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The second phase particles and mechanical properties of 2124 aluminum alloy processed by accumulative back extrusion

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ABSTRACT

An age-hardenable 2124 aluminum alloy was severely deformed by accumulative back extrusion (ABE) method up to three passes at 100 and 200 °C. The characteristics of the second phase particles were studied using scanning electron microscopy. The results indicated that the size of primary particles had been reduced after the first ABE pass where even much finer particles was obtained as the successive passes were applied. In addition, the secondary particles were fragmented into finer pieces after ABE at 100 °C, whereas a particle coarsening was realized as the deformation temperature rose to 200 °C. The latter was attributed to the Ostwald ripening mechanism. However, the volume fraction of secondary particles was significantly decreased after three ABE passes at 200 °C due to the occurrence of deformation induced dissolution. Additionally, the tensile properties of the processed materials were measured utilizing a miniaturized tensile testing method. The results were justified considering the evolution of the second phase particles.

1. Introduction

The severe plastic deformation (SPD) techniques are now widely applied to generate ultrafine-grained (UFG) microstructures in metals and alloys [1]. UFG materials are receiving more and more interest due to their potential applications in diversified industries [2]. Generally, it is believed that processing by SPD introduces a high density of dislocations in order to induce substantial grain refinement leading to the production of advanced materials holding superior physical and mechanical properties [3].

The UFG structure possesses the capability of increasing the tensile strength through the Hall–Petch relationship at low temperatures [4,5]. When it come to the age-hardenable alloys, however, the influence of second phase characteristics on the final mechanical properties must be taken into consideration as well as the grain size [6,7]. This is of great importance since the characteristics of second phase such as its size, distribution and morphology may significantly be affected by thermomechanical parameters of any SPD process [8]. For instance, Kim et al. [9] achieved high strength and high ductility in an Mg–Al–Zn alloy using the synergetic effects of severe plastic deformation and precipitation hardening. Shin and Park [10], investigated the effect of grain refinement through SPD together with utilization of second phase particles on the properties of low carbon ferrite/pearlite and dual phase ferrite/martensite steels.

In the case of heat treatable aluminum alloys, a review of published reports indicates that the influence of SPD processing on the mechanical properties is relatively complex [8,11,12]. Depending on the specific alloy, the effect could be positive or negative. The reason for the possible degradation of properties is that the effects of structural strengthening due to UFG structure cannot surpass the precipitation hardening effect. For instance, the results obtained after equal channel angular pressing (ECAP) of a low-alloyed aluminum 6063 showed that the size of β'' second phase particles decreased into nano-scale due to the dynamic breaking-up during ECAP [8]. Moreover, it was discussed that the β'' particles may also nucleate around or at dislocations, where the dynamic aging induced by ECAP resulted in a much finer precipitates than that of observed after static aging [8]. However, the recent results on an ECAPed 6060 aluminum alloy demonstrates that the imposed shear deformation may reduce the volume fraction of secondary particles due to the partial dissolution and transformation of the particles [11]. The latter may adversely influence the grain refinement strengthening.

The 2xxx series of aluminum alloys are used in aircraft structures and automotive bodies owing to their good combination of strength and toughness [13,14]. Nevertheless, it has been reported that 2xxx alloys show such a low ductility that the cracks are easily developed after a single ECAP pass at low temperatures [15].

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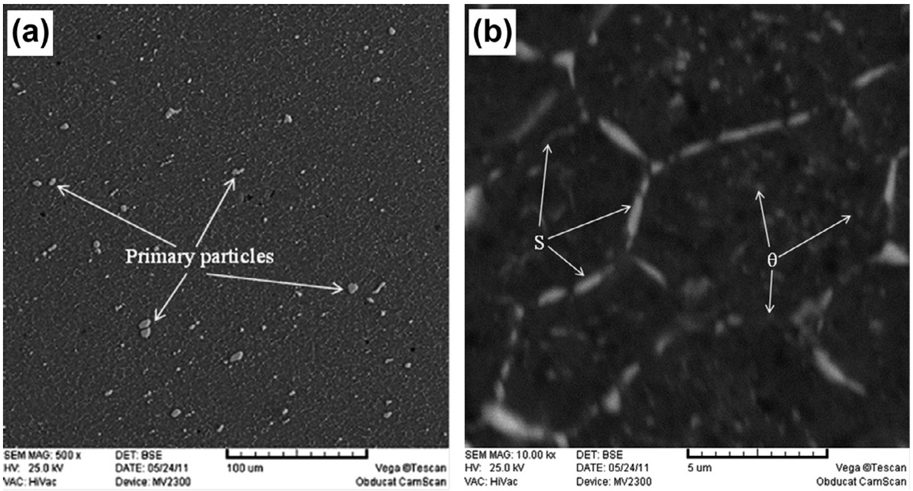

Fig. 1. The SEM micrographs of the experimental alloy initial microstructure.

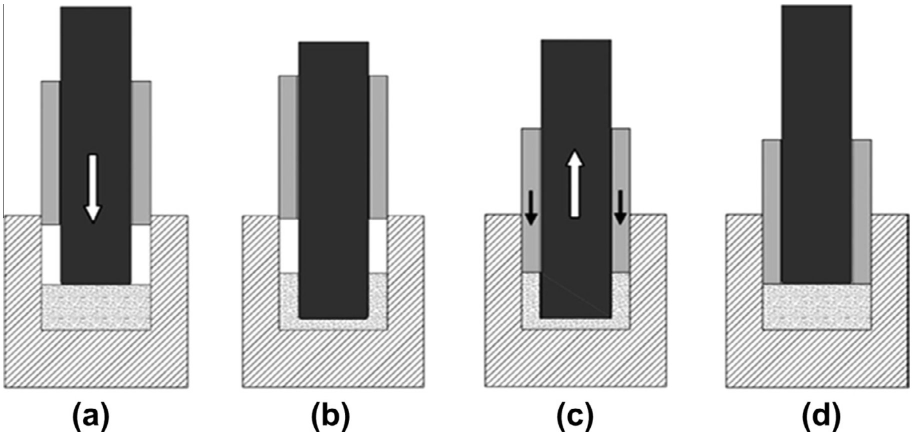

Fig. 2. The schematic illustration of ABE process: (a) initial state, (b) step one, back extrusion, (c) step two, compression back and (d) end of one pass processing [17].

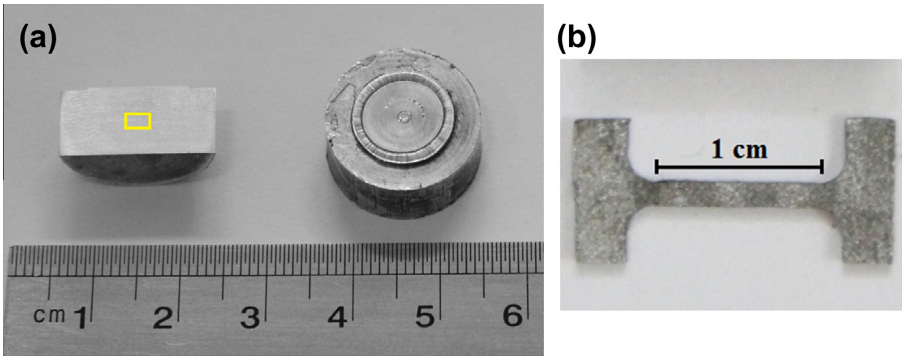

Fig. 3. (a) An ABEed workpiece and its cross section parallel to extrusion axis. The yellow rectangle shows the area which was examined by SEM and (b) a miniaturized tensile specimen extracted from the ABEed workpieces.

However, it has been shown that by applying a high back-pressure, a significant grain refinement could be introduced in 2124 alloy via ECAP [16]. Moreover, ECAP processing at high temperatures led to the formation of fine grained structure in a 2219 aluminum alloy, where the fraction of high angle boundaries started to increase after third pass [17]. However, quite rare researches may be found in the literature dealing with the evolution of second phase particles during SPD processing of 2xxx aluminum series.

Recently, a new continuous SPD method called accumulative back extrusion (ABE) was innovated and introduced by two of present authors [18]. It has been shown that this process is capable of significant grain refinement in pure copper [19] as well as AZ81