LLNL-PROC-484219

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May 17, 2011

The 3rd International Conference on Heterogeneous Materials Mechanics
Shanghai, China
May 22, 2011 through May 26, 2011

Advances in Heterogeneous Material Mechanics (2011)
3rd International Conference on Heterogeneous Material Mechanics (ICHMM-2011)
May 22-26, 2011, Shanghai (Chong Ming Island), China

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ABSTRACT

Computer simulations and empirical studies of the core structure of single dislocation in bcc metals over the last few decades have made enormous contributions to interpret many abnormal mechanical behaviors of bcc metals: tension/compression stress asymmetry, high Peierls (friction) stress for the motion of screw dislocations, and strong strain-rate and temperature dependence of yield and flow stresses at low temperatures [1]. However, the single-dislocation core model remains inconclusive to elucidate a peculiar anomalous slip behavior of bcc metals, which occurs on planes for which the Schmid factors are fifth and sixth in the order of largest Schmid factors for the {110} <111> slip systems, and for which the resolved shear stress is less than half that on the $(\bar{1}01)$ [111] primary system. Note that the anomalous slip behavior is also known as the violation of Schmid′s law, which states that plastic deformation of a single-crystal metals would begin on a slip system (a combination of the slip plane and the slip direction) when the resolved shear stress on the slip plane and in the slip direction reached a critical value (i.e., critical resolved shear stress). The resolved shear stress (τ) is given by $\tau = \sigma \cos \phi \cos \lambda$, where σ is applied stress, ϕ is angle between the stress axis and the normal to the slip plane, and λ is angle between the stress axis and the slip direction. The factor $\cos \phi \cos \lambda$ is usually called the Schmid factor (m). Schmid′s law in general is well obeyed by close-packed face-centered cubic (fcc) and hexagonal closed-packed (hcp) metals, which deform by slip in close-packed directions on planes that are close-packed planes. Body-centered cubic (bcc) metal is however not a close-packed structure, which deforms by slip in the most closely packed direction: <111> on a number of different planes

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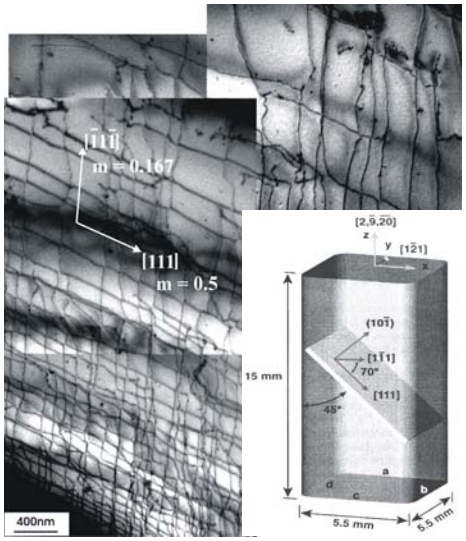
belonging to the <111> zone such as {110} and {112} planes. Figure 1 shows an example of the operation of anomalous slip in a Mo single crystal oriented with the stress axis parallel to a nominal “single-slip” orientation of $[\bar{2}\ 9\ 20]$, in which $(\bar{1}01)\ [111]$ is the primary slip system that has a maximum Schmid factor (m = 0.5) and requires the lowest stress to operate among the twelve $\{\bar{1}10\}$ <111> slip systems. TEM examination of the dislocation structure formed on the $(\bar{1}01)$ primary slip plane reveals that in addition to the $(\bar{1}01)\ [111]$ slip system, the coplanar $(\bar{1}01)\ [1\bar{1}1]$ slip system which has a much smaller Schmid factor (m = 0.167) is also operative. Although numerous and intensive studies have been conducted for the last four decades since Duesbery first reported the occurrence of anomalous slip in Nb single crystals in 1967 [2], the governing mechanisms remain elusive. Results of numerous studies [3] have indicated that the anomalous slip in bcc metals in general occurs in ultrahigh-purity crystals with large sample sizes (> 3 mm) deformed at low temperatures; it accompanies a high work-hardening rate and fine and planar slip traces. This is in contract to a low work-hardening rate in association with coarse and wavy slip traces when the anomalous slip disappears at elevated temperatures. It is noteworthy that coarse and wavy slip traces appear when both {110} <111> and {112} <111> slip systems become operative. Progress has been made recently on obtaining crucial evidence to rationalize the anomalous slip behavior of bcc metals through careful TEM observations of dislocation substructures evolved in the primary and anomalous slip planes of single-crystal Mo compressed at room temperature. Critical results are presented here to elucidate the underlying mechanism for the anomalous slip.

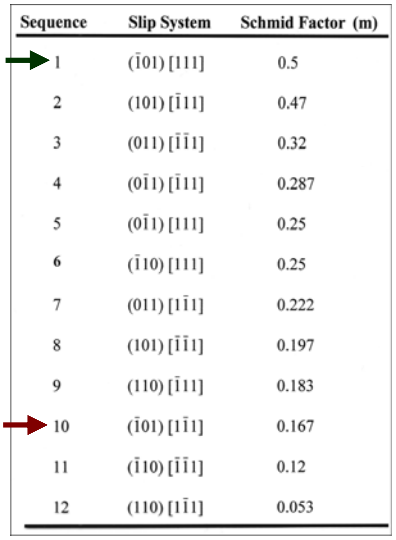
Acknowledgements

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Key Words: Single-slip orientation; anomalous slip; coplanar dislocation arrays



(a)



Sequence	Slip System	Schmid Factor (m)
→ 1	$(\bar{1}01)\ [111]$	0.5
2	$(101)\ [\bar{1}11]$	0.47
3	$(011)\ [\bar{1}\bar{1}1]$	0.32
4	$(0\bar{1}1)\ [\bar{1}11]$	0.287
5	$(0\bar{1}1)\ [111]$	0.25
6	$(\bar{1}10)\ [111]$	0.25
7	$(011)\ [1\bar{1}1]$	0.222
8	$(101)\ [\bar{1}\bar{1}1]$	0.197
9	$(110)\ [\bar{1}11]$	0.183
→ 10	$(\bar{1}01)\ [1\bar{1}1]$	0.167
11	$(\bar{1}10)\ [\bar{1}\bar{1}1]$	0.12
12	$(110)\ [1\bar{1}1]$	0.053

(b)

Fig. 1. (a) A bright-field TEM image showing the operation of the $(\bar{1}01)$ $[1\bar{1}1]$ anomalous slip system in a $[\bar{2}\ 9\ 20]$-oriented Mo crystal. (b) A list of Schmid factors for the {011} <111> slip systems in the $[\bar{2}\ 9\ 20]$-oriented test sample.

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