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Nano-grained copper strip produced by accumulative roll bonding process

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Abstract

Accumulative roll bonding (ARB) process is a severe plastic deformation (SPD) process that has been used for pure copper (99.9%). The ARB process up to 8 cycles was performed at ambient temperature under unlubricated conditions. Microstructural characterizations were done by transmission electron microscopy (TEM) and electron backscattered diffraction (EBSD). It was found that continuous recrystallization resulted in microstructure covered with small recrystallized grains with an average diameter below 100 nm. The tensile strength and hardness of the ARB processed copper has become two times higher than initial value. On the other hand, the elongation dropped abruptly at the first cycle and then increased slightly. Strengthening in ARB processed copper may be attributed to strain hardening and grain refinement. In order to clarify the failure mode, fracture surfaces after tensile tests were observed by scanning electron microscopy (SEM). Observations revealed that failure mode in ARB processed copper is shear ductile rupture with elongated small dimples.

Keywords: Nano-grained copper; Accumulative roll bonding; Severe plastic deformation

1. Introduction

In recent years research on the processing, structure and mechanical behavior of nanocrystalline ($d < 100$ nm) and ultra-fine grained ($100\text{ nm} < d < 1\ \mu\text{m}$) materials has thrived. Two basic and complementary approaches have been developed for the synthesis of ultra fine grain (UFG) materials and these are known as the "bottom-up" and the "top-down" approaches. In the "bottom-up" approach, UFG materials are fabricated by assembling individual atoms or by consolidating nanoparticulate solids. Examples of these techniques include inert gas condensation, electrodeposition, ball milling with subsequent consolidation, etc. In practice, these techniques are often limited to the production of fairly small samples. The "top-down" approach is different because it is dependent upon taking a bulk solid with a relatively coarse grain size and processing the solid to produce a UFG microstructure through heavy straining or shock loading. This approach avoids the small product sizes and the contamination, which are inherent features of materials produced using the "bottom-up" approach. The "top-down" approach includes severe plastic deformation (SPD) processing techniques [1,2].

SPD can be explained as deformation to large strains below recrystallization temperature without intermediate thermal treatments that can result in UFG structures [3]. A number of techniques, such as equal channel angular pressing (ECAP) [2,4], cyclic extrusion-compression (CEC) [5,6], high pressure torsion (HPT) [7,8], repetitive corrugation straightening (RCS) [9,10], hydrostatic extrusion [11] and accumulative roll bonding (ARB) have been developed. Very high strains have been successfully obtained by means of these methods in many different metals and alloys, and significant structural refinement has been obtained. Among these processes, the ARB process has been successfully applied to various kinds of metallic materials. The advantage of this process is its applicability to large bulky materials [12–14].

The accumulative roll bonding (ARB) is a relatively new method of severe plastic deformation proposed by Saito et al. [15]. The basic goal of ARB is to impose an extremely high plastic strain on the material, which results in structural refinement and strength increase without changing specimen dimensions.

In accumulative roll bonding, the surfaces of the strips to be joined are roughened and cleaned and then stacked. After stacking, the specimen is roll-bonded by rolling. The rolled

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