EFFECTS OF SMALL Ag ADDITIONS ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF ALLOY 2195 ①

Huang Biping, Zheng Ziqiao, Yin Denfeng, Mo Zhiming
Department of Materials Science and Engineering, Central South University of Technology, Changsha 410083

ABSTRACT The effects of small Ag additions on the mechanical properties and microstructure of an aluminum alloy 2195 were investigated. The results showed that Ag additions in the 2195 alloy greatly stimulated the precipitation of T_1 phases, ensuring high aging strength in both T_6 and T_8 conditions. Mg favored the precipitation of θ' phase, but the formation of θ' phase was suppressed when Ag was added. The prior cold work significantly improved the tensile strength by enhancing T_1 precipitation whether in the 2195 alloy or in the Ag-free alloy.

Key words alloy 2195 Ag addition mechanical property microstructure

1 INTRODUCTION

In 1960s, Polmear's studies showed that Ag had little or no effect on age-hardening behavior of binary Al-Cu alloy[1], but trace addition of Ag (≈0.1%) to Al-Cu-Mg alloys with high Cu:Mg ratio allowed remarkable age-hardening by promoting Ω phases[2]. However, a recent study by Garg *et al*[3] had showed that Ag wasn't required for but greatly enhanced the precipitation of Ω. In 1989, Polmear's further work showed that Al-4Cu-0.3Mg-0.4Ag alloy containing 1.0% Li had a high level of age-hardening[4]. Based on Polmear's investigations, Picken *et al*[5] have subsequently developed the Weldalite family containing Ag and Mg to promote copious T_1 phases (Al_2CuLi). But it is still uncertain about the roles of Mg and Ag on the precipitation process of T_1[6] as well as Ω[7].

The present study emphasizes the difference of the mechanical properties and the precipitation events between an Al-Cu-Li-Mg-Ag-Zr alloy 2195 and the corresponding Ag-free alloy. The purpose of this paper is to get more understanding about the roles of small Ag additions on aging characteristic of alloy 2195.

2 EXPERIMENTAL PROCEDURE

The measured chemical compositions of two alloys are shown in Table 1. The small chill ingots were prepared from commercial purity materials in argon atmosphere. The ingots were homogenized at 450 ℃ for 16h and at 500 ℃ for 18 h, then scalped and fabricated to sheets by rolling to 2mm thick. All of the specimens were solution-treated at 504 ℃ for 1 h in a salt bath, then water-quenched and followed by different aging treatments. Samples of T_6 temper were aged at 180 ℃ for various time, while those of T_8 temper were aged at 160 ℃ after prior rolling 6%. The specimens for transmission electron microscopy (TEM) analysis were prepared by the

Table 1 Measured chemical compositions of two alloys used in the experiment(%)

Alloy	Cu	Li	Mg	Ag	Zr	Ti	Al
2195	3.97	1.07	0.43	0.43	0.15	0.11	bal
Ag-free	4.01	1.11	0.39	0	0.18	0.11	bal

① Supported by Key Program of the 8th Five-Year Plan of China Received Dec. 27, 1995; accepted Jul. 29, 1996

twin-jet polishing technique in a solution of 1/3 nitric - acid and 2/3 methanol cooled to about - 30 ℃ and examined in a H-800 instrument operating at a voltage of 175 kV.

3 RESULTS

Fig. 1 shows the tensile properties of two alloys after aging for various time. The 2195 alloy displays much more rapid and pronounced age-strengthening effect than the Ag-free alloy. For the 2195 alloy T_6, the increament of tensile strength from the as-quenched value (316.8 MPa) to the peak value (498.7 MPa) can reach 182 MPa, which is much higher than that (111.6 MPa) of the Ag-free alloy. Meanwhile, the 2195 alloy achieves maximal strength only after aging for 10 h, shorter than that (16 h) for the Ag-free alloy. Prior deformation enhances aging response, accelerates the age-strengthening and increases maximum tensile strength. The tensile strength of the 2195 alloy T_8 can reach 570.2 MPa (UTS) with an elongation above 7%, which indicates that a promising combination of strength and ductility is achievable in the 2195 alloy. The fact that the age-strengthening of the 2195 alloy in T_6 or T_8 temper is much higher than that of the Ag-free alloy leads to a conclusion that Ag plays an important role on the age-hardening process of alloy 2195.

Fig. 2 shows dark field TEM images for the 2195 alloy aged for 10 h in T_6 temper. The predominant hardening precipitate is T_1 phase, together with a certain amount of θ' phases (Al_2Cu). In comparison to the 2195 alloy, the bright field TEM images of the Ag-free alloy aged for 16 h/T_6 (cf Fig. 3) shows that θ' is the relatively predominant precipitate. The lengthening of T_1 in the 2195 alloy is more significant than in the Ag-free alloy. The Ag-free alloy has greater density of θ' phases than the 2195 alloy.

As for the deformed samples of the 2195 alloy, Fig. 4 shows that the dispersion of T_1 phases is significantly more uniform and finer than in the undeformed samples. θ' phase is absent in the 2195 alloy T_8. Fig. 5 shows the obvious decrease of θ' and the somewhat increase of T_1 in the Ag-free alloy T_8. These investigations indicate that the prior cold work significantly enhances the precipitation of T_1 at expense of θ'.

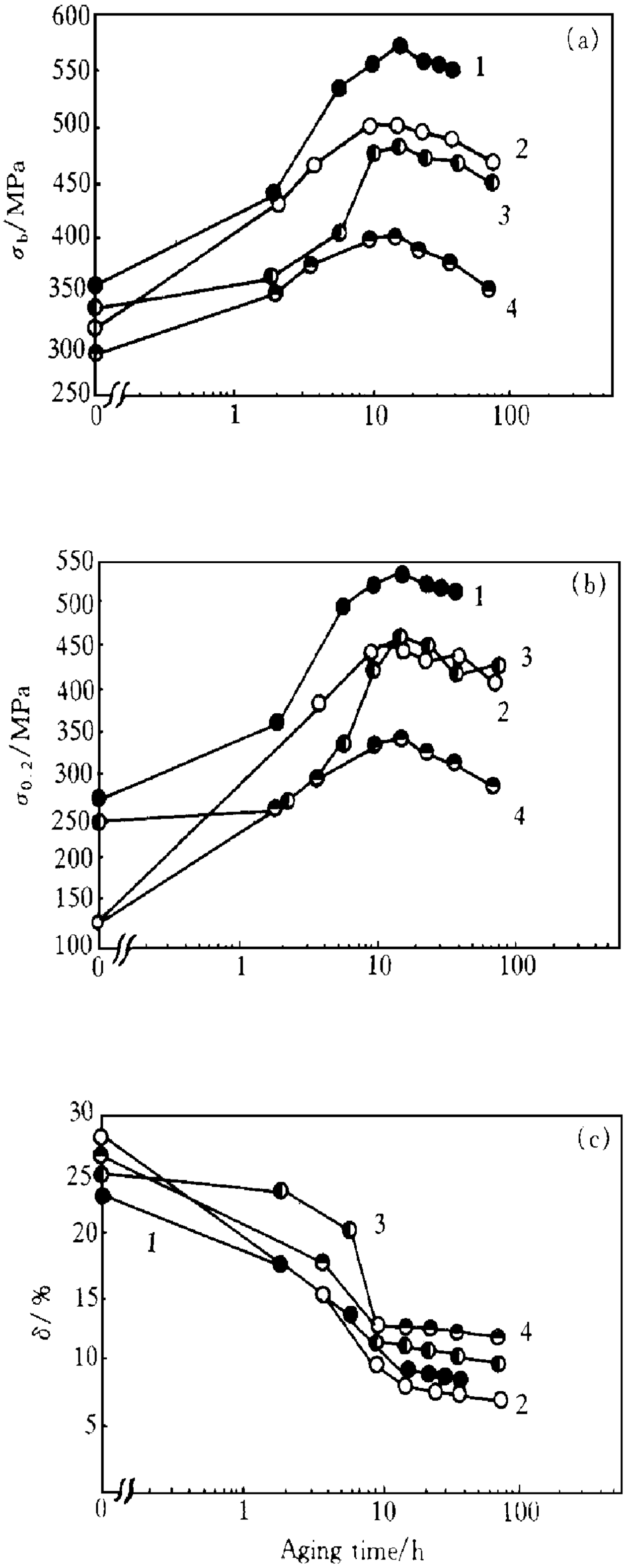

Fig. 1 Tensile properties *vs* aging time curves for the 2195 alloy and the Ag-free alloy

1 —2195 alloy T_8;
2 —2195 alloy T_6;
3 —Ag-free alloy T_8;
4 —Ag-free alloy T_6

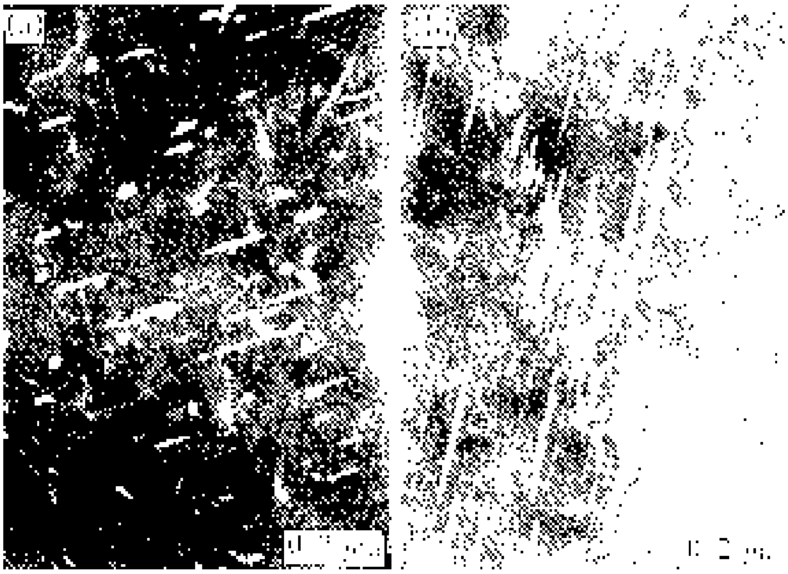

Fig. 2 Microstructure of the 2195 alloy (aged for 10 h/ T_6)

(a) —$\boldsymbol{B}$= [001], showing θ′ lying on {100}$_\alpha$ and lath-like phase T_1 lying on {111}$_\alpha$;
(b) —$\boldsymbol{B}$= [011], showing three variants of T_1 phase lying on {111}$_\alpha$

Fig. 3 Microstructure of the Ag-free alloy (aged for 16 h/ T_6)

(a) —$\boldsymbol{B}$= [001], showing a high density of θ′; (b) —Image of short T_1 phases

As the zone axis of the matrix grain in Fig. 5(b) is inclined to the electron beam, the T_1 variant for this orientation appears to be thicker than in the 2195 alloy. Hence, T_1 precipitates are present in all samples examined, but their amounts and morphologies depend on temper conditions and alloy contents.

The addition of Ag in the 2195 alloy ensures the high age-strengthening by greatly stimulating the precipitation of T_1 phase, which is the most strengthening phase among other precipitates in Al-Li alloys.

4 DISCUSSION

Early studies showed that the addition of Mg (above 0.1%) can accelerate and intensify the hardness increase in aging by encouraging the formation of GP zones[8]. Entwistle *et al*[9] suggested the formation of GP zones was stimulated by Cu/Mg/vacancy groups diffusing together. They proposed that the formation of Mg/vacancy pairs during quenching was due to the high binding energy (0.4 eV) between Mg atoms and vacancies. Meanwhile, the strong

Fig. 4 Microstructure of the 2195 alloy(aged for 16 h/ T_8) showing finer and uniform T_1 precipitates

interaction of Mg/ Cu encouraged the Mg/ vacancy pairs to seize small-sized Cu atoms so as to reduce the misfit energy. The Cu/ Mg/ vacancy complexes would act as nucleation sites of GP zones which would develop into θ'' and then to θ' phases. In agreement with the above effect of Mg element, the Ag-free alloy with Mg in the present study exhibits a great number of θ' in T_6 condition. Li additions also have strong interactions with vacancies and Cu atoms as Mg, so the Li clusters (or Li/ Cu clusters) on $\{111\}_\alpha$ would act as the nuclei of T_1. As a result, T_1 precipitates are present in the Ag-free alloy T_6.

Many strong evidences[10, 11] support that there is a preferred strongly interaction of Ag with Mg. When Ag was added in the 2195 alloy, the density of θ' phases is reduced, indicating that the individual role of Mg on encouraging θ' precipitation is still effective but the strong interaction between Mg and Ag weakens this effect by expending a certain amount of Mg atoms to form Mg/ Ag clusters which would act as nucleation sites of T_1 phases. On the other hand, the stacking fault energy of aluminium, a metal with a relatively high value($0.15\,J\cdot m^{-2}$) when in the pure state, can be lowered if the most soluble elements such as Ag or Mg is added. T_1 phases are known to nucleate through stacking fault mechanism or the dissolution of perfect dislocations near jogs. So Ag additions in the 2195 alloy contribute to the lower stacking fault energy and then lead to a larger number of T_1 phases than that in the Ag-free alloy.

In T_8 condition, a great number of dislocations introduced by the prior deformation would pick up the quenched vacancies, decrease the density of Mg/ Cu/ vacancy groups and thus reduce the amount of θ'. The dislocation jogs also act as preferable heterogeneous nucleation sites of T_1 phases, thus resulting in increased amount of

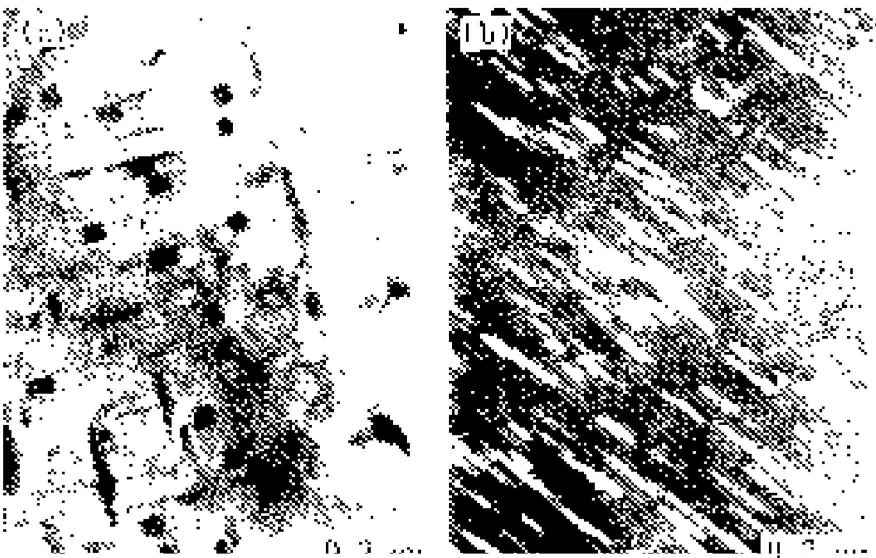

Fig. 5 Microstructure of the Ag-free alloy(aged for 16 h/ T_8)

(a) —$\boldsymbol{B}$= [001], showing lower density of θ' than in T_6 temper;

(b) —Image of T_1 phases, $\boldsymbol{B}\approx$[112]

T_1 at expense of θ' in the Ag-free alloy T_8. For the 2195 alloy with Ag additions, a great number of fine T_1 phases are encouraged by the large number of dislocation jogs and the precipitation of θ' is entirely suppressed.

In addition, it is very likely that the role of Ag is to change the thermodynamics or the kinetics of the precipitation process of T_1 phase, as the lengthening of T_1 in the 2195 alloy T_6 is greater than that in the Ag-free alloy. However, this effect of Ag is much less significant when prior deformation is employed. The explanation in detail deserves further studies.

5 CONCLUSIONS

(1) The addition of Ag in the 2195 alloy ensures the high aging strength by enhancing T_1 precipitates.

(2) Mg prefers the precipitation of θ' to that of T_1 but the formation of θ' is suppressed when Ag is added.

(3) Both in the 2195 alloy and in the Ag-free alloy, prior deformation promotes T_1 phases at expense of θ', therefore improves aging strength significantly.

REFERENCES

1 Polmear I J. Nature, 1960: 186: 303.
2 Taylor J A, Parker B A, Polmear I J. Met Sci, 1978: 478.
3 Garg A. Chang Y C, Polmear I J. Scritpta Metall Mater, 1990, 24: 677.
4 Polmear I J, Chester R J. Scripta Metall Mater, 1989, 23: 1213.
5 Pickens J R, Heubaum F H, Kramer L S. Scripta Metall Mater, 1990, 24: 457.
6 Pickens J R *et al*. In: Proceeding of 5th International Aluminium-Lithium Conference, MCE Publication Ltd, Birmingham U K, 1989: 1397.
7 Muddle B C, Polmear I J. Acta Metall, 1989, 37: 777.
8 Khan A Q. Trans JIM, 1972, 13: 149.
9 Entwistle K M, Fell J H, Koo K I. J Inst Met, 1962 – 1963, 91: 84.
10 Polmear I J. Mater Sci Forum, 1987, 13/14: 195.
11 Polmear I J. J Inst Met, 1960– 1961, 89: 51.

(Edited by Zhu Zhongguo)