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Original Research Article

Influence of heat treatment on the formation of ultrafine-grained structure of Al–Li alloys processed by SPD

K. Rodak [a,*], A. Urbańczyk-Gucwa [a], M. Jabłońska [a], J. Pawlicki [b], J. Mizera [c]

[a] Institute of Materials Science, Silesian University of Technology, Krasińskiego 8, 40-019 Katowice, Poland
[b] Chair of Automotive Vehicle Construction, Silesian University of Technology, Krasińskiego 8, 40-019 Katowice, Poland
[c] Materials Science and Engineering Faculty, Warsaw University of Technology, Woloska 141, 02-507 Warsaw, Poland

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ABSTRACT

In this study, binary Al–2.3wt%Li alloy, ternary Al–2.2wt%Li–0.1wt%Zr alloy and quaternary Al–2.2wt%Li–0.1wt%Zr–1.2wt%Cu alloy in the solution treated condition and additionally in aging condition were severely plastically deformed by rolling with cyclic movement of rolls (RCMR) method to produce ultrafine grained structure. Scanning transmission electron microscopy (STEM), scanning electron microscopy with EBSD detector (SEM/EBSD) were used for microstructural characterization and hardness test for a preliminary assessment of mechanical properties. The results shows, that the combination of aging treatments with RCMR deformation can effectively increase the hardness of Al–Li alloys. Second particles hinders the annihilation of dislocations in Al matrix during deformation leading to an increase of dislocation density. Significant amount of nanometric second particles in refined structure to ultrafine scale especially in Al–2.2wt%Li–0.1wt%Zr–1.2wt%Cu alloy effectively prevents the formation of high angle boundaries.

1. Introduction

Al–Li alloys are important group of materials, widely used for demanding applications [1,2]. The high mechanical properties and low densities of Al–Li alloys make them particularly interesting for aerospace applications due to their superior specific strength, modulus, and good cryogenic toughness properties [3,4]. From literature it is known, that addition of lithium to aluminum reduces the density by about 3%, and increases the elastic modulus by about 6% [5,6]. The metastable δ′ (Al_3Li) phase formed during aging of supersaturated solid solution contributing to increase in strength of Al–0.7wt%Li and Al–1.6wt%Li [7]. The shareable nature of the δ′ particles results in strain localization which leads to premature failure of these alloy [6,8]. A small addition (0.1%) of zirconium results in grain size control and the formation of dispersoid particles which have a retarding influence on recrystallization [2]. In Al–2.2wt% Li–0.1wt%Zr, Al–2.2wt%Li–0.1wt%Zr–1.2wt%Cu alloy and Al–2.3wt%Li–0.12wt%Zr–1.2wt%Cu–0.7%Mg alloy are produced highly stable, spherical Al_3Zr particles during heat treatment. Addition of copper in Al–Cu–Li, Al–Li–Cu–Mg, Al–Li–Zr–Cu

* Corresponding author.
E-mail address: kinga.rodak@polsl.pl (K. Rodak).
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systems leads to the formation of new precipitating $T_1(Al_2LiCu)$ phase [2,4,6,7].

The high mechanical properties of Al–Li alloy comparing to pure aluminum is achieved thanks to precipitation strengthening, but their properties may be improved by grain refinement to ultrametric scale. Improving of the material properties by using severe plastic deformation method (SPD) has been investigated in many papers [9–12]. For example, in the case of commercial Al subjected to multi-axial compression [12] and for polycrystalline Cu subjected to compression with oscillatory torsion [10], the mechanical properties are about two times higher compared with initial state.

Many of the SPD processes are well known in literature and are commonly available.

Several noble techniques have been developed for creating tapes and strips products among which are: Constrained groove pressing (CGP), and accumulative roll-bonding (ARB). According with literature CGP and ARB techniques has several advantages over other SPD processes because: (1) it does not need forming facilities with large load capacity and expensive dies, (2) the amount of material to be produced is not limited. These methods are appropriated to manufacture nanocrystalline and ultrafine grained sheets and plates. Rolling with cyclic movement of rolls method (RCMR) is a severe plastic deformation process that allows large deformations. This original method has been patented at Silesian University of Technology, Faculty of Materials Engineering and Metallurgy in Poland [13]. The rolled strip is deformed by reducing the height and additionally is affected by movement of the material layers in a direction perpendicular to the main direction of rolling. By repeating this procedure, very high strains have been introduced into material and significant structural refinements has been achieved [14].

The use of new severe plastic deformation method to improve the properties of alloy through grain refinement it is commercial interest in the development of aluminum lithium alloys. Proposed in this article RCMR method for refining of Al–Li alloys structure is not known in literature, for this reason the present paper describes some aspects of influence of heat treatment conditions of Al–Li alloys on the formation of ultrafine grained structure (UFG) structure and mechanical properties after rolling with cyclic movement of rolls. And should been provide additional information on the understanding of the behavior of this alloys during RCMR process.

2. Research methodology

The following alloys as: Al–2.3wt%Li, Al–2.2wt%Li–0.1wt%Zr and Al–2.2wt%Li–0.1wt%Zr–1.2wt%Cu with dimension $8 \times 8 \times 60$ were prepared through:

1) solution treatment followed by quenching into iced water at 500 °C for 1 h (S state)
2) solution and aging treatment followed at 200 °C for 12 h (S + A state).

The average grain size of alloys after solution was 300 μm. During aging treatment form dispersoid particles as shown in Fig. 1.

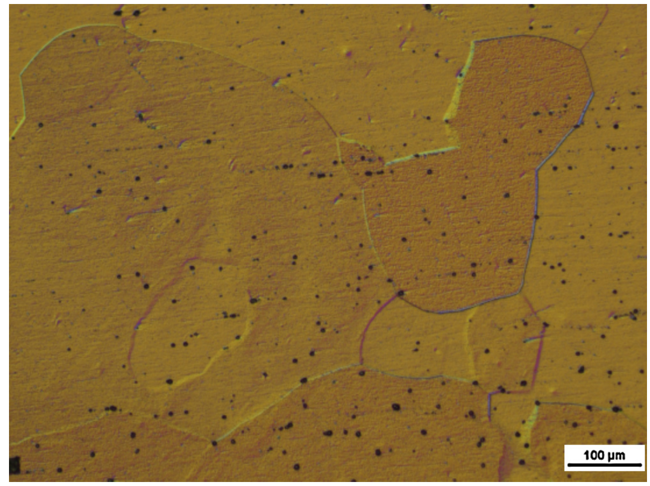

Fig. 1 – Precipitates in Al–2.2wt%Li–0.1wt%Zr–1.2wt%Cu alloy after aging.

Specimens with two distinctly different initial conditions were deformed by using RCMR method. The samples in solution condition and next deformed by RCMR referred to as S + RCMR state and samples in solution and aging state and next deformed by RCMR referred to as S + A + RCMR.

Fig. 2 is a schematic presentation of the RCMR set up. Rolling mill consists of two working rolls, the power unit and mechanism for cyclic movement of the rolls - transverse to the rolling direction. During the RCMR processing, the rolls rotate

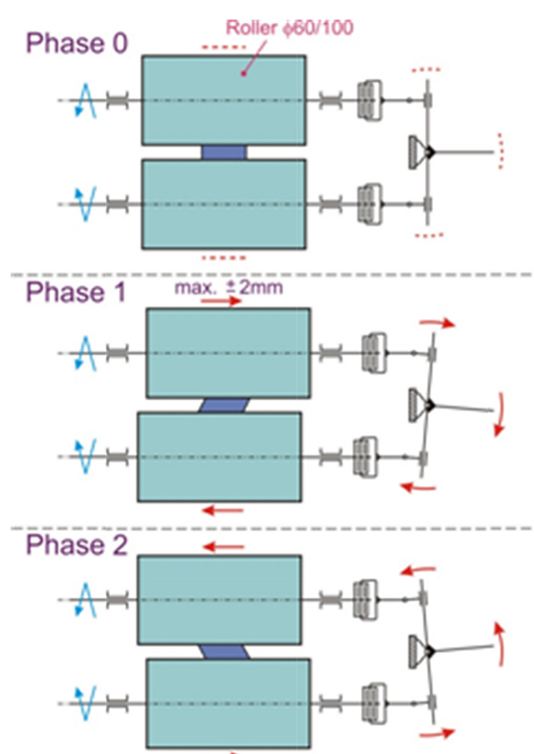

Fig. 2 – Scheme of RCMR method.