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Age-hardening of an Al–Li–Cu–Mg alloy (2091) processed by high-pressure torsion

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ABSTRACT

This research presents the successful strengthening of an Al–Li–Cu–Mg alloy (2091) through the simultaneous use of grain refinement and age hardening. Following solid–solution treatment, the alloy was processed by high-pressure torsion (HPT) at room temperature and the grain size was refined to ~140 nm. The Vickers microhardness increased with increasing strain, and saturated to a constant level of 225 Hv. A further increase in the hardness to ~275 Hv was achieved by aging the HPT-processed alloy at 100 °C and 150 °C. Bending tests for the samples treated using the peak aging conditions demonstrated that the stress was significantly increased while considerable ductility was retained. Transmission electron microscopy revealed that the small grains are well retained even after prolonged aging, and the precipitation of fine δ′ particles occurred within the small grains, which confirms that simultaneous strengthening from grain refinement and age hardening is feasible in this alloy.

1. Introduction

Lithium (Li), which has a density of 0.53 g/cm^3, is the lightest metal found in nature, and the addition of lithium to aluminum significantly reduces the density of high strength alloys [1]. Al–Li alloys are strengthened by aging treatment through a fine dispersion of precipitate particles. The precipitation in the Al–Li alloys occurs in a two-step process as follows [2]; however, the first process is far more important for the strengthening of the alloy.

$$\alpha\,(\text{super saturated solid solution}) \rightarrow \delta'\,(Al_3Li) \rightarrow \delta\,(AlLi)$$

Grain refinement is also an important technique that is utilized to increase the strength of metallic materials. Approximately 2 decades ago, the severe plastic deformation (SPD) process was shown to be an effective method for grain refinement, resulting in grains that were typically on the submicrometer and/or nanometer scale [3]. Although several SPD methods are available, the process of high-pressure torsion (HPT) produces finer grain sizes than the other methods [4]. However, it is generally difficult to achieve the combined effects of both grain refinement and the fine dispersion of precipitates. This difficulty arises in practice because grain refinement to the submicrometer range is not easy in alloys with supersaturated conditions using conventional thermomechanical treatment. Provided that supersaturation is achieved within an ultrafine-grain alloy, it is also important to create fine precipitations within the fine grains by subsequent aging while keeping the small grain size.

There are a few reports concerning the combined effects of grain refinement and fine precipitation in alloys that can be age-hardened [5–7]. The objective of this research is to investigate the possibility of simultaneously combining the effects of grain refinement and fine precipitation in an alloy of Al–Li–Cu–Mg (2091), which is well known to be age-hardenable [8–11]. HPT [12] is adopted as a technique for grain refinement and samples are aged for various times and temperatures because it is applicable to many metallic materials without heating processes [13].

2. Experimental materials and procedures

This study used a cold-rolled sheet of a 2091 aluminum alloy (2.09 wt% Li; 1.99 wt% Cu; 1.55 wt% Mg; 0.12 wt% Zr; 0.03 wt% Si; 0.05 wt% Fe; 0.03 wt% Ti with balance of Al) with a 1.6 mm thickness.

Disks with a 10 mm diameter were cut from the sheet using an electrical discharge machine (EDM). The disks were solution treated at 505 °C for 30 min followed by quenching in cold water. The treated disks were then ground to a thickness of 0.85 mm and subjected to HPT under an applied pressure of 6 GPa for 1/4, 1/3,

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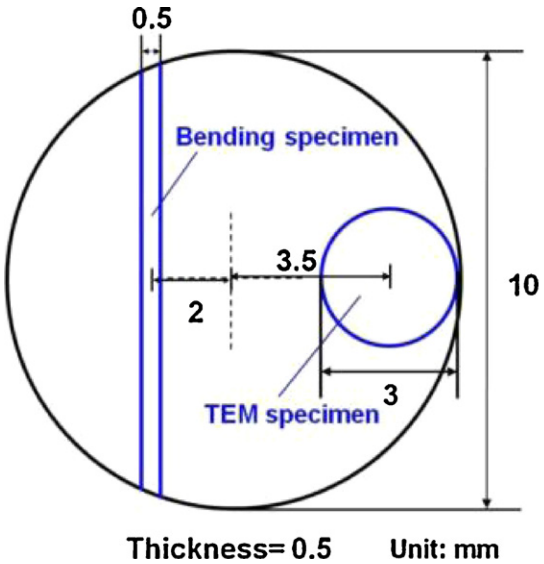

Fig. 1. Dimensions of HPT disk sample showing positions for TEM and bending specimens.

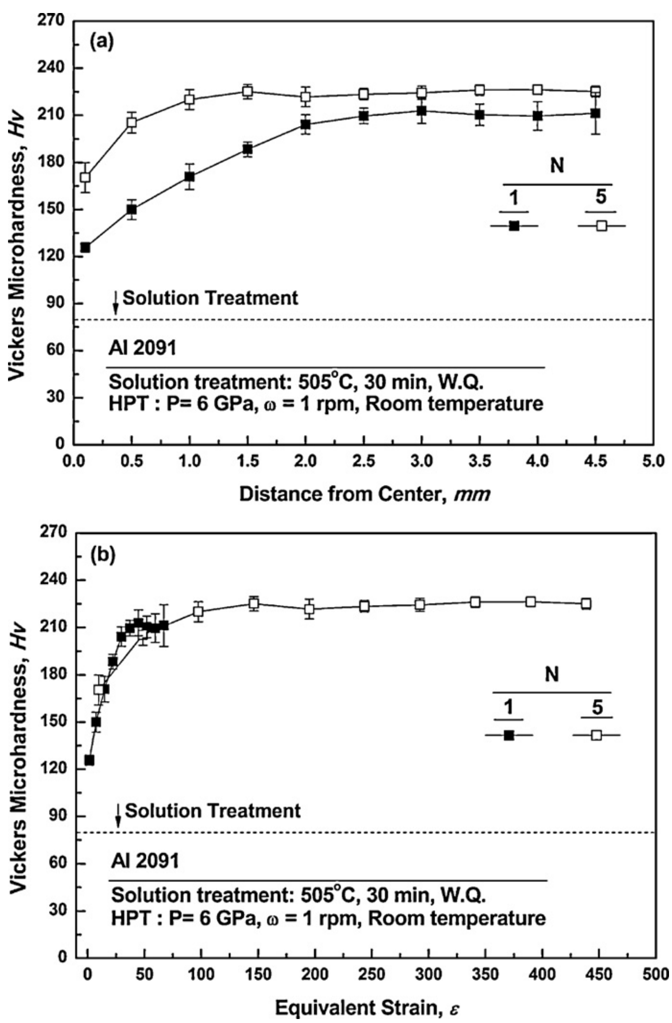

Fig. 2. Vickers microhardness plotted (a) against distance from disk center and (b) against equivalent strain for 2091 alloy after HPT processing under 6 GPa for 1 and 5 revolutions.

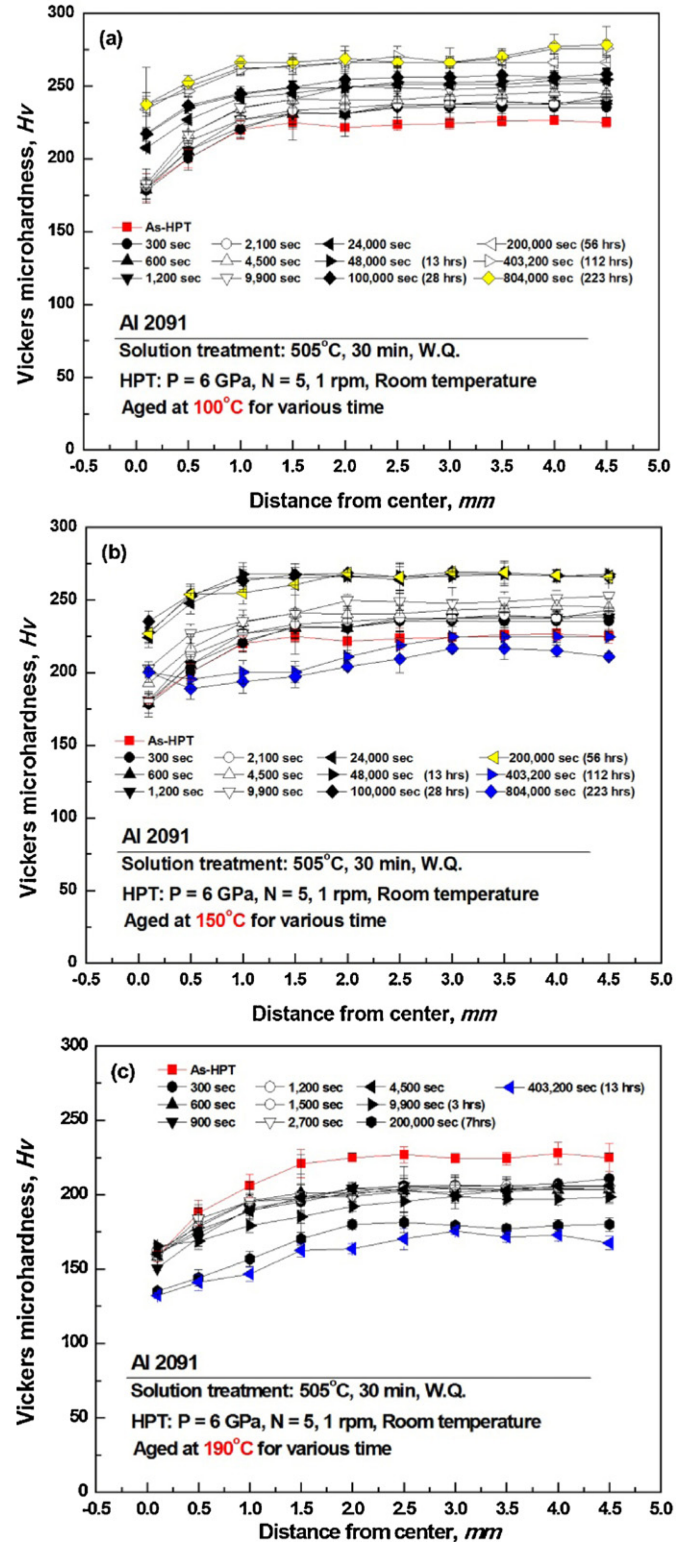

Fig. 3. Hardness variation with distance from disk center after processing by HPT and aging at (a) 100 °C, (b) 150 °C for periods up to 804 ks (223 h) and (c) 190 °C for periods up to 403 ks (13 h).

2 or 5 revolutions with a rotation speed of 1 rpm at room temperature. The upper and lower rotation axis alignment was adjusted to within ±0.01 mm for the HPT process. The slippage between the disk and the anvils was measured after 1/4 revolution using the previously described procedure [14]. Aging treatments were performed on the HPT-processed alloys at 100 °C, 150 °C and 190 °C for