Peculiarities of High-Rate Deformation of Copper with Different Grain Size Under Convergence of Cylindrical Channels of Small Diameter

A.N. Malyshev, O.N. Ignatova, A.M. Podurets, V.A. Raevsky, M.I. Tkachenko, I.S. Tselikov, O.A. Tyupanova

RFNC-VNIIEF, Sarov, Russia

The authors present new experimental data on peculiarities of metal deformation at micro- and mesoscale levels at strain rates of 10^5-10^7 s^{-1} during convergence of cylindrical channels. Application of the method is demonstrated by the example of convergence of channels in copper samples having the initial grain sizes of 0.5, 30, and 110 *mm* under loading by impactors with thicknesses of 3 and 5 mm, which were accelerated up to velocities of 102-136 *m/s.*

To investigate peculiarities of plastic deformation of metals, tests were performed with loading of copper samples having various grain sizes by shock wave when using the method of convergence of cylindrical channels. Intensity of the shock wave, which was formed in the sample by a copper impactor having thicknesses of 1 and 5 mm and accelerated up to velocities of 102-136 *m/s*, was varied from σ_X=1.6 to 2.6 GPa, the time of effect was t_{SW}=1.4-2.55 *ms*.

Convergence of the channels is accompanied with growth of heterogeneous deformation at the following scale levels: intergranular (sliding) and subgrain (formation of shear bands of the twin structure). Twin shear bands are formed only near the aperture surface, and their number grows as the initial diameter decreases. Therefore, knowing radius *R* (or diameter *D*) of the formed deformation shear bands, it is possible to determine the parameters of their formation in this stress-strain state in the first approximation:

$$\sigma_X \sim 1.6 \text{ GPa}, \qquad \dot{\varepsilon}_i \approx \frac{W_{imp}}{R} \sim 2\times10^5 \text{ s}^{-1}, \qquad \varepsilon_i \approx \frac{R_0 - R}{R_0} \sim 80\ \%,$$

where W_{imp} is the impactor velocity; R_0 is the initial radius of channel; *R* is the final radius of channel.

It should be noted that formation of these shear bands was earlier observed in coarse-grain copper only under planar shock-wave loading with intensity σ_X > 27 GPa, total strain ε_i ~ 0.2 and strain rate $\dot{\varepsilon}_i$ >10^8-10^{10} s^{-1}. These shear bands were not revealed at the same intensity of compression wave, but lower strain rate ($\dot{\varepsilon}_i$ ~3×10^6).

When the loading conditions are similar, the smallest convergence of the channels is observed for copper having grain size of 0.5 *mm*. The largest convergence is typical for the 30-micron copper, but not for 110-micron copper, as it was expected.

The attempt was made to simulate collapse of the channels with use of the homogeneous relaxation model, which was based on the methods of continuum mechanics, by two-dimensional Lagrange technique. The model does not take account for the heterogeneous processes, which were revealed in these tests, and it does not claim to be precise. It is most likely employed for estimation of the used average parameters of flow. In the frames of this model, it appeared impossible to simulate the final shape of the aperture, localized shear band, grain boundary sliding, etc. Nevertheless, numerical description of the average diameter of the aperture after test allows making the conclusions on adequacy of the used models and parameters from these models.

Though deformation of material around investigated cylindrical channels has significantly heterogeneous character, the considered numerical-experimental method seems to be promising in terms of providing verification of wide-range models of shear strength in the field of low pressures (σ_X~(2-5)×σ_{HE}), but

high strain rates ($\dot{\varepsilon}_i$ ~105¸ 107 s-1) and strong strains (ε_i~0.2¸ 2.0). Besides, the method allows evaluating the main parameters of compaction, namely, amplitude and time of shock wave effect, which are required for total collapse of the considered channels.