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Enhanced strength and toughness in ultra-fine grained 99.9% copper obtained by cryo-hydrostatic extrusion

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ABSTRACT

Ultrafine grained 99.9% Cu with enhanced strength and toughness was produced by hydrostatic extrusion conducted at the temperature of liquid nitrogen. The cryo-extruded Cu has a tensile yield strength of 490 MPa, hardness of 145 HV0.2, and tensile fracture toughness of 39.5 MPa $m^{1/2}$, which means that their values increased by 380%, 185% and ~10%, respectively, compared to those of the starting material. The significant strengthening is due to the strong grain refinement to 320 nm and the high energy of defects stored during the processing at liquid nitrogen temperature. The short term post deformation annealing doubles the ductility of material even by above 10% of the elongation to fracture at a slight expense of the yield strength (485 MPa). The observed behavior of Cu can be explained in terms of its low stacking fault energy, the susceptibility to dynamic recrystallization within the working zone of the extrusion die, and the triaxial strain components with the very large strain gradients, combined with the significant adiabatic heating effect active during the hydrostatic extrusion. The better homogeneity of the grain refinement and the higher efficiency of the distribution of defects and of the energy storage accompanied by the decreased dislocation mobility during the cryo hydrostatic extrusion contributed to the higher strength.

Keywords: Hydrostatic extrusion; Cryo-deformation; Grain refinement; Strength; Fracture toughness; Ductility

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