ABSTRACT

Cu-4.5Cr, Cu-4.5Cr-3Ag and Cu-10Cr-3Ag (in wt %) alloys, with or without nanocrystalline Al_2O_3/ZrO_2 dispersion, have been synthesized by mechanical alloying/milling. The milled powders were consolidated by conventional cold compaction and sintering (at 600 and 800^{o}C), laser sintering (with 100 and 150 W power and 1 and 2 mm/s scan speed) equal channel angular pressing (ECAP) at ambient temperature and high pressure sintering (at 8 GPa, 600 and 800^{o}C). Microstructural characterization by scanning and transmission electron microscopy and phase analysis by X-ray diffraction evidence that the final milling product (after 25 h) is Cu-rich extended solid solution with nanometric (< 50 nm) crystallite size with uniformly dispersed nano-alumina particles embedded in it. However, the microscopic and diffraction analysis of sintered products suggest that the alloyed matrix undergoes significant grain growth after sintering while the dispersoids retain their ultrafine size and uniform distribution in the matrix. Conventional cold compaction and sintering produces compacts of density ~ 7.0 Mg/m^3, hardness of about 80 VHN to 120 VHN, and improved wear resistance. However, these conventional sintering products record relatively lower conductivity of ~ 10 to 15 % IACS (international annealing copper standard). In laser sintering, dispersion of nanometric Al_2O_3 seems more effective than ZrO_2 in enhancing the mechanical properties. In general, laser sintering of mechanically alloyed Cu-4.5 Cr and Cu-4.5Cr-3Ag alloys with 10 wt % nanocrystalline Al_2O_3 at 100 W laser power and 1-2 mm/s scan speed yields the optimum combination of high density (7.1-7.5 Mg/m^3), hardness (165-225 VHN), wear resistance and electrical conductivity (13-20 % IACS). ECAP consolidated compacts show better mechanical and electrical properties than the compacts produced by the previous two methods. 10 wt % nanocrystalline Al_2O_3 dispersed Cu-4.5Cr-3Ag alloy consolidated by 8 ECAP passes records an exceptionally high hardness of 390 VHN and enhanced wear resistance. The electrical conductivity of these pellets after ECAP without Al_2O_3 is about 30 % IACS (international annealing copper standard) whereas pellets with 5 or 10 wt % Al_2O_3 dispersion record a conductivity of about 20 to 25 % IACS. Among all four consolidation methods high pressure sintering produces compacts of highest density, and mechanical and electrical properties. 10 wt % Al_2O_3 dispersed Cu-4.5Cr-3Ag alloy consolidated by high pressure sintering at 800^{o}C shows the maximum hardness (435 VHN) and wear resistance. The electrical conductivity of the pellets without and with nano-Al_2O_3 dispersion is about 40-45 % IACS (international annealing copper standard) and 35 % IACS, respectively. Thus, the present approach of mechanical alloying followed by sintering using an appropriate consolidation method seems a potential route for developing nano-Al_2O_3 dispersed Cu-Cr/Cu-Cr-Ag alloy for heavy duty electrical contacts.

Keywords: Cu alloys, mechanical alloying, ultrafine oxide dispersion, laser sintering, ECAP, high pressure sintering, electrical conductivity