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INFLUENCE OF SUPERPLASTIC DEFORMATION ON KINETICS OF AGING FOR ALUMINUM ALLOYS

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Abstract. The paper considers the influence of hot deformation under superplastic conditions on posterior solid solution decomposition at zonal and phase aging of aluminum alloys. The direct and hereditary influence of superplastic deformation on decomposition of supersaturated solid solution has been shown. Features of kinetics of aging for aluminum alloys after superplastic deformation have been analyzed.

1. INTRODUCTION

Aluminum alloys display high values of relative elongation and low flow stress at high temperatures of superplastic deformation. In the case of precipitation-hardening alloys, this temperature is above the line of ultimate solubility, i.e. it corresponds to the temperatures of heating for quenching [1,2]. That is why it is interesting to study the influence of superplastic deformation on processes of consequent aging.

The present paper considers natural and artificial aging for alloys AK6 (Al-2,2%Cu-0,6%Mn-1,0%Si-0,6%Mn), V96ts (Al 8,2%Zn-2,6%Cu-3,1%Mg-0,15%Zr), and 1420 (Al-5,2%Mg-2,0%Li-0,15%Zr).

2. EXPERIMENTAL

Kinetics of natural and artificial aging has been studied using samples in two states. In particular, samples with microcrystalline structure (a grain size of about 6-10 mm) after quenching (MC state) and samples with microcrystalline structure after SPD at temperature above the line of ultimate solubility and following quenching cooling (SPD state). Superplastic deformation was realized by compression at the strain value 50% and the strain rate $7 \cdot 10^{-4}$ s^{-1} being optimal for SPD.

After quenching, measurements of hardness (HB) and electric conductivity ($1/\rho$) were made to study kinetics of aging at room temperature. Kinetics of artificial aging was studied by yield stress and electric conductivity. Electric conductivity was measured using a IE-1 device with threshold sensitivity of 0.05 m om^{-1} mm^{-2} and an error of ±2.%. The artificial aging temperature for alloys AK6, B96ts, and 1420 was selected 160, 140, and 120 ^{o}C, respectively.

3. RESULTS AND DISCUSSION

The microstructure of the alloys in MC and SPD states was almost similar. It was fine-grained and homogeneous. The later is attributed to features of the mechanism of superplastic deformation [1] and a relatively small strain value. Reasoning from the

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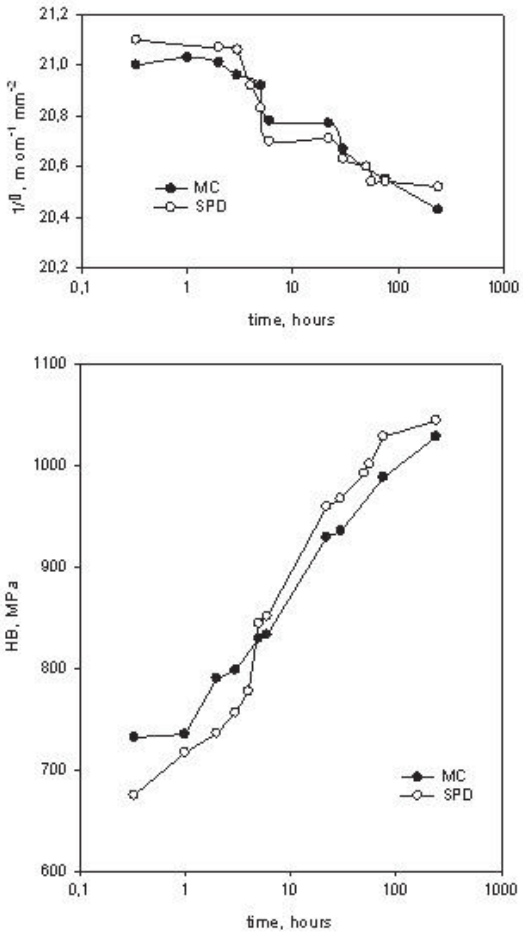

Fig. 1. Aging curves for alloy AK6 at room temperature in MC and SPD states.

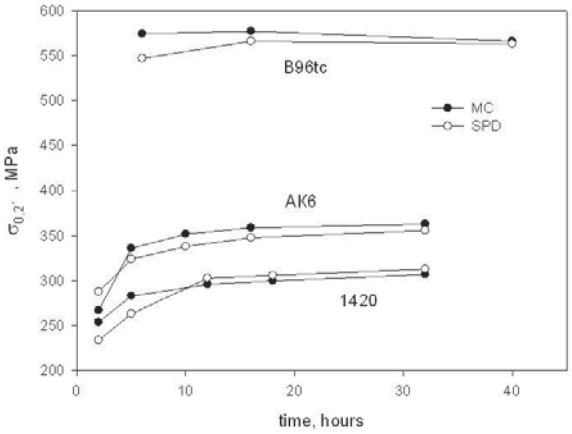

Fig. 2. Artificial aging curves for alloys AK6, VB96ts, 1420 in MC and SPD states.

comparison of the results of testing in MC and SPD states, one can evaluate the contribution of SPD to kinetics of aging.

The study of AK6 alloy in the as-quenching state (10 minutes later after cooling of samples in water *T*= 20°C) has shown that in samples subjected to SPD (SPD state) a value of hardness is lower and a value of electric conductivity is higher than in the samples subjected only to heating without any deformation (MC state) (Fig. 1). However, at holding especially for 10 hours, a rate of aging is higher in the samples after SPD that is confirmed by a more essential decrease in electric conductivity and a more intense growth of hardness.

After two hour aging, the values of yield stress and electric conductivity in the AK6 alloy samples subjected to SPD are higher than in the samples not subjected to SPD. During further aging, the growth of conventional yield stress becomes much slower in the samples after SPD as compared the MS state samples and the level of conventional yield stress in the state without deformation becomes higher. The values of electric conductivity in both states after 15 hour aging coincide. The character of changes in yield stress for alloy V96ts is the same (Fig. 2).

As for alloy 1420, the character of changes in yield stress during artificial aging in SPD and MC states is different. Strengthening starts later in the SPD samples; but due to its more intense growth after 10 hour aging, the value of yield stress becomes higher as compared the MC state samples (Fig. 2).

One can assume the following reason for this difference in kinetics of aging. Solid solution is not uniform at the temperature above the line of ultimate solubility. It is due to the action of forces of atomic interaction of alloying elements. The strength of interatomic bonds between one type atoms is higher than between atoms of different types, in particular, A-A and B-B **>** A-B. After quenching, the available structure heterogeneities become centers for initiation of precipitates. Deformation reduces concentration heterogeneity. In this connection, the number of centers for initiation of precipitates after annealing will be larger in MC state without deformation as compared SPD state. The presence of segregation causes the growth of hardness and the decrease in electric conductivity [3] because of increased scattering of conduction electrons in sites of lattice regularity distortions. That is why the hardness is higher and electric conductivity is a bit lower in the initial stage of natural aging, i.e. in 10 minutes after quenching without deformation.

Vacancies exert an essential influence on kinetics of aging combined with dissolved atoms. The vacancies create conditions for more rapid migration of impurities, and, thus, accelerate generation and growth of Ginje-Preston zones [3].

At SPD, the concentration of vacancies increases due to contribution of deformation vacancies [4]. Quenching after superplastic deformation holds the concentration of vacancies being excessive as compared the MC state. As a result, after SPD the rate of diffusion increases and, consequently, the process of aging accelerates. There occurs sink of vacancies at room temperature. That is why the influence of SPD on kinetics of aging is most essential in the initial period after quenching. The presence of a wide near-boundary zone which is precipitate-free confirms the occurrence of a more intense sink of vacancies at aging after SPD. In particular, in alloy V96ts subjected to SPF the width of the zone precipitate-free after aging at 200 °C for 4 hours is about 128 nm and in MC state – 107 nm.

Artificial aging was started in 1 hour after quenching. In the initial stage, the decomposition of supersaturated solid solution in alloys AK6 and V96ts is accompanied by formation of Ginje-Preston zones and, at further, artificial aging by metastable phase precipitation [5]. During the first hours, the aging after SPD is more intense as compare the MC state because of larger concentration of vacancies. The formation of Ginje-Preston zones increases the yield stress of alloys AK6 and V96ts. The measurements made after 2 hour aging have shown that values of $\sigma_{0,2}$ are higher after SPD. Further artificial aging is accompanied by formation of hardening metastable phase precipitation. The density of Ginje-Preston zones increased by SPD leads to essential dealloying of matrix that further prevents generation of hardening metastable phase.

The stage of natural aging is absent in alloy 1420. Hardening of alloy 1420 occurs only at artificial aging due to generation and growth of δ' -phase particles [6]. Unlike alloys AK6 and V96ts where in the initial stage of natural aging the accelerated decomposition of supersaturated solid solution after SPD causes dealloying of matrix and prevents the rate of phase aging as compared to the MC state, the rate of hardening is higher in alloy 1420 after SPD due to vacancies.

The results reported in [7,8] confirm the fact that high temperature deformation affects directly on solid solution decreasing its concentration heterogeneity at temperatures above the ultimate solubility line and the hereditary one via elevated concentration of deformation induced vacancies in the process of solid solution decomposition at below the ultimate solubility line. The authors studied the influence of high temperature deformation on decomposition of supersaturated solid solution for alloys V93 and AK6 by plotting thermal kinetic diagrams.

The investigations have shown that the deformation accelerated high temperature decomposition of supersaturated solid solution in alloy AK6, while the decomposition after deformation proceeds slowly in alloy V93. This difference can be attributed to the following. The supersaturated solid solution was more stable in alloy V93 and its decomposition started in 3 minutes and more after quenching depending on the rate of cooling. The decomposition of supersaturated solution in alloy AK6 started at once (in 3 seconds). Thus, the sink of deformation vacancies may occur in alloy V93 during the period before decomposition onset and the decreased heterogeneity of solid solution at hot deformation can only influence the solid solution decomposition, while deformation induced vacancies contributed to diffusion processes at decomposition of supersaturated solid solution in alloy AK6.

4. CONCLUSION

1. The direct influence of SPD on solid solution is seen in a decrease of its concentration heterogeneity. It is confirmed by a shift of aging curve to the right, lower values of hardness and higher values electric conductivity in the initial stage of aging.
2. The hereditary influence of SPD on solid solution is connected with deformation induced vacancies which accelerate the process of solid solution decomposition.
3. The revealed different influence of SPD on kinetics of artificial aging can be attributed to the additional preliminary hardening occurring in alloys AK6 and V96ts due to natural aging at room temperature.

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