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Improvement of strength and ductility of Al−Cu−Li alloy through cryogenic rolling followed by aging

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Abstract: To develop an improved approach in achieving an excellent combination of high strength and ductility, the solutionized Al−Cu−Li plates were subjected to rolling at cryogenic and room temperatures, respectively, to a reduction of 83%, followed by aging treatment at 160 °C. The results indicate that Al−Cu−Li alloys through cryogenic rolling followed by aging treatment possess better mechanical properties. Rolling at cryogenic temperature produces a high density of dislocations because of the suppression of dynamic recovery, which in turn promotes the precipitation of T_1 (Al_2CuLi) precipitates during aging. Such high density of T_1 precipitates enable effective dislocation pinning, leading to an increase in strength and ductility. In contrast, room temperature rolled alloys after aging treatment exhibit lower strength and ductility due to low density of T_1 precipitates in the grain interior and high density of T_1 precipitates around subgrain boundaries.

Key words: Al−Cu−Li alloy; cryogenic rolling; dislocation; T_1 precipitate

1 Introduction

Al−Cu−Li alloys are extensively used for aerospace applications due to their high specific strength, good damage tolerance and excellent property stability [1]. An increased usage of Al−Cu−Li alloys depends on enhancing their mechanical properties such as strength and ductility further. For precipitation of hardenable alloys, recent results [2,3] have shown that a new processing route of severe plastic deformation (SPD) followed by aging treatment could significantly improve both strength and ductility. KIM et al [3] combined equal channel angular pressing (ECAP) in solid solution state with post-ECAP low-temperature aging of 2024 Al alloy and found that the yield strength was improved to ~630 MPa while a reasonable elongation to failure (~15%) was maintained. The SPD processes, such as ECAP, multiple compression, and high pressure torsion, have their own limitations for commercial application, for example, the requirement of a large load, the small size of the products, and the high labor and fuel expenses [4−6]. Recently, rolling at cryogenic temperature has been identified as one potential method to refine the grain microstructure in the bulk alloys, which could be as effective as the SPD processes [7−9].

A lot of investigations [7,8] have shown that cryogenic rolling at large strains followed by aging treatment could significantly improve both strength and ductility in Al and Cu alloys. For instance, by combining solid solutionizing, cryogenic rolling and aging treatment, the yield strength of 7075 Al alloy was improved to 615 MPa, with a good uniform elongation of 7.5% [2]. Generally, the significant improvement of strength through cryogenic rolling at large strains is attributed to the refinement of grain microstructure and the relatively high density of dislocations in the bulk alloys [8]. The aging treatment of cryogenic rolled alloys could significantly improve their strength and ductility due to the precipitation hardening and the occurrence of recovery and recrystallization, respectively [8,9]. However, HUANG et al [10] pointed out that another economic process of room temperature rolling at large strains followed by aging could also achieve a good combination of strength and ductility in Al−Cu−Mg alloys. This is due to the formation of high density of dislocations and nanosized S'' precipitates. Then, an important question will be raised naturally: which

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process is better for Al−Cu−Li alloys to improve their mechanical properties through cryogenic or room temperature rolling followed by aging? Up to date, the related investigation is scarce in Al−Cu−Li alloys.

Therefore, the purpose of this work is to develop a procedure for significantly enhancing the strength and maintaining a reasonable ductility of age-hardened Al−Cu−Li alloys. The goals of the present work are: 1) to study the microstructure features and mechanical properties in cryogenic rolled (CR) and room temperature rolled (RTR) alloys; 2) to analyze the effect of rolling temperature on the evolution of mechanical properties, microstructure and precipitation behavior during aging.

2 Experimental

The Al−Cu−Li hot-rolled plates were provided by Southwest Aluminum (Group) Co., Ltd., China. The chemical composition of this material is 2.8% Cu, 1.4% Li, 0.3% Mn, 0.1% Zr and Al balance (mass fraction). The alloy plates were solution-treated and quenched, followed by cryogenic temperature rolling (CR) or room temperature rolling (RTR) to a total thickness reduction of 83%. In the case of rolling at cryogenic temperature, the solutionized plates were dipped in liquid nitrogen for 30 min before starting the first pass of cryogenic temperature rolling, and the plates were immersed in liquid nitrogen for 2 min before the next pass. To study the age hardening behavior, the CR and RTR samples were artificially aged at 160 °C for various time (1−84 h).

Mechanical properties were determined by room-temperature Vickers hardness and tensile tests. Hardness measurements were conducted under a load of 1 kg and a dwell time of 15 s, and the average hardness value was obtained from ten different measurements. Sheet tensile samples with a cross-section of 4 mm × 2 mm and a gauge length of 20 mm were prepared by electro-discharge machining. Tensile tests along the rolling direction of the samples were conducted on a tensile testing machine (SHIMADZU AG-X) at a strain rate of 10^{-4} s^{-1}. The yield strength was determined with the 0.2% offset plastic strain method.

The microstructure features were characterized using an FEI TECNAI G2 F20 transmission electron microscope (TEM) with an operating voltage of 200 kV. The specimens for TEM investigations were cut parallel to the RD/ND plane (longitudinal section). And the TEM foils were prepared by mechanical grinding to a thickness of 60 μm and then thinning by a twin-jet electro polishing unit with a solution of 30% nitric acid and 70% methanol at −30 °C.

3 Results

3.1 Mechanical properties

Figure 1(a) shows the engineering stress−strain curves of CR and RTR samples, and the corresponding yield strength, ultimate tensile strength, elongation-to-failure are presented in Table 1. For the CR sample, it shows higher yield strength (447 MPa) and ultimate tensile strength (455 MPa), but a lower elongation-to-failure (0.6%) as compared with the RTR sample. Additionally, the Portevin-Le Chatelier (PLC) phenomenon can be observed in the stress−strain curves, indicating that plastic flow instability appeared in both CR and RTR samples, which has been previously recognized by GANG et al [11]. The serrated flows of the curves of CR and RTR samples are magnified in Fig. 1(a), where the CR sample has higher strength and larger flow serration than RTR sample. The PLC

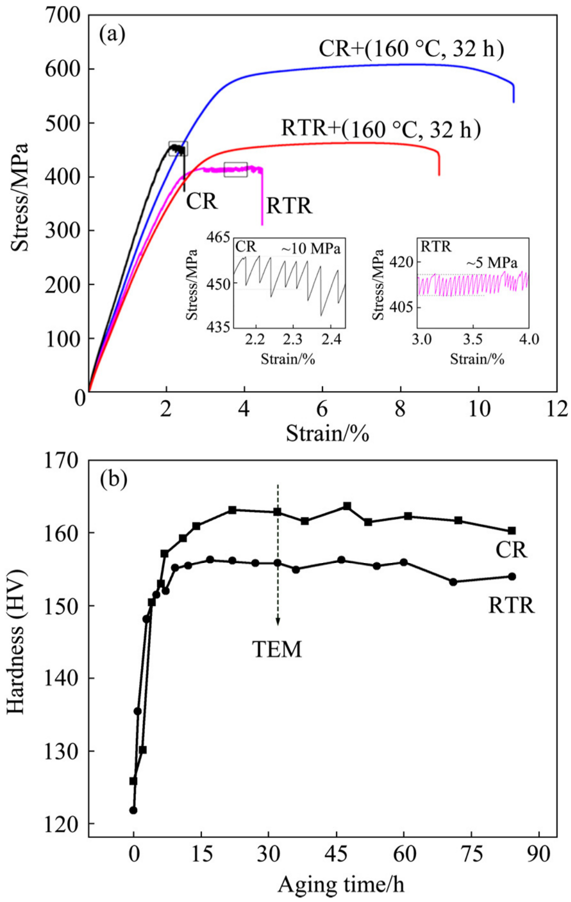

Fig. 1 Engineering stress−strain curves of CR, RTR, CR + peak-aged and RTR + peak-aged samples (Two small regions of the curves of CR and RTR samples are magnified to more clearly reveal the serrations) (a) and Vickers hardness of CR and RTR samples vs aging time (1−84 h) at 160 °C (To characterize the difference of microstructure features of peak-aged CR and RTR samples, CR and RTR samples aged at 160 °C for 32 h were examined using TEM) (b)