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Short Communication

Temperature effect on mechanical properties of Cu and Cu alloys

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ABSTRACT

The effect of temperature on the rolling behavior of ultrafine-grained Cu and Cu-alloys with different stacking fault energies (SFEs) is reported. The strength and ductility of the materials increase simultaneously with SFE decreasing by liquid nitrogen temperature (LNT) rolling and room temperature (RT) rolling. Compared with RT-rolled samples with the same low SFE, LNT-rolled ones have a higher strength and better ductility. X-ray diffraction measurements indicate that decreasing SFE leads to a decrease in the average grain size and a concomitant increase in twin density. Special attention should be paid that it is more evident in the LNT-rolled samples. The results show that temperature plays a key role in the rolling process.

1. Introduction

In recent years, ultrafine grained materials with average grain size in the range from 1 nm to 100 nm are referred to as nanocrystalline materials, which have been intensively investigated from researchers for the potential mechanical properties [1]. Of the various methods used to fabricate ultrafine-grained (UFG)/nanostructured (NS) metallic materials, severe plastic deformation (SPD) has been found to be effective [2]. Rolling is the fundamentally used SPD process which is more convenient than equal channel angle pressing (ECAP) and high pressure torsion (HPT) for different working temperature [3].

Stacking fault energy (SFE) is an important material parameter that could affect grain refinement during SPD processing, as SFE determines the probability of cross slip, which along with dislocation climb is possible mechanism of dynamic recovery [4–7]. Zhu et al. [7] and Zhang et al. [8] found that lowering the stacking fault energy simultaneously increases the strength and ductility. Temperature is known to be a primary factor in deformation process. The effect of temperature on deformation behavior and deformation mechanism in the nanotwinned Cu (nt-Cu) samples has been studied in previous studies [9,10]. This study is to systematically investigate the effect of temperature on the ductility of ultrafine-grained (UFG)/nanostructured (NS) Cu–Zn alloys with stacking fault energy decreasing.

2. Experimental details

Cu–10 wt.% Zn and Cu–20 wt.% Zn with SFEs of 36 and 18 mJ/m^2 [8], respectively, were produced by induction vacuum melting. Then, these as-cast and commercial copper (99.9% purity, with SFEs of 80 mJ/m^2) [11] were made into plates with the same thickness of 7.9 mm by hot-rolling. Before cold-rolling, these plates were homogenized at 600 °C, 750 °C and 800 °C for 4 h in argon atmosphere, respectively, which diminished the effect of mechanical processing. The homogenized samples were rolled at room temperature and at liquid nitrogen temperature in multiple passes (~40 μm thickness reduction per pass). For LNT-rolling, the samples were immersed in liquid nitrogen for about 5 min before each rolling pass to cool the samples completely. These plates were cold rolled from 7.9 mm to about 0.5 mm in thickness at LNT and RT.

Microhardness measurements were carried out on a HX-1 Vickers hardness testing machine with a load of 20 g and a loading time of 12 s. The hardness values obtained are averaged from at least 15 indentations for each sample.

Tensile specimens were cut into sheets with gauge length of 15 mm and width of 10 mm, and then were polished into ones with thickness of about 0.5 mm. Uniaxial tensile tests were carried out at room temperature using a Shimazu Universal Tester operating at strain rate of 1.0×10^{-4} s^{-1}.

Quantitative XRD measurements of the rolled samples were performed on an X-ray diffractometer equipped with a Cu target operating at 1.8 kW. A series of θ-2θ scans were performed to provide a record of the XRD patters at room temperature. Pure Cu sheet (99.95% purity) annealed at 400 °C in vacuum was used as an XRD peak-broadening reference for both the grain size and the twin density.

3. Experimental results

Fig. 1 shows the microhardnesses of Cu, Cu–10 wt.% Zn and Cu–20 wt.% Zn at different temperatures. The microhardnesses of all samples increase with SFE decreasing. In addition, the

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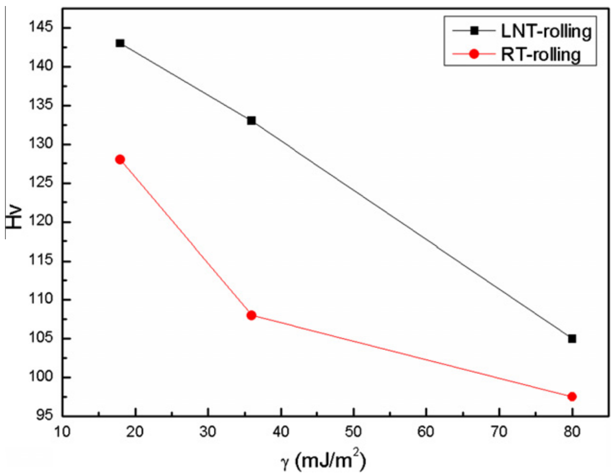

Fig. 1. Vickers microhardness of Cu, Cu–10 wt.% Zn and Cu–20 wt.% Zn vs. stacking fault energy for different temperature.

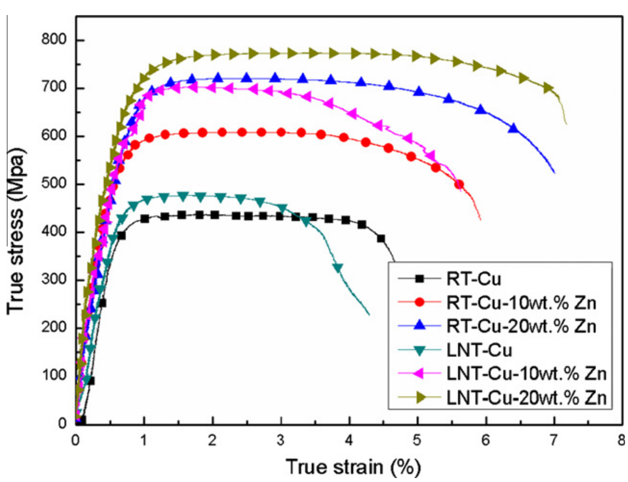

Fig. 2. True stress–strain curves of the UFG Cu, Cu–10 wt.% Zn, and Cu–20 wt.% Zn.

Table 1
Lists of the yield strength ($\sigma_{0.2}$), fracture strength (σ_b), uniform elongation (ε_u) (before necking) and elongation to failure (ε_e) of samples.

Samples	$\sigma_{0.2}$ (Mpa)	σ_b (Mpa)	ε_u (%)	ε_e (%)
Cu				
RT-rolling	417.12	435.75	1.74	4.68
LNT-rolling	445.35	476.79	1.61	4.29
Cu–10 wt.%Zn				
RT-rolling	538.91	609.44	1.90	5.92
LNT-rolling	609.46	702.70	1.78	5.63
Cu–20 wt.%Zn				
RT-rolling	610.00	720.48	2.32	7.01
LNT-rolling	630.18	773.84	3.41	7.18

LNT-rolled samples has a higher Vickers microhardness than RT-rolled samples.

Fig. 2 shows the tensile mechanical behavior of the UFG Cu, Cu–10 wt.% Zn, and Cu–20 wt.% Zn samples. As is shown in Fig. 2, the yield strength and the ultimate strength increase with SFE decreasing (increasing Zn content in the alloy). In addition, the uniform elongation and the elongation to failure increase with SFE decreasing.

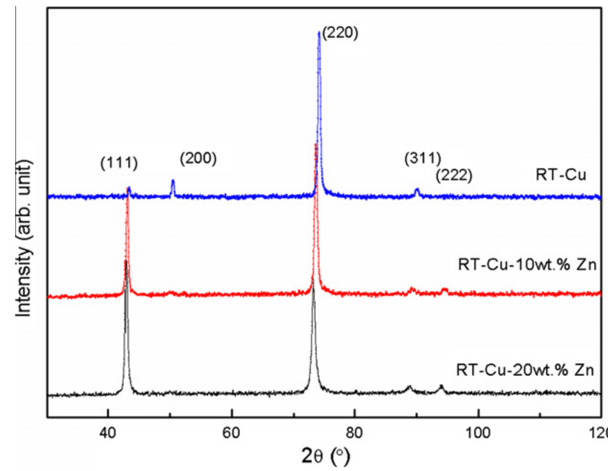

Fig. 3. XRD patterns for LNT-rolling processed copper, Cu–10 wt.% Zn and Cu–30 wt.% Zn.

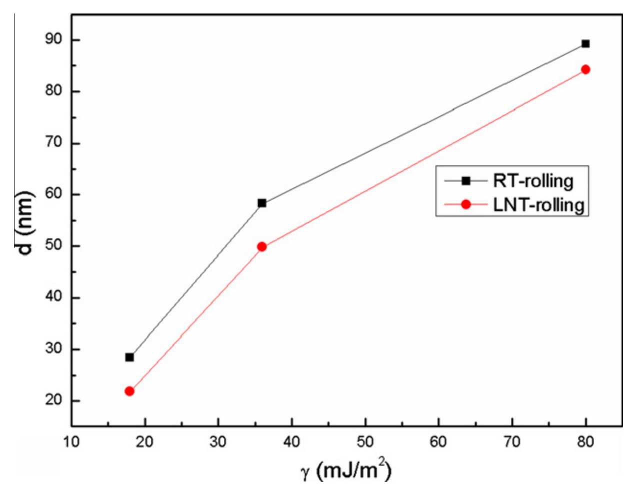

Fig. 4. The XRD-measured average grain sizes vs. stacking fault energy.

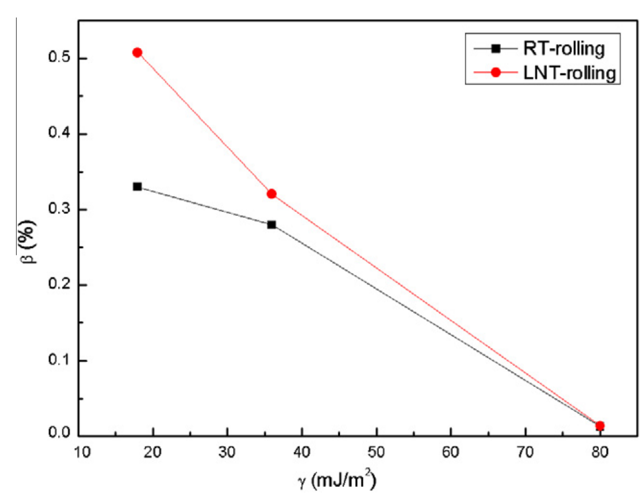

Fig. 5. The XRD-measured the twin density (β) vs. stacking fault energy.

Table 1 shows the tensile properties of the specimens at different temperature. It has been found that the yield strength and the fracture strength are higher at LNT than RT with the same SFE. The