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Grain structure effect on quench sensitivity of Al−Zn−Mg−Cu−Cr alloy

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Abstract: The effect of grain structure on quench sensitivity of an Al−Zn−Mg−Cu−Cr alloy was investigated by hardness testing, optical microscopy, X-ray diffraction, scanning electron microscopy, transmission electron microscopy and scanning transmission electron microscopy. The results show that with the decrease of quenching rate from 960 °C/s to 2 °C/s, the hardness after aging is decreased by about 33% for the homogenized and solution heat treated alloy (H-alloy) with large equiaxed grains and about 43% for the extruded and solution heat treated alloy (E-alloy) with elongated grains and subgrains. Cr-containing dispersoids make contribution to about 33% decrement in hardness of the H-alloy due to slow quenching; while in the E-alloy, the amount of (sub) grain boundaries is increased by about one order of magnitude, which leads to a further 10% decrement in hardness due to slow quenching and therefore higher quench sensitivity.

Key words: grain structure; Al−Zn−Mg−Cu−Cr alloy; dispersoids; quench sensitivity

1 Introduction

Al−Zn−Mg−Cu alloys are often quench sensitive, i.e., their hardening capability by aging decreases after slow quenching from solution heat treatment temperature. Quench sensitivity receives great influence from chemical compositions, such as main alloying elements Zn, Mg, Cu [1−4], and trace elements like Cr, Mn, Zr and Sc [5−7]. The addition of trace elements gives rise to the formation of fine dispersoids, which can inhibit recrystallization and grain growth and therefore improve properties remarkably [8−12]. However, the presence of these dispersoids may increase quench sensitivity because coarse quench-induced particles often form on them preferentially during slow quenching [2,3,13]. As a result, fewer η' hardening precipitates can be obtained after subsequent aging, which leads to lower hardness and strength. Al_3Zr dispersoids are often small and coherent with Al matrix, and therefore lead to low quench sensitivity; however, they may lose coherency with Al matrix due to recrystallization and become preferential nucleation sites for quench-induced phase, and consequently increase quench sensitivity [14,15]. By contrast, Cr-containing dispersoids often lead to very high quench sensitivity [3,7], because they are large and incoherent with Al matrix and act as effective heterogeneous nucleation sites.

Apart from dispersoids, grain structure can have great influence on quench sensitivity. Subgrain boundaries and especially grain boundaries have high interfacial energy, and thus there is a strong tendency for heterogeneous precipitation to occur at them during slow quenching [6,13]; consequently, quench sensitivity is increased [16,17]. An increased number and mis-orientation angle of subgrain boundaries can give rise to higher quench sensitivity of Al−Zn−Mg−Cu alloys such as 7055 and 7050 aluminum alloys [17,18]. The degree of recrystallization has effect on quench sensitivity. For instance, DORWARD and BEERNTSEN [19] reported that with recrystallization fraction increasing from 15% to 80% in 7050 aluminum alloy, the strength reduction

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due to slow quenching increased from 6% to 12%. However, the effect of grain structure on quench sensitivity relative to hardness and strength was not fully understood because of the complex microstructure due to partial recrystallization in these alloys. In the Zr-containing alloys, the occurrence of recrystallization changes the number of (sub)grain boundaries and characteristics of Al_3Zr dispersoids as well. During slow quenching, heterogeneous precipitation can form both at (sub)grain boundaries and on Zr-containing dispersoids located in the recrystallized and unrecrystallized regions [17,18]. Therefore, it is difficult to distinguish their respective contribution to quench sensitivity.

In this work, an attempt has been made to further understand grain structure effect on quench sensitivity by using a fully homogenized ingot and an extruded rod of Al−Zn−Mg−Cu−Cr 7075 aluminum alloy. The ingot and rod have the same chemical compositions but very different grain structure. It is well known that the interface between Cr-containing dispersoids and Al matrix is unlikely to change much after recrystallization [7], so it is probably to distinguish the contribution of Cr-containing dispersoids from that of grain structure to quench sensitivity.

2 Experimental

The studied materials were cut from a fully homogenized ingot and an extruded rod of high strength aluminum alloy with the chemical composition of Al−5.74Zn−2.74Mg−1.75Cu−0.27Cr−0.15Fe−0.086Si (mass fraction, %). After solution heat treatment at 470 °C for 1 h, the specimens were subjected to end quenching test, room temperature (RT) water quenching and boiling water quenching to obtain different quenching rates. Thermocouples were inserted into the specimens to record time−temperature data to estimate quenching rate. End quenching test led to quenching rates from 2 °C/s to 11 °C/s through the critical temperature range of 415−185 °C; while RT water and boiling water quenching led to a high quenching rate of about 960 °C/s and 100 °C/s, respectively. After quenching, the specimens were aged at 120 °C for 24 h in an air furnace. For convenience, the homogenized and solution heat treated alloy was named H-alloy, and the extruded and solution heat treated alloy was named E-alloy.

The Vickers hardness testing was performed on the aged specimens with a load of 3 kg, and five measurements were made to obtain an average value. Specimens for grain structure examination were ground, polished and etched by Graff Sargent's reagent (1 mL HF, 16 mL HNO_3, 3 g CrO_3 and 83 mL distilled water), and then observed by a MX3000 microscope. Second phase in the as-quenched specimens was examined by X-ray diffraction (XRD) performed on a Rigaku D/Max 2500 diffractometer. Some aged specimens were examined using FEI Quanta−200 scanning electron microscopy (SEM), JEM−2100F transmission electron microscopy (TEM) and Tecnai G^2 F20 S-Twin scanning transmission electron microscopy (STEM). Specimens for SEM examination were ground and polished. Specimens for TEM and STEM examination were thinned to about 0.08 mm, electro-chemically polished using solution of 20% HNO_3 + 80% CH_3OH below −20 °C .

3 Results

3.1 Hardness curves

The hardness of the aged specimens is plotted as a function of quenching rate in Fig. 1(a). The shape of hardness curves is quite different for the H-alloy and the E-alloy. For the H-alloy, the hardness does not change above about 10 °C/s, but drops rapidly at lower quenching rate; while for the E-alloy, the hardness decreases slightly in the range of 1000−100 °C/s and then more rapidly with a further decrease of quenching rate. Above about 100 °C/s, the E-alloy exhibits slightly

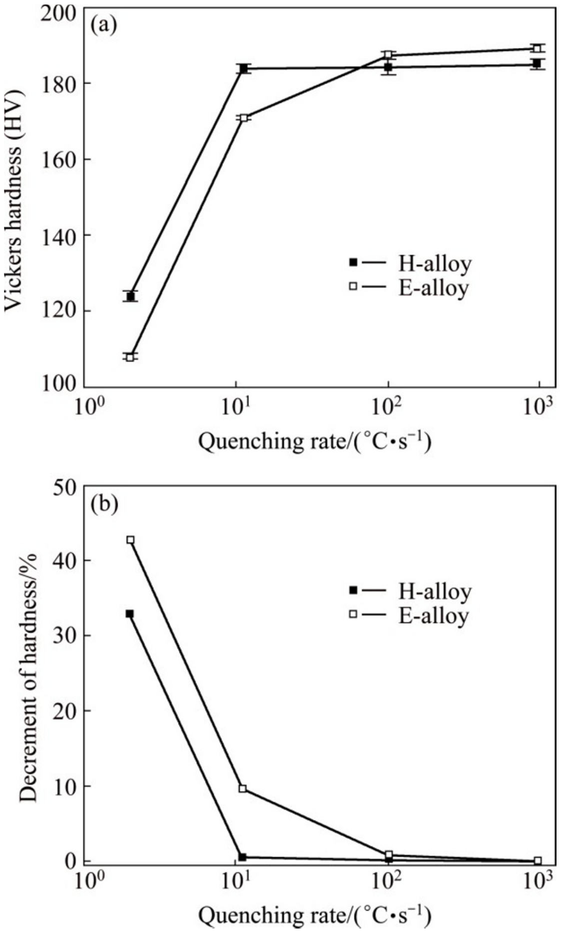

Fig. 1 Effect of quenching rate on hardness (a) and decrement of hardness (b) of aged specimens