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Short Communication

Modeling of microstructure and mechanical behavior of ultra fine grained aluminum produced by accumulative roll-bonding

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ABSTRACT

Mechanical behavior of AA1100 aluminum alloy processed by accumulative roll-bonding was modeled on the basis of a generalized three-dimensional dislocation-density-based two-phase composite model. The simulated yield stress and cell size were compared with the experimental data, obtained by accumulative roll-bonding after several passes. A good agreement between experimental and simulated results was obtained. The results showed that both yield stress and average cell size of the ultra fine grained materials, produced by accumulative roll-bonding, can be simulated using a dislocation-density-based two-phase model. Moreover, dynamic recovery in cell interior was governed by cross slip, while climb processes were responsible for that in cell walls.

1. Introduction

Severe plastic deformation (SPD) processing has been widely used for producing bulk ultra fine grained materials, having grain sizes in the sub-micrometer or nanometer range [1–3]. Several SPD processing techniques, such as accumulative roll-bonding (ARB) [4], cyclic extrusion and compression (CEC) [5], multi-directional forging (MDF) [6], equal channel angular pressing (ECAP) [7], and high pressure torsion (HPT) [8] have been developed and successfully utilized for producing sub-micron materials. Among these SPD techniques, ARB has unique characteristics. This process can be performed by the conventional rolling mills, and thus, it is capable of producing ultra fine grain sheets in a mass production scale with low price [4]. Accumulative roll-bonding involves securely stacking two sheets of the same materials after proper surface treatments. These treatments, may involve degreasing and surface contaminant removal with the use of steel wire brush. After surface treatment, the stacked sheets are usually preheated and rolled to a reduction of 50%. The rolled sheet is cut into two equal halves and this sequence is repeated as many times as necessary [4,9,10].

Grain refinement by severe plastic deformation is often related to the evolution of subgrain or dislocation cell boundaries [11], although the mechanisms of grain refinement are not fully understood. Tsuji et al. reported that the formation process of ultra fine grains in ARB is a continuous recrystallization phenomenon characterized by grain subdivision, recovery and even short range grain boundary migration to form ultra fine grains or subgrains [9]. Lee et al. have found that shear strain plays a decisive role in forming ultra fine grains during accumulative roll-bonding [12]. Based on the studies of Saito et al. [4], high shear strains are produced in the specimen surface because of the friction between roll and the specimen surface. This shear strain increases the imposed strain and promotes grain refinement. Moreover, in ARB process the surface layers shift inside the specimen by repeating each pass. Therefore, the shear strains affect the whole thickness of the specimen and make a complicated shear strain distribution which may assist grain refinement.

Estrin et al. [13] proposed a two-dimensional dislocation cell structure model which has been recently generalized to three-dimensional states [14]. The model takes into account strain rate sensitivity and evolution of cell structure [15] and can predict the strain hardening of dislocation cell-forming materials during all stages of hardening; from stage II up to the end of stage V. There have been several attempts to predict stress–strain behavior and microstructure produced by some SPD processes by the use of the dislocation cell structure model. McKenzie et al. [16] predicted the behavior of a wrought AA6016 alloy during ECAP up to 16 passes using a two-phase composite model, and showed that the model can predict the evolution of cell wall and cell interior dislocation densities very well. They also found that these parameters are functions of accumulated plastic strain as well as the level of hydrostatic pressure. Hosseini and Kazeminezhad [17–19] utilized the dislocation-density-based model for simulating the ECAP process and found that using this model, different microstructures produced by ECAP with different die shapes can be predicted fairly well. They also investigated deformation behavior of Cu, Al and Ta through ECAP and showed that the dislocation-density-based model can simulate the behavior of these materials well. The dislocation-density-based model has also been applied to the case of HPT, where a good correlation between simulated and

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