15wt% on the structure-property relationships in an 8090 alloy.

Studies have also shown that about 0.5wt% (i.e. about 0.2at%) Zn additions to Al-Li-Cu-Mg alloys of 8090 composition result in materials of greatly improved SCC resistance [6,7]. Such an improvement has been conceptualized [6,7] to be due either to the incorporation of Zn to the grain boundary T_2 (Al_6CuLi_3) and δ (AlLi) phase particles [10], or to the simultaneous refinement of the S phase within the grain body by the Zn additions [7]. However, no work has been carried out to correlate such microstructural changes with the resultant mechanical properties of these alloys.

In this paper, using transmission electron microscopy, scanning electron microscopy and tensile tests, results on the influence of independent and combined additions of Be and Zn on the structure-property relationships in an 8090 alloy are presented.

EXPERIMENTAL PROCEDURE:

The mass compositions of the alloys used in this investigation are shown in Table 1. The alloys were produced through ingot casting route in the laboratory. The alloys were homogenized at 535°C for 40h followed by air cooling, scalped and hot rolled to 5 mm sheets. The alloys were solution treated at 535°C for 90 min followed by water quenching at room temperature. The as-quenched samples were then artificially aged at 170°C for varying times up to about 100h. Aging for 55h represents the near peak aged condition for the baseline alloy. Specimens for TEM were prepared by electrolytic polishing using 30% nitric acid and 70% methanol at -35°C. Thin foils were examined on a Phillips EM 430T electron microscope operating at 150kV. Although, quantitative measurements on the number density and the size of the precipitates (formed during aging) were not carried out, the TEM micrographs presented in this paper are representative of several such results obtained in this work. Tensile tests were carried out using ASTM E8 sub-size sample on INSTRON 8500 materials testing system. SEM examination of the fractured surfaces of the failed tensile specimens were carried out on a ISI 100 A scanninmg electron microscope opearting at 15kV.

Table 1 Chemical Compositions (wt%) of the Alloys Investigated.

ALLOY	Li	Cu	Mg	Zr	Be	Zn	Fe	Si
A1	2.22	1.21	0.82	0.095	0.031	--	0.05	0.03
A2	2.18	1.20	0.78	0.10	0.028	0.55	0.06	0.03
A3	2.18	1.20	0.77	0.10	0.088	--	0.05	0.02
A4	2.12	1.23	0.78	0.10	0.150	--	0.07	0.02
A5	2.22	1.25	0.76	0.10	0.093	0.58	0.07	0.03
A6	2.17	1.18	0.81	0.10	0.145	0.57	0.07	0.03

RESULTS AND DISCUSSION

I. Development of Microstructure: Figs.1(a) through (c) show the development of microstructure in the baseline and in the baseline containing 0.60wt% Zn and 0.09wt% Be alloys respectively, when artificially aged for 55h. The micrograph in (d) represents the microstructure developed in the baseline alloy, when artificially aged for 96h. The presence of a well developed distribution of spherical $\delta'(Al_3Li)$ precipitates in these micrographs is evident. Figs.(b)-(d), show, in addition, the presence of a fine and uniformly distributed rods of S precipitates: the S rods appear as dark dots (a few arrowed) when viewed end-on in $<100>_{Al}$ orientation. The absence of the homogeneous distribution of S phase in (a) and their presence in (b)-(d) implies that the nucleation of the S phase is accelerated by the presence of Zn and Be [5,7], and that a uniform precipitation of S phase eventually occurs in the baseline alloy after prolonged aging [11]. Our TEM results further showed that the nucleation of S phase is accelerated in all the alloys containing Zn and Be (i.e. alloys A2 through A6) irrespective of their amounts and/or combinations in which they are added.

Figs.2(a) and (b) show the presence of coarse precipitates at the grain boundary of the baseline and baseline+0.6wt%Zn alloys respectively, when artificially aged for 96h. A comparison of these micrographs definitely shows the presence of a greater number of coarser precipitates in the case of the materials containing Zn. Our TEM results showed that such phase precipitates are based on T_2 and δ. These observations are consistent with the previously documented results obtained in the similarly treated materials [7,10], and with Zn decreasing the solid solubility of Li in Al [12], and a consequent greater driving force for the formation of Li-containing precipitates at the grain boundary.

Fig.3(a) shows the presence of coarse precipitates at the grain boundary as well as in the matrix of the baseline+0.15wt%Be alloy. These type of coarse precipitates are not observed in the alloys containing 0.09wt%Be. Fig.3(b) presents a selected area electron diffraction pattern obtained from one such coarse particle (arrowed) present in the matrix. The diffraction pattern can be indexed for a structure based upon a face centred cubic unit cell with lattice parameter a=1.015nm. Diffraction patterns obtained from several such particles produced similar results. The crystal structure and the lattice parameter of the present phase are, therefore, consistent with the $MgBe_{13}$ phase of the constituent Mg-Be system i.e. cubic with a=1.016nm [13]. Fig.3(c) represents a centred dark field

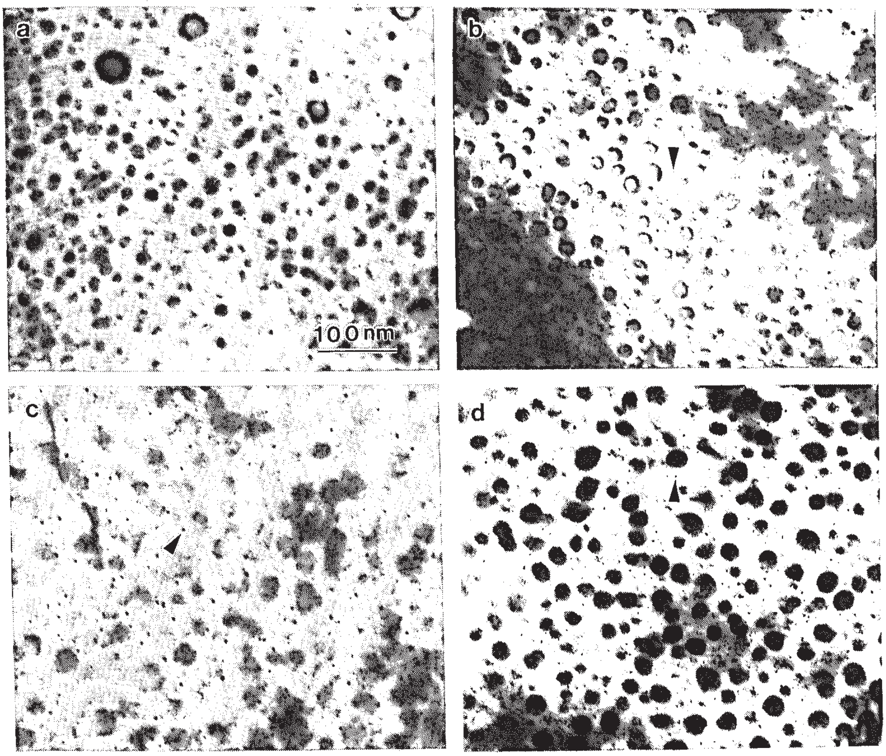

Fig. 1: Development of microstructure in the (a) baseline, and baseline containing (b) 0.60wt% Zn, (c) 0.09wt% Be alloys, when artificially aged for 55h, and (d) the microstructure obtained from the baseline alloy artificially aged for 96h; $<100>_{Al}$ orientation. Arrows in (b) -(d) show the presence of end-on rods of S phase.

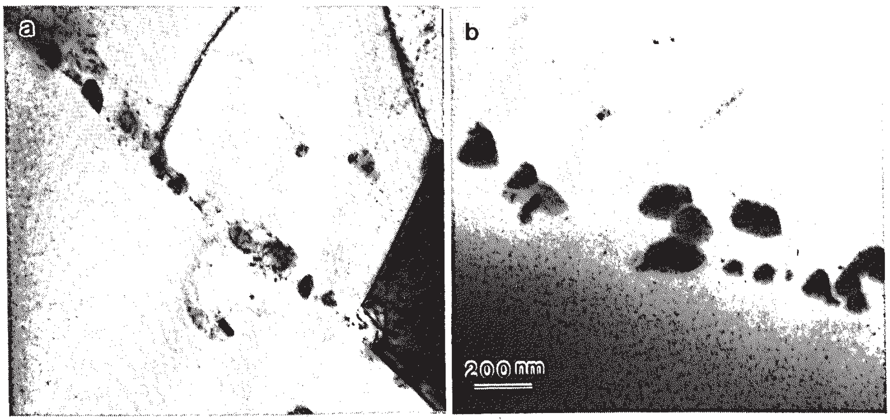

Fig.2: Formation of coarse precipitates (T_2 and δ) at the grain boundary of the (a) baseline and (b) baseline + 0.60wt% Zn alloys, respectively.

image taken using (200) reflection obtained from the matrix particle arrowed in (a). The micrograph shown in (c) demonstrates that the $MgBe_{13}$ particles are present in the matrix as well as at the grain boundary. The presence of $MgBe_{13}$ particles only in the alloy containing 0.15wt% Be, on the other hand, implies that this amount of Be has clearly exceeded the maximum solid solubility of Be in Al [8].

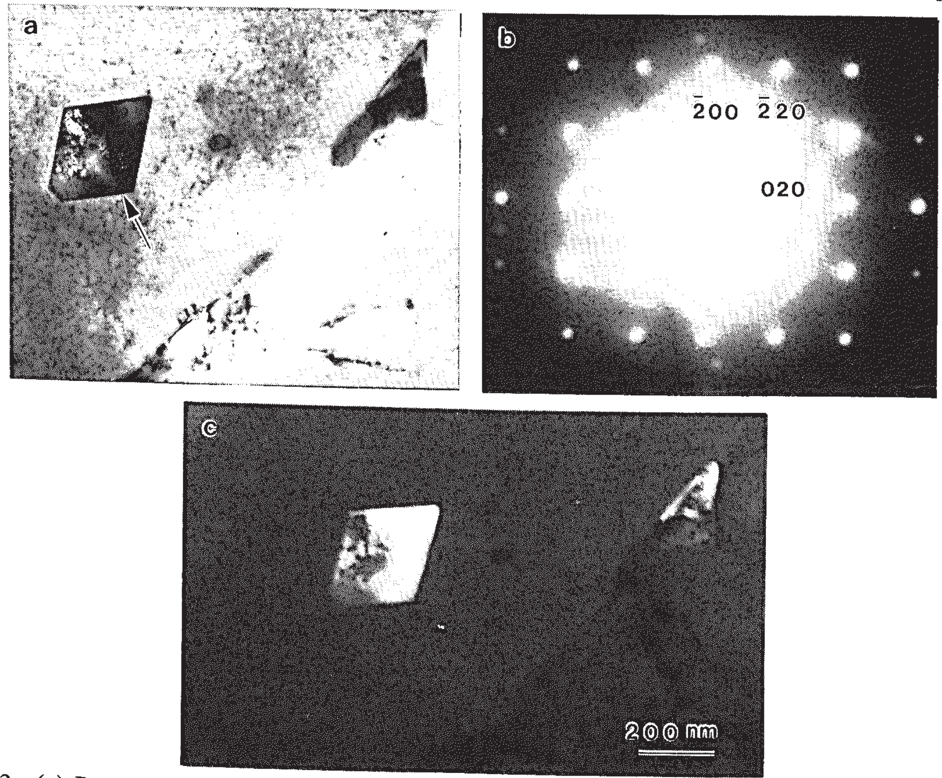

Fig.3: (a) Presence of coarse $MgBe_{13}$ insolubles in the baseline+0.15wt% Be alloy, (b) an SAED pattern of [100] zone axis obtained from the $MgBe_{13}$ particle arrowed in (a), and (c) a CDF image using (200) reflection obtained from the matrix particle arrowed in (a).

II. Variations in Tensile Properties: The variations in tensile properties of the alloys as functions of aging times are presented in Figs.4(a) through (c). The results show that the strength properties of the baseline alloy are increased by Zn additions, and this trend persists even when such materials are further alloyed with 0.09wt%Be. Such an effect is attributed to an increase in the volume fraction of δ' precipitates due in turn to the reduction in the solid solubility of Li in Al by Zn additions [12].It is further pointed out that an increased rate of strength increment with aging observed for the alloys containing Zn, 0.09wt% Be and Zn+0.09wt%Be is due additionally to an increased rate of S precipitation (refer to Fig.1). However, the strength properties of the alloys containing 0.15wt% Be are always lower than those attained by other alloys, and this is attributed to the formation of $MgBe_{13}$ particles in such alloys. Firstly, the formation of such particles reduces the contribution of Mg to the age hardening process. Secondly, the vacancies annihilated at the $MgBe_{13}$/Al interfaces are not available for the formation of δ', resulting in δ'-free zones surrounding the $MgBe_{13}$ particles formed in the matrix.

The ductility of the baseline alloy, on the other hand, initially decreases with aging up to about 60h following which time the ductility increases with aging up to about 100h. The initial reduction in the ductility is attributed to the formation of coarse precipitates at the grain boundary, and an increase in the width of the precipitate free zones (PFZs) adjacent to the grain boundary. However, with continuing aging, the S precipitates form uniformly in the matrix, homogenize the deformation and improve the ductility of the materials [11]. The trend of initial reduction in ductility followed by its recovery with further aging persists for all the alloys except the ones containing 0.15wt%Be; in the case of the latter alloys, the ductility decreases continuously with aging. It is suggested (as evidenced by our SEM results, obtained but not included in this paper) that the coarse $MgBe_{13}$ particles present at the grain boundary of such materials act additionally (i.e. in addition to the coarse δ and T_2 particles) as the nucleation sites for void formation, causing premature grain boundary failure, and reducing the ductility considerably.

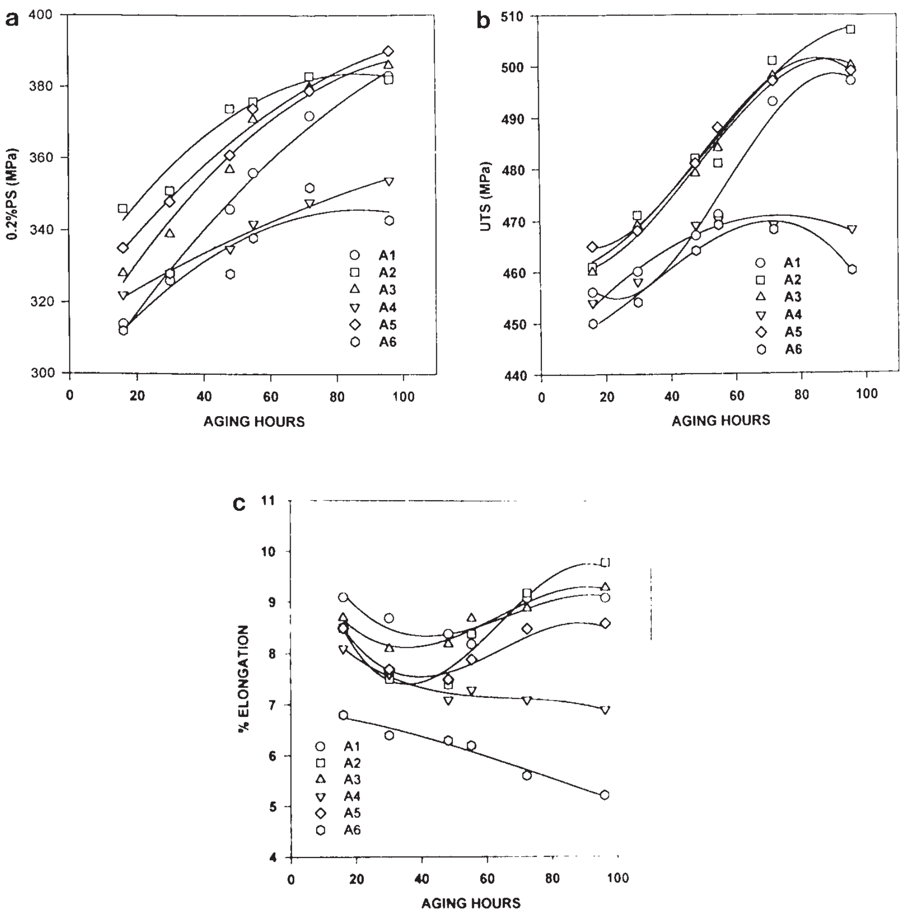

Fig.4: Variations in tensile properties (a) 0.2 PS, (b) UTS and (c) % elongation, of the alloys as functions of aging times at 170°C.

SUMMARY AND CONCLUSIONS:

Small additions of Zn (~0.60 wt%) to an 8090 alloy promotes δ' precipitation and accelerates S precipitation within the matrix, whilst it gives rise to the formation of coarser T_2 and δ precipitates at the grain boundary upon artificial aging. This results initially in an increase in the strength of the alloy at the expense of ductility; however, the ductility later increases with aging due to the widespread precipitation of S phase within the matrix. 0.09wt% Be additions to the baseline alloy also accelerates S precipitation within the matrix, and this increases the strength of the alloy slightly without any considerable effect on the ductility. Increasing the Be content to 0.15wt%, however, brings about considerable reductions in both strength and ductility of the alloy due to the presence of coarse $MgBe_{13}$ insolubles within the grain as well as at the grain boundary. The role of $MgBe_{13}$ particles, when present in the matrix, is to partly remove the contributions of Mg and vacancies to the age hardening process. Whilst, such particles, when present at the grain boundary, act additionally as the nucleation sites for void formation, thus causing premature grain boundary failure, and reducing the ductility of the materials considerably.

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