Abstract

Blends of Cu powders and 3 vol.% carbon nanotubes (CNTs) were consolidated by High Pressure Torsion (HPT) at room temperature (RT) and 373 K. An additional sample was consolidated from pure Cu powder. The grain size, the lattice defect densities as well as the hardness of the pure and composite samples were determined [1]. The thermal stability of the HPT processed Cu and Cu-CNT composite microstructures were investigated by differential scanning calorimetry.

1. Sample preparation

Processing steps:
1) Mixing in high-energy mill
2) Pre-compaction by cold isostatic pressing
3) HPT (revolutions: 10, applied pressure: 2.5 GPa)

2. Results

2.1. Phase composition and porosity in the consolidated samples

MCWNTs were not observed in the TEM images taken on the consolidated samples. At the same time, small graphite-like fragments were revealed from the interlayer spacings (about 0.34 nm) determined in the HRTEM images.

Calculated density was obtained as an average of the theoretical densities of Cu (8.95 g/cm³) and graphite (2.16 g/cm³). From the difference between the calculated and measured densities, an average porosity of about 3 vol.% was determined for both specimens Cu-CNT-RT and Cu-CNT-373.

2.2. Hardness of the HPT-processed disks

The hardness increases with increasing the distance from the center and gets saturated already at about 20% of the radius for all the three samples. The saturation hardness values of the Cu-CNT composites are higher than that for the pure Cu sample.

2.3. Microstructure of the samples consolidated by HPT

2.3.1. X-ray line profile analysis

The microstructure of the HPT-processed samples was investigated at the center, half-radius and periphery by X-ray line profile analysis. The line profiles were evaluated by the extended Convolutional Multiple Whole Profile (eCMWP) analysis [2]. This method gives the crystallite size \( \langle \alpha \rangle \), the dislocation density \( \rho_d \) and the twin boundary frequency \( \beta \). The crystallite size is smaller while the dislocation density and the twin boundary frequency are higher at the half-radius and periphery than in the center due to the larger imposed torsional strain. The addition of CNTs increases the defects densities and decreases the crystallite size.

3. Summary

The Cu-CNT composite processed at RT exhibited very high hardness (2.31 GPa) due to the extremely high dislocation density \( 1.14 \times 10^{18} \) m⁻². Due to the pinning effect of CNTs, the dislocation density is about three times larger, while the grain size is about half of that obtained in the sample consolidated from pure Cu powder at RT. Both the high stresses at glide obstacles and the small grain size may contribute to the significant twinning in the composite that was not observed in the pure Cu sample.

The increase of the HPT-processing temperature from RT to 373 K resulted in only a slight increase of the grain size in the Cu-CNT composite while the dislocation density and the twin boundary frequency were reduced to one-half and one-third of the values determined at RT, respectively.

The flow stress obtained experimentally agrees well with the value calculated by the Taylor-formula indicating that the strength in both pure Cu and Cu-CNT composites is determined mainly by the interaction between dislocations. This agreement also reveals that the CNT fragments strengthen the composite rather indirectly via the increase of the dislocation density.

The grain size, the dislocation density and the hardness remained in pure Cu samples by HPT-processing up to high strains are not sensitive to the powder or bulk form of the initial coarse grained material. At the same time, the thermal stability of Cu processed of powder met alurgy is better than bulk Cu processed by severe plastic deformation.

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References
