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Effect of Quenching Condition on the Growth of GP Zones in Al-1mass%Ag Alloy

Akira SAKAKIBARA,* and Teruto KANADANI**

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SYNOPSIS

Aging of Al-1mass%Ag alloy at 273K after quenching under various conditions was studied by measurement of electrical resistivity. Scattering of the quasi-equilibrium value of resistivity (ρ_e) was not random but closely related to the as-quenched value (ρ_0); ρ_e increased with increasing ρ_0. When the quenching temperature (T_q) was lower than or equal to 773K, the state at ρ_e was controlled substantially by the concentration of quenched vacancy. On the other hand, when T_q>823K, GP zones formed during quenching played an important role, instead of quenched vacancies, in determining the state.

1. INTRODUCTION

GP zones in Al-Ag alloys have been studied extensively by many workers, but little attention has been paid to the conditions of quenching by which super-saturated solid solution would be obtained. Ohta and Hashimoto(1) and Ohta et al(2) first found out the effect of

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* Department of Mechanical Engineering
** Okayama University of Science

the quenching conditions to the aging behavior of Al-10mass%Zn alloy by measurement of electrical resistivity and investigated the effect in detail. According to their report, quasi-equilibrium state obtained after aging was closely related to as-quenched state; in the case of low quenching temperature (T_q), retained vacancy concentration played a leading role, and in the case of high T_q, clustering of Zn atoms during quenching had an increasing effect.

In this paper, dependence of the aging behavior of Al-1mass%Ag alloy on quenching conditions is revealed by resistometry and the role of retained vacancies and the solute clusters are discussed.

2. EXPERIMENTAL PROCEDURES

Al-1mass%Ag (nominal composition) alloy was prepared by melting 99.996% pure Al and 99.999% pure Ag in a high alumina crucible in the air. Such a dilute composition should be used because aging would occur rapidly in a more concentrated alloy and the detail of the process could not be observed. Thus slight changes in aging behavior induced by the change of quenching condition was able to be detected only by resistometry. Ingots, 15mm in diameter and about 150mm in length, were homogenized at 773K for 180ks. After peeling, they were hot-forged repeatedly at around 773K to plates of 5mm thickness. The plates were cold rolled several times, with appropriate intermediate annealings at 773K, to strips of 0.4mm thickness. Specimens, of which the shape and size were the same as reported previously by Ohta(3), were cut out of the strips.

Solutionization was done by inserting the specimen between the slit made in an aluminum block placed in a furnace and holding it at 773K for 3.6ks. It was furnace cooled to the quenching temperature (T_q), held there for 3.6ks, and quenched by extracting from the slit and immersing into iced water quickly with manipulation. Aging was carried out in an ethanol bath at 273K with an accuracy of +0.1K.

Resistivity was measured by a conventional potential drop method, the specimen being immersed in the liquid nitrogen bath. The effect of the temperature of the liquid nitrogen was canceled by using a dummy specimen in the same bath.

3. RESULTS AND DISCUSSION

Fig.1 shows aging curves of four specimens aged at 273K after quenching from 673K. Resistivity of each specimen was calibrated by the as-quenched resistivity from 473K. The curves have a typical feature of formation of GP zones; resistivity increases from the as-quenched value (ρ_0) to the maximum (ρ_m), and decreases to the quasi-equilibrium value (ρ_e). Values of ρ_0 scatter a little, but ρ_e's differ largely from each other without any relation to ρ_0. A single specimen was quenched and aged repeatedly under the same conditions, three curves of which are presented in Fig.2. This time also ρ_0's scatter, but very slightly. ρ_e's still take various values, but the difference among them is smaller than that in Fig.1. It should be noted in particular that they correspond systematically to ρ_0's. Large variation in ρ_0 and ρ_e with specimen observed in Fig.1 may be due to the difference in grain size and to the slight deviation in composition. Therefore only one specimen was used afterward in this study.

The difference in ρ_0 left when a single specimen was used is considered to be due to the various quenching conditions, perhaps slight difference in T_q and in cooling rate during quenching. The curve with the highest ρ_0 reaches the maximum value, ρ_m, the earliest of the three and the one with the lowest ρ_0 does the latest, which means that the higher ρ_0 value corresponds to the higher

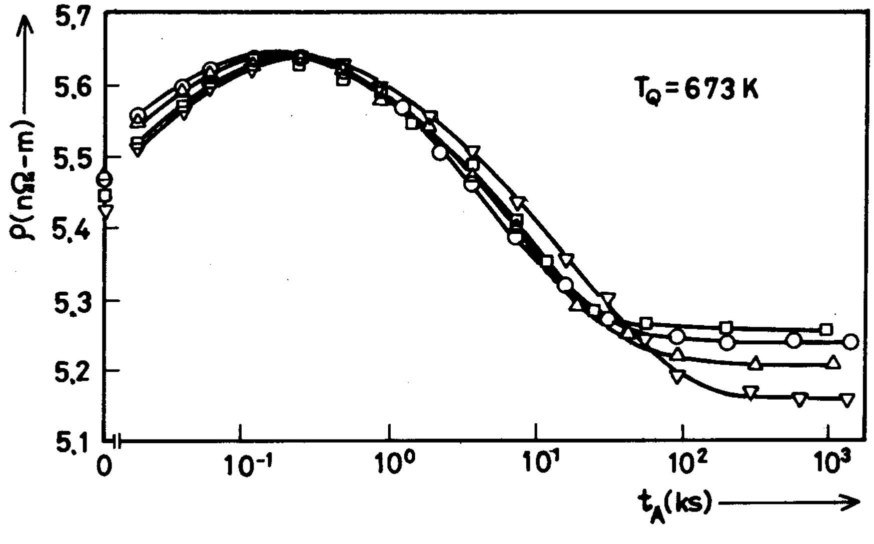

Fig.1 Aging curves at 273K for various secimens of Al-1mass%Ag alloy after quenching from 673K.

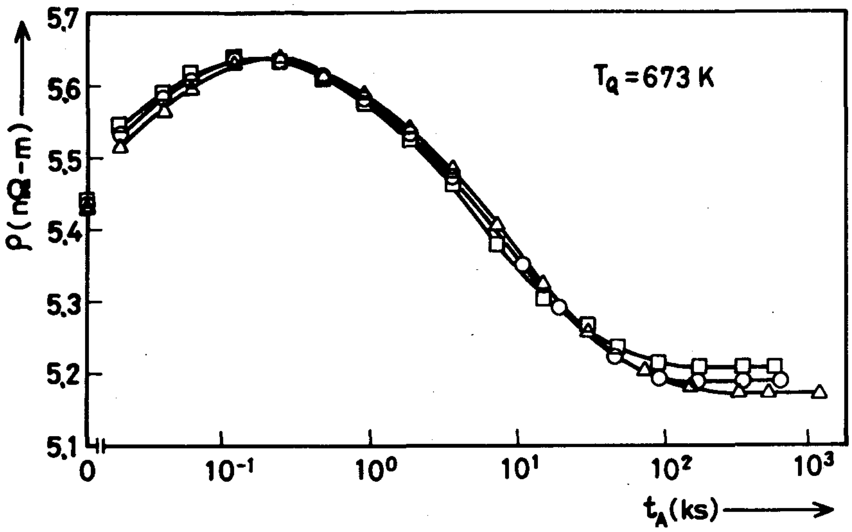

Fig.2 Aging curves at 273K for a single specimen of Al-1mass%Ag alloy quenching from 673K.

concentration of retained vacancies and thus to the quicker formation of GP zones.

Aging curves for a higher T_q, 773K, are shown in Fig.3. ρ_0's and ρ_e's still scatter, but the difference among them becomes smaller than that for T_q=673K in Fig.2. Even in this small difference, order of ρ_e corresponds to that of ρ_0; ρ_e is higher according to ρ_0. The relation between ρ_0 and ρ_e was examined for various T_q's and plotted with open circles in Fig.4. Strong dependence of ρ_e on ρ_0 can be confirmed, but it seems that the dependence below 773K is different from that above 773K.

Aging curves for a still higher T_q, 823K, was shown with open circles in Fig.5, where the maximum resistivity cannot be observed due to rapid formation of GP zones during quenching. Therefore ρ_0 then is considered to involve the contribution of the GP zones as well as that of the retained vacancies. To investigate further the effect of zone formation during quenching, other quenching methods were employed so as to suppress it. Fig.6 shows schematically the three methods employed in this study. Ordinary quenching is the one so far employed that consists of quenching from T_q to T_1(273K iced water) and then immersing into liquid nitrogen. In two-step quenching, the quenching into iced water was followed by the second quench-

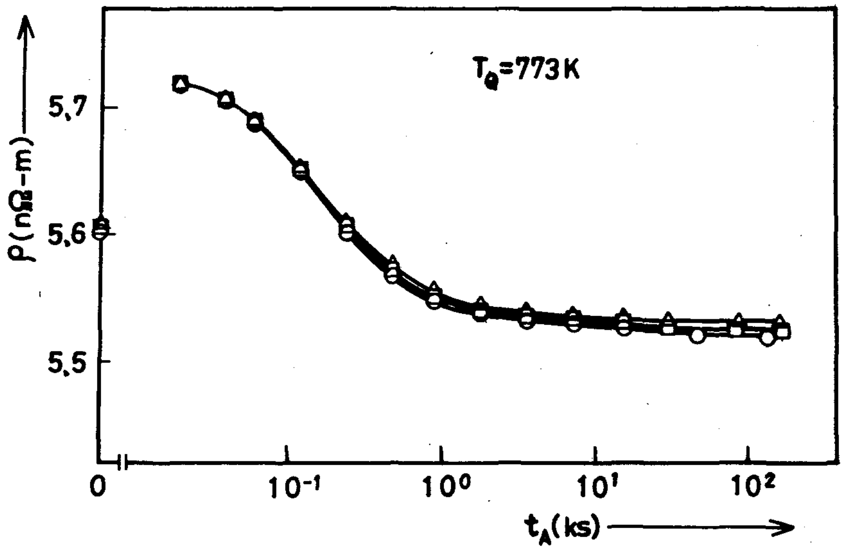

Fig.3 Aging curves at 273K after quenching from 773K.

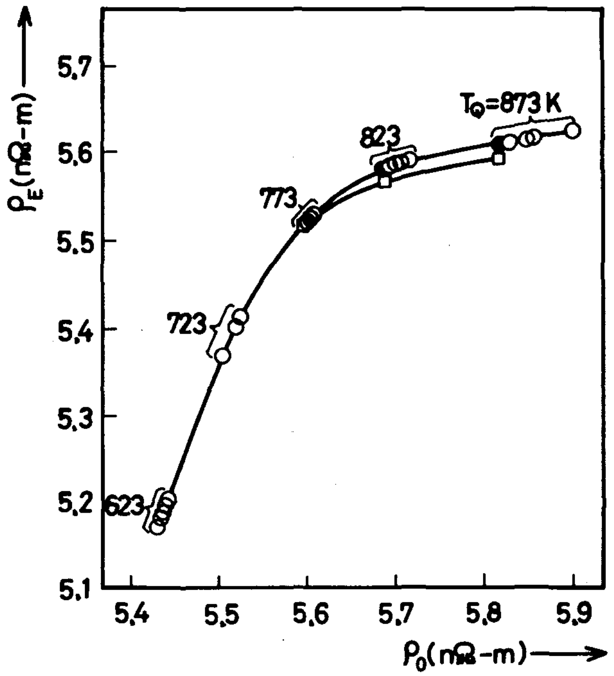

Fig.4 ρ_e vs. ρ_0 plot. ordinary quencing, two-step quenching, direct quenching.

ing from 273K to 213K(dry ice alcohol) to pass faster the region above 213K where the formation of GP zone may be active due to solute and vacancy supersaturation. Direct aging was carried out to omit the process below the aging temperature(273K) until the first resistivity measurement at 60s of aging. This method was expected to eliminate largely the effect of the GP zones formed during quenching to the aging in its very initial stage, where most quenched vacancies annihilated and supersaturation of solute reduced. An aging curve obtained after the two-step quenching is shown with closed circles in Fig.5. In spite of larger cooling rate and hence more retained vacancies, the obtained value of ρ_0 is lower than those for ordinary quenching. This confirms that the ρ_0's for ordinary quenching contained contribution not only of the retained vacancies but also of the GP zones formed during quenching. ρ_e value became a little lower accordingly. Relation of ρ_0 and ρ_e for the two-step quenching is plotted in Fig.4 with closed circles, where also the effect of the GP zones formed during quenching is clearly revealed. A direct aging curve is represented by crosses in the same figure, of which ρ_e is much lower than any other curves owing to the least effect of the GP zone formation during quenching. ρ_e's for the direct aging are plotted in Fig.4 with squares against the ρ_0 values for two-step quenching of which the quenching condition may be similar to that of the direct aging. Increase of ρ_e with T_q observed yet in the direct aging may be due to the resistivity of the residual vacancies even in the quasi-equilibrium stage.$^{(2)}$

In conclusion, aging of Al alloys in which GP zones form is remarkably influenced by the quenching condition. For the Al-1mass%Ag alloy quasi-equilibrium value of resistivity obtained after

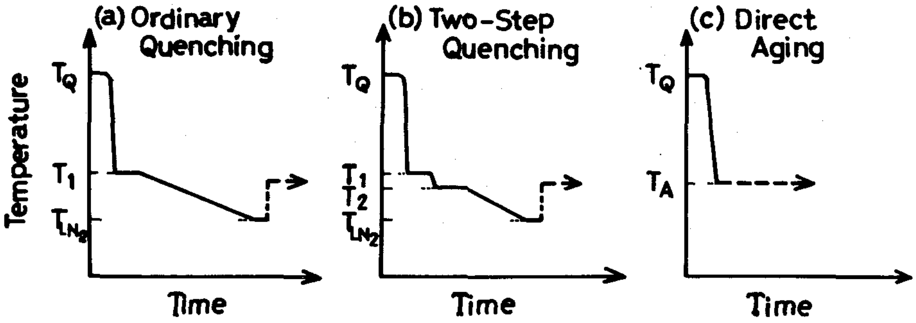

Fig.5 Temperature change in various quenching method, schematically.

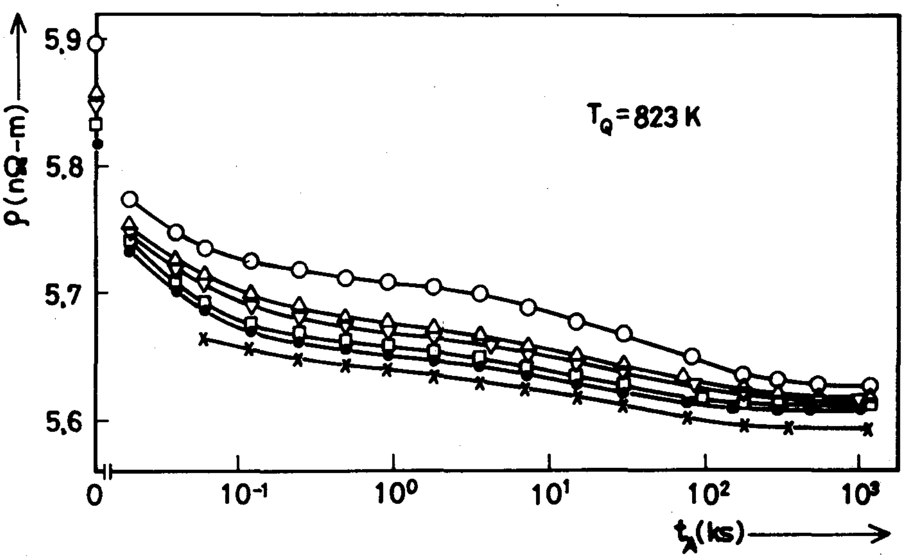

Fig.6 Aging curves at 273K after quenching from 823K. Open symbols represent ordinary quenching, closed circles two-step quenching, and crosses direct aging.

a long time of aging is closely related to the as-quenched resistivity; the lower the ρ_0, the lower the ρ_e. When T_q<773K, ρ_e value is controlled mainly by the concentration of retained vacancy. When T_q>823K, on the other hand, the effect of retained vacancies decreases and GP zones formed during quenching play an increasing roll.

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