DYNAMIC PROPERTIES OF COPPER-BASED ALLOYS AND COMPOSITES

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The effect of the dispersion and defectiveness of the crystalline structure of copper doped with microadditives of chromium, zirconium, graphene, and carbon nanotubes on the resistance to high-speed deformation and fracture has been studied. The submicrocrystalline (SMC) structure (0.5–1.0 microns) in the materials was obtained by dynamic channel-angle pressing (DCAP). The DCAP method is a high-speed (10^4–10^5 s^{-1}) variant of the well-known quasi-static ECAP method. The deformation of a simple shear, which forms the structure during ECAP, is high-speed in the case of DCAP, in addition, the shock wave compression deformation acts on the sample, which creates an additional source of deformation riveting [1]. The mechanical properties of the materials were studied under conditions of shock compression with an intensity of 4.7–7.3 GPa and a strain rate of $(0.9–3.2)\times10^5$ s^{-1}. Wave processes in the samples were recorded using a VIZAR laser Doppler velocity meter, which has a time resolution of about 1 ns and a spatial resolution of about 0.1 mm [2]. From the analysis of the obtained wave profiles, the following were calculated: dynamic Hugoniot elastic limit (σ_{HEL}), dynamic yield strength (*Y*), and spall strength (σ_{sp}) of materials before and after DCAP to various modes [3].

It was determined that the studied copper and dispersion-aging Cu-0.1%Cr and Cu-0.03%Zr alloys with a SMC structure (0.5–1.0 μm) obtained by the DCAP method, under shock compression conditions, demonstrate an increase in σ_{HEL} and *Y* by 1.8−2.8 and 1.8−3.7 times, respectively, according to compared with the initial coarse crystalline (CC) state. This is due to the formation of a specific nonequilibrium and defect SMC structure as a result of high-speed fragmentation processes. Thus, the strengthening effect of DCAP is preserved under extreme conditions of shock wave loading at submicrosecond durations of loading [3, 4].

It is shown that grain size refinement from CC (200–400 μm) to SMC state (0.5–1.0 μm) increases σ_{HEL} and *Y* of the Cu–0.03% Zr alloy by factors of 1.9 and 1.8, respectively, but the spall strength is reduced by a factor of 1.4 times. The subsequent annealing at 400 and 450°C, which is accompanied by the decomposition of a supersaturated solid solution with the precipitation of nanosized (3–5 nm) Cu_5Zr particles, makes it possible to increase the characteristics of the elastic–plastic transition by factors of 3.0 and 3.7 and the σ_{sp} is increased almost to the level of the CC analogue. A combined treatment mode with DCAP, $n = 3$ and annealing at 450°C for 1 h is determined, which makes it possible to obtain the Cu–0.03% Zr SMC alloy with high dynamic characteristics and microhardness values.

It is established that dispersion of the structure in the Cu–0.10% Cr alloy from CC to SMC state not only substantially increases the dynamic elastic limit and the dynamic yield stress by factors of 3.7 and 2.6, respectively. This also leads to a 1.5-fold increase in the spall strength compared to the values in the CC state. The increase of the spall strength is associated with the formation of a structure consisting of highly misoriented dispersed grains with predominantly nonequilibrium high angle boundaries during DCAP, which hinders the growth of microcracks and slows down the spall fracture process in comparison with the CC state [4].

It was determined that the use of copper-based composites with microadditives of graphene (Cu-0.02 % Gn) and carbon nanotubes leads to an increase in the dynamic elastic limit, dynamic yield strength by 4.0–5.6 times and spall strength by 1.2–1.8 times. The increased level of mechanical properties of alloys and composites compared with copper [3] is associated with hardening caused by the precipitation of nanoparticles of the second phases (Cu_5Zr and Cr) in alloys during DCAP and subsequent annealing, and the introduction of reinforcing microadditives of graphene and carbon nanotubes. The data obtained on the dynamic properties and the nature of the fracture of the SMC of copper-based alloys and composites make it possible to predict their behavior under extreme operating conditions.

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