Dislocation Density in Copper And Tantalum After Shock Loading Up To 20-100 GPA

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Introduction

A microstructure of metals at shock loading is determined by the same processes, which occur at any deformation including a competition of two basic mechanisms of plastic strain – dislocation slip and twinning. The action of a specified mechanism of plastic deformation under the conditions of dynamic loading is usually defined by the help of the analysis of samples recovered after loading. We consider the dislocation structure of two metals having various crystal lattices: face-centered cubic copper and body-centered cubic tantalum.

Results and Discussion

The dislocation density ρ was studied using a X-ray method in recovered samples of copper with the grain size from 0.5 to 100 μm and in recovered samples of tantalum after loading by shock waves with the amplitude from 20 to 100 *GPa*. It was confirmed that high speed loading generates greater dislocation density in copper compared with quasi-static deformation (Fig. 1).

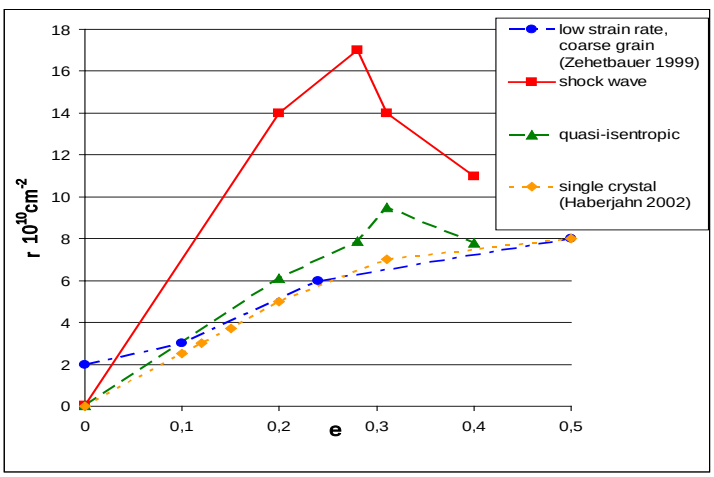

Figure 1. Dislocation density in copper with 20µm grain size after shock ($\dot{\varepsilon} \sim 10^9 s^{-1}$) and quasi-isentropic ($\dot{\varepsilon} \sim 10^6 s^{-1}$) loading. Comparison with static compression data [1, 2]

The greatest value ρ was recorded in 100-micron copper loaded by the pressure of 40 *GPa* – approximately $10^{12} cm^{-2}$. The relatively small increase ρ was observed, that is two times, to the maximum value ~ $3 \cdot 10^{11}$ cm^{-2} in ultra-fine-grained (UFG) copper with the grain size 0.5 μm having the largest initial dislocation density ($2 \cdot 10^{11}$ cm^{-2}). The maximum ρ can be seen in all the samples in the range between 40 *GPa* and 50 *GPa* (what conforms to deformation 0.25-0.3), after which a fall follows. We can explain such a fall through annealing defects at adiabatic heating as a result of compression. The most severe fall of dislocation density occurs in UFG copper, in which there is an initial structure mostly saturated with defects. The value ρ decreases practically till the value for the standard after loading down to P=60 *GPa*. The rise ρ is noted in recovered copper with increase in the grain size and with decrease in the sample's temperature (Fig. 2).

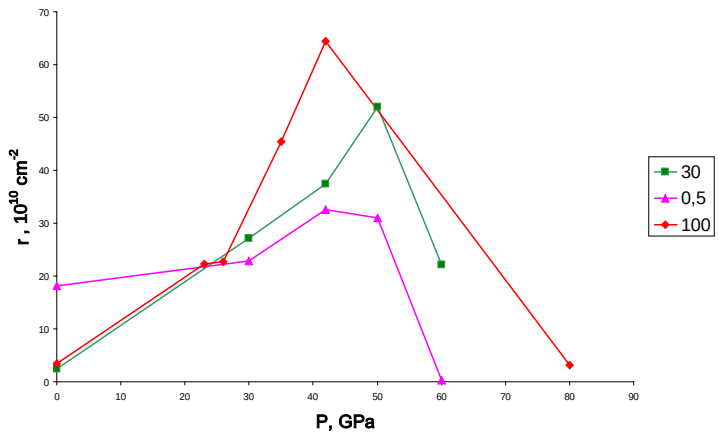

Figure 2, Dislocation density in copper with grain size 0.5, 30 and 100 µm after shock loading

We recorded a monotonic increase in dislocation density to the value ~ $3 \cdot 10^{10}$ cm^{-2} in tantalum with increasing a pressure in a shock wave. The influence of heating on defect annealing was not found out even at the maximum pressure (Fig. 3).

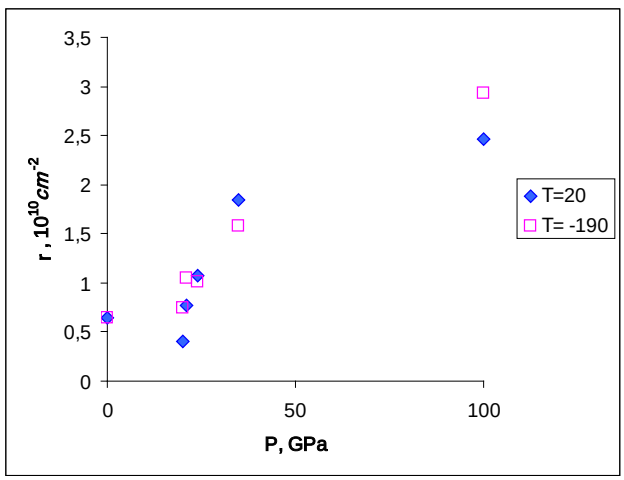

Figure 3, Dislocation density in tantalum at 20 и -190°C

A comparison between the achieved results and the earlier measurements for twin density [3] in copper and tantalum shows that the strength depends on the presence of defects of both kinds in the structure.

References

[1] M. Zehetbauer et.al., “Scanning X-ray diffraction peak profile analysis in deformed Cu-polycrystals by synchrotron radiation”, *Acta Materialia* 47, 1053-1061 (1999).

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[3] A.M. Podurets et al., “Structural changes in metals during high-rate deformation”, in Advances in materials science, eds. D.Kusnezov, O.N.Shubin (Prague, Czech Republic, Proc. Conf. August 31 – September 4, 2009) IV-2.