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Weakening rolling texture in a nanotwinned copper

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ABSTRACT

A randomly oriented copper embedded with nanotwin bundles was prepared by means of dynamic plastic deformation at cryogenic temperature. The subsequent cold rolling at room temperature induced shearing of nanotwin bundles, and resulted in a lamella structure after 90% thickness reduction. The volume fraction of copper-type rolling texture of the rolled nanotwinned copper is about 24.9 ± 4.9 vol%, much less than the rolled coarse-grained ($\sim$76 vol%) and ultrafine grained ones. Detailed microstructure and texture characterizations show that the weaker texture is attributed to the evolution of nanotwin bundles retarding the formation of texture during cold rolling.

1. Introduction

In polycrystalline metals, plastic flow causes reorientation of the crystal lattices of grains and tends to develop a crystallographic texture. Face centered cubic (f.c.c.) metals with high and medium stacking fault energy (SFE) (e.g. Al, Ni, Cu) deform mainly by homogeneous slip, resulting in formation of the copper-type rolling texture during cold rolling [1–3]. The copper-type rolling texture consists of S {123}⟨634⟩, C (Copper) {112}⟨111⟩ and B (Brass) {110}⟨112⟩ texture components [1,3]. Texture components become stronger with increasing rolling reductions [3]. The strong rolling texture leads to formation of a strong cube recrystallization component after subsequent annealing [4]. Deformation texture components and a stronger cube recrystallization in sheet metals cause plastic anisotropy. For example, the copper-type texture causes a lower yield stress for tensile strain in the direction that is 45° to the rolling direction and the cube texture causes the lowest yield stress with the loading axis oriented at 0° and 90° to the prior rolling direction [5]. In some cases of industrial application, plastic anisotropy is undesirable because it strongly affects formability of sheet metals and causes earing during deep drawing [1,2,5]. In addition, the stronger cube recrystallization texture is harmful to the use of Al-sheets by inducing paint-brushes lines [6]. Therefore, it is necessary to investigate the textural evolution during deformation and find ways to weaken texture for these purposes.

For conventional cold rolled pure metals and alloys with high and medium SFE subjected to a large reduction, formation of strong textures is attributed to homogeneous slip, which can be explained by Taylor model [2,7]. It is known that the two-dimensional nanotwins usually lead to inhomogeneous slip during plastic deformation [8–10]. Furthermore, different deformation modes usually result in different texture evolution modes in the deformed materials. However, few investigations on texture effects of presetting nanotwins were reported due to the difficulty in induction of high density of nanotwins in these materials with high and medium SFEs. In this work, two-dimensional nanotwins in bundles were introduced in bulk Cu samples to study the effects of presetting nanotwins on the evolution of texture during cold rolling. A randomly oriented copper with a large volume fraction of nanotwins was prepared by using dynamic plastic deformation (DPD) at liquid nitrogen temperature (LNT). Much weaker rolling texture is found in this Cu sample after 90% cold rolling in comparison with its coarse-grained (CG) and ultra-fine grained (UFG) counterparts. The effects of nanotwins on the texture evolution under large rolling reductions are discussed.

2. Experimental

Pure Cu with the purity of 99.995 wt% and the grain size of 200 μm is used in this work. The initial samples are cubic in shape with the edge length of 20 mm. The cubic samples were deformed repeatedly along the three orthogonal directions using the DPD setups (the details of DPD setup and processing could be found in Refs. [11,12]) at 77 K. The sides of the cubic sample are designated as A, B, C. The DPD procedure was as follows: the first impact was carried out on face A, giving rise to a true strain of 0.2; after rotating the samples by 90°, the second impact with a strain of 0.2 was carried out on face B; rotating the samples by 90° again,

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the third impact with a strain of 0.2 was carried out on face C. The above procedure was repeated ten times until the cumulative nominal strain reached 6.0. The DPD Cu sample was subjected to subsequently cold rolling (CR) at room temperature (RT) with final impacted face C ‖ normal direction (ND) and face A ‖ rolling direction (RD).

Microstructure observations were conducted on a Leica MPS 30 optical microscope (OM) and a JEOL JEM-2010 transmission electron microscopy (TEM) operated at 200 kV. Microtexture characterization was investigated using a Nova NanoSEM 430 scanning electron microscopy equipped with automatic HKL EBSD software, when two 80 μm × 80 μm maps were taken at a step size of 200 nm. Macrotexture analysis was performed by the Schultz reflection method on a Bruker D8 DISCOVER X-ray diffractometer. Calculated pole figures were obtained by the DIFFRAC plus TEXEVAl software and measured incomplete {200}, {220} and {111} pole figures.

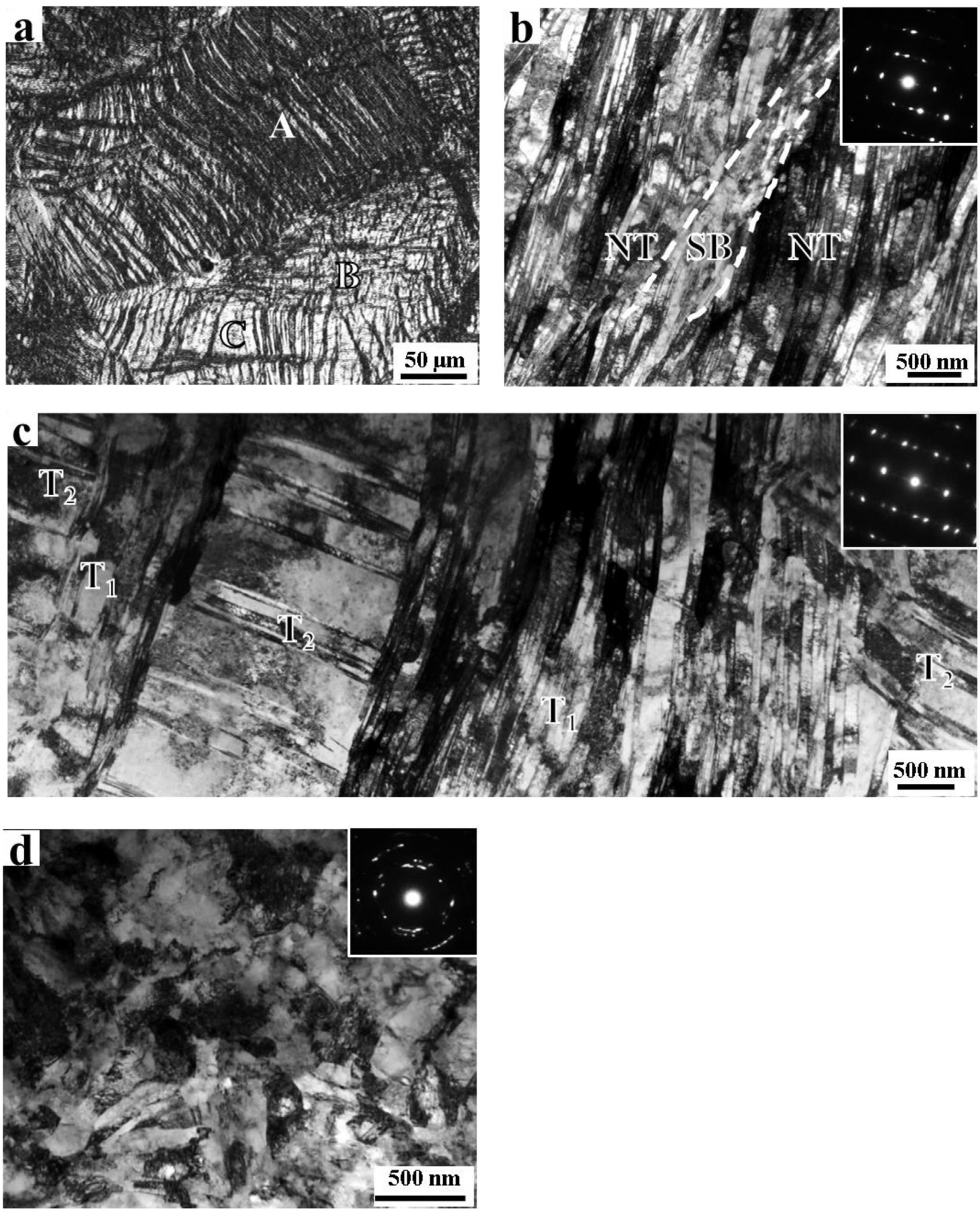

Fig. 1. (a) Cross-sectional metallographic observations of the NT Cu sample. TEM images of (b) a wide twin bundle with a narrow shear band, (c) two sets of twin bundles, and (d) undeveloped dislocation cells. The insets are the SAED patterns.