Strain rate sensitivity in a cryorolled Al2024 alloy

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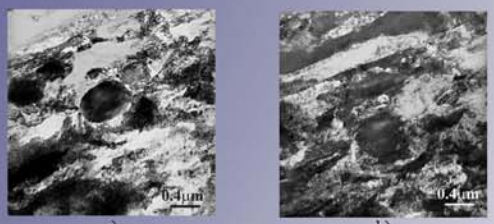
1. Introduction

A number of aluminum alloys exhibit dynamic strain ageing, which is related to dynamic interaction between mobile dislocations and solutes. Negative strain rate sensitivity of the flow stress is a key feature of dynamic strain aging. This work focuses on this effect in ultra-fine grained aluminum alloy Al2024 processed by rolling at liquid nitrogen temperature.

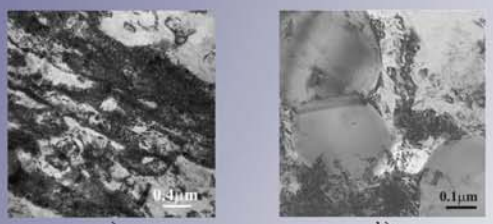
The Al2024 alloy was studied in solutionized condition. Billets 100x60x10 mm³ were rolled at liquid nitrogen temperature with a total reduction ratio of 78%. This condition of the material is referred to as "CR". Part of material was annealed at 160ºC for 2 h for recovery (referred to as "CR-A").

2. Microstructure of the Al2024 alloy



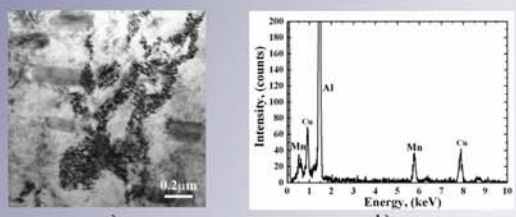
a) b)

Fig. 1. Microstructure of the CR Al2024 alloy.



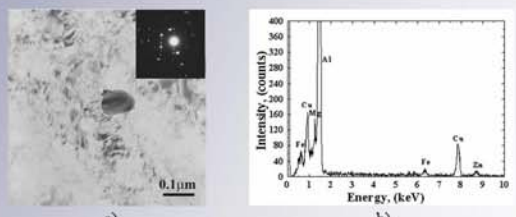
a) b)

Fig. 2. Microstructure of the CR-A Al2024 alloy.



a) b)

Fig. 3. a) Microstructure of the CR-A Al2024 alloy; b) the results of EDX analysis of the rod-like particles



a) b)

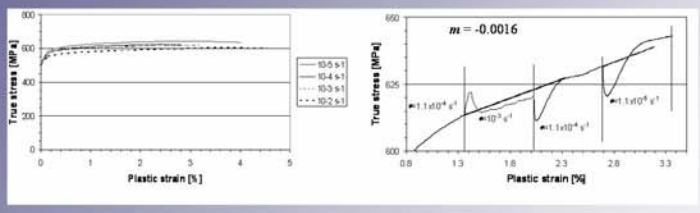
Fig. 4. a) Microstructure of the CR-A Al2024 alloy; b) the results of EDX analysis of the small round particles

The microstructure in the CR condition is characterized by very high dislocation density (ρ=10^{15} m^{-2}) and consisted predominantly of a dislocation cell structure (a few hundred nanometers in diameter) (Fig. 1). Shear bands are seen. Annealing at 160ºC for 2h resulted in recovery of the microstructure. The dislocation density decreased to ρ=10^{14} m^{-2} and a few recrystallized grains are observed (Fig. 2b).

Two types of particles are found in the microstructure of the CR-A Al2024 alloy: coarse rod-like particles having the length of 0.3±0.02μm and the thickness of 0.1±0.04μm (Fig. 3a) and small round particles with the average size of 0.1±0.04μm (Fig. 4a). The coarse rod-like particles are most probably Cu-Mn-Al compounds (Fig. 3b). The EDX analysis and analysis of the diffraction patterns of small round particles show the formation of *S* orthorhombic Al_2CuMg (Fig. 4b).

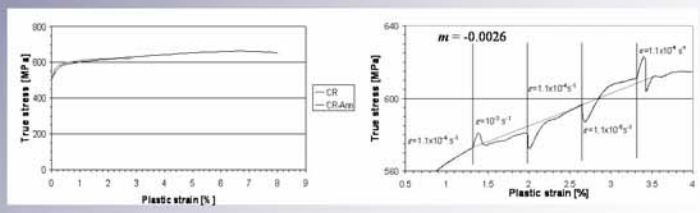
3. Mechanical properties

Room temperature tensile tests were carried out on an Instron 8801 machine with the strain rates of 10^{-2}, 10^{-3}, 10^{-4}, and $1.1x10^{-5}$ s^{-1}. It is seen that flow stress decreases with increasing strain rate (the effect of negative strain rate sensitivity). The value of instantaneous strain rate sensitivity ***m*** was measured using strain rate jump tests.



a) b)

Fig. 5. True stress – strain curves for the CR Al2024 alloy: a) at different strain rates, b) strain rate jump test at the base strain rate of 10^{-4} s^{-1}.



a) b)

Fig. 6. a) The effect of annealing at 160ºC for 2h on the true stress – strain curves, b) strain rate jump test at the base strain rate of 10^{-4} s^{-1}.

4. Dynamic strain aging

Negative strain rate sensitivity indicates the effect of **dynamic strain aging**. It has been suggested that this is due to dynamic interaction of mobile dislocations with solute atoms. The latter are segregated at temporarily arrested dislocations and produce additional pinning. This is also confirmed experimentally by our atom probe tomography analysis (Fig. 7).

a) b)

Fig. 7. a) Selected atom map and corresponding iso-concentration surface of segregation of Mg atoms on the dislocation; b) selected atom map and corresponding iso-concentration surface of segregation of Cu atoms on the dislocation.

5. Conclusions

1) Negative strain rate sensitivity was found for both CR and CR-A conditions.
2) Recovery annealing results in significant increase of the ductility (from 3% to 8% at the strain rate of 10^{-4} s^{-1}) and increase of the absolute value of the negative strain rate sensitivity. The latter effect may be attributed to the depletion of Mg solute solution as a result of annealing.

6. Work in progress

1) The effect of annealing on the concentration of solute atoms in the matrix of the CR Al2024
2) Comparison of existing theoretical models of dynamic strain aging in alloys with solute atoms with experimental results.

Acknowledgments

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