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EFFECT OF COMBINED HYDROEXTRUSION ON LOW-TEMPERATURE PLASTICITY AND STRENGTH OF ULTRAFINE GRAINED COPPER

High interest in the bulk ultrafine grained (UFG) metals is caused by unconventional mechanical properties and wide application of these materials. The effective method of obtaining of the UFG state is severe plastic deformation (SPD) combined with direct hydroextrusion (HE) and equal-channel angular hydroextrusion (ECAH) with subsequent drawing. Recently, it was demonstrated that such processing of copper provides very high mechanical properties at room temperature and higher.

The aim of this study is investigation of the mechanical properties of UFG Cu-FRTP (Fire Refined Tough Pitch, 99.95%) and Cu-OF (Oxygen Free, 99.98%) at low temperatures. The rod samples of 0.5 mm in diameter prepared by HE (sample I) and by combination of HE and ECAH (sample II) with subsequent drawing are studied. The samples were deformed by tension at the temperatures of 4.2, 77 and 295 K with using deformation machine with cryostats for liquid nitrogen and helium.

It was demonstrated that SPD schemes and purity of the initial material affected substantially the magnitude and the temperature dependence of strength and plasticity at tension. At room temperature, the ultimate tensile strength (UTS) for Cu-FRTP was found larger for sample II (670 MPa) than for sample I (560 MPa). The same difference was observed for Cu-OF, where UTS = 460 MPa (sample I) and 500 MPa (sample II). When the test temperature was reduced down to 4.2 K, the values of UTS essentially increased to the maximum of 870 MPa in the case of Cu-FRTP processed by HE&ECAH. However the low temperature plasticity of these samples is smaller as compared to Cu-OF once deformed at 4.2 K. Another feature is unstable flow of Cu-FRTP in contrast to Cu-OF sample observed at 4.2 K.

The received data are discussed in terms of the structure influence on the plastic deformation processes at low temperatures. When the temperature decreased, yield stress of UFG copper increased due to thermally activated interaction of dislocations and local defects. At the same time, SPD scheme affected only the level of internal strains. When the temperature dropped down to 4.2 K, plasticity of SMC copper increased as a consequence of deceleration of dynamical rest. In this case, plasticity of sample II can be limited because of the presence of big pores developed during drawing.

Keywords: ultrafine grained copper, severe plastic deformation, direct hydroextrusion, equal-channel angular hydroextrusion, low-temperature mechanical test

Fig. 1. General SPD scheme

Fig. 2. Scheme of low-temperature device of the deformation plant: *1*, *2* – nitrogen and helium Dewars, respectively, *3* – the sample, *4* – stock, *5* – dinamometer, *6* – vacuum chamber

Fig. 3. Microstructure of UFG samples of Cu-FRTP of 2 mm in diameter (in longitudinal section), I (*a*) and II (*б*, *в*)

Fig. 4. Histograms of size distribution of micropores (by *S* surface) on the longitudinal polished section of the Cu-FRTP wire of 0.5 mm in diameter: *а* – sample I, Σe = 9.6; *б* – sample II, Σe = 15.4

Fig. 5. Tension curves of the samples of UFG copper Cu-FRTP (*а*, *в*, *д*) and Cu-OF (*б*, *г*, *е*) after SPD by scheme I (dashed lines) and II (solid lines) at different temperatures *T*, K: *а*, *б* – 295; *в*, *г* – 77; *д*, *е* – 4.2. On the inserts (*д*), jumps of the stress are presented that are observed at the strains marked by arrows

Fig. 6. Temperature dependences of conventional yield strength $\sigma_{0.2}$ (*а*), tensile strength σ_u (*б*) and uniform elongation (before neck formation) ε_u (*в*) of the Cu-FRTP samples (А) and Cu-OF (Б): --- – sample I, —– sample II