

ABSTRACT

This PhD work systematically investigated the effects of Ca addition, heat treatment, extrusion-based processing, and severe plastic deformation (SPD) on the microstructure, mechanical properties, and electrical conductivity of Cu-0.7Mg (wt.%) alloy, as well as the development of a density-reduced Cu/Mg composite structure via KoBo extrusion. The addition of 0.1 wt.% Ca to the Cu-0.7Mg (wt.%) alloy promoted the formation of Cu₅Ca intermetallic particles, which were uniformly distributed inside grains as well as along grain boundaries, while also transforming the as-cast columnar microstructure of the binary alloy into an equiaxed structure in the ternary alloy. Consequently, the ternary alloy exhibited a 33% increase in hardness, a 13% increase in yield strength (YS), and a 13% increase in ultimate tensile strength (UTS) compared with the binary alloy, accompanied by a 15% reduction in total elongation (EL) and a 13% decrease in electrical conductivity. Subsequent heat treatment consisting of annealing at 650 °C for 90 min followed by water quenching induced partial spheroidization of the Cu₅Ca particles in the ternary alloy and also enhanced the YS, UTS, and EL of both alloys. SPD processing using the MaxStrain module of the Gleeble thermomechanical simulator resulted in pronounced grain refinement and an increased fraction of high-angle grain boundaries (HAGBs), particularly in the ternary alloy, where the intermetallic particles effectively impeded dislocation motion during deformation. Sequential processing routes involving either forward extrusion at 400 °C or KoBo extrusion at room temperature prior to MaxStrain deformation produced substantially finer grain structures, reducing grain size by 76% and 66%, respectively, compared with MaxStrain processing alone. In the binary alloy, MaxStrain deformation, with or without prior extrusion, increased YS by 251–360% and UTS by 95–169% relative to the annealed condition due to the combined effects of grain refinement and deformation strengthening. Although SPD processing caused minor reductions in electrical conductivity, all processed alloys maintained a favorable balance between strength and conductivity and remained within the range characteristic of high-strength and high-conductivity (HSHC) Cu alloys. In addition, a density-reduced Cu/Mg composite structure (with a density of 7.85 g/cm³) composed of a pure Cu matrix reinforced with continuous pure Mg filaments was successfully fabricated using KoBo extrusion. Microstructural analyses confirmed strong mechanical interfacial bonding without detectable interdiffusion, continuous and defect-free Mg filament distribution, dynamic recovery and recrystallization within the Cu matrix, and the formation of an ultrafine-grained (UFG) Mg microstructure with an average grain size of ~354 nm. These microstructural features contributed to hardness increases of approximately 43% in the Cu matrix and 11% in the Mg filaments. Mechanical properties evaluation revealed an early YS value of $\sim 119 \pm 12$ MPa for the composite structure, which was associated with the onset of plastic deformation of the relatively softer Mg filaments within the Cu matrix. Despite deformation-induced defects that slightly increased electron scattering, the composite maintained a high electrical conductivity of 52.6 ± 1.2 MS/m due to the continuous Cu conduction network. Overall, the results demonstrated that the controlled integration of alloying elements, heat treatment, extrusion-based processing, and SPD constitutes an effective strategy for the development of advanced HSHC Cu-Mg alloys and density-reduced Cu/Mg composite structures with a desirable combination of mechanical properties and electrical conductivity.

Keywords: High-strength and high-conductivity copper alloys; Solid solution strengthening; Second-phase hardening; Heat treatment; Microstructure engineering; MaxStrain process; Gleeble thermomechanical simulator; KoBo extrusion; Simulation; Mechanical properties; Electrical conductivity, Composite materials.
