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by

Jack Washburn* and Gollapudi Murty*

The cell-like substructures that are observed in work hardened metals often give the impression of being isotropic. However the plastic properties of a deformed crystal, even one that has been extended along [111] and therefore contains dislocation segments of all six $\frac{1}{2}$ <110> Burgers vectors are highly directional. If a test is interrupted and plastic straining is continued along a new tensile axis the continuation of the stress strain curve generally is very different from that, that would have been obtained by continued extension along the original axis.(1) A striking example of this effect was obtained by cutting new tensile specimens out of a large copper crystal after an initial extension in the [111] multiple slip orientation.(2) The new tensile axis was such as to produce single slip on the (111) plane, which was inactive during the prestrain. The portion of the stress strain curve immediately following the change in direction of tensile axis invariably started at a higher resolved shear stress than the highest stress reached during the prestrain but the strain hardening rate was initially very small. The length of the region of small hardening rate increased with increasing prestrain.

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The purpose of the present note is to suggest a general explanation for the region of small hardening and the associated tendency for slip to cluster into heavy slip bands. The dislocations that are left in a uniformly strained crystal are predominantly in pairs of opposite sign. They may be close pairs or dipoles or they may be more uniformly distributed. In any case if long range lattice curvature or twisting is not produced by the deformation then the numbers of dislocations of opposite sign must be equal. When two or more systems operate simultaneously dislocation recombination reactions cause the dislocation substructure to become a three dimensional network or tangle. However, it is still true that most dislocation segments can in effect be paired with an antiparallel segment within a distance that is small compared to the dimensions of the crystal. Antiparallel pairs are prevented from getting together by the development of metastable arrangements. Therefore an increase in dislocation density resulting in strain hardening is usually associated with each increment of strain.

In experiments where the active slip plane is changed, the sudden increase in flow stress is due to the greater density of the forest of intersecting dislocations on the new plane.[3] We would like to suggest that the following region of small hardening rate and the tendency of slip to cluster into bands can be explained by an increased rate of dislocation annihilation; the dislocations that start to multiply on the new slip plane make this possible for both edge and screw dislocation pairs that had achieved metastable positions during the old deformation conditions.

Consider first the screw dislocations: Dislocation tangles in deformed FCC crystals should be anisotropic in one very important respect. Most of the dislocation segments will be split into partials such that the ribbon of stacking fault lies on one of the active glide planes. Fig. 1 represents a small section of a dislocation tangle in which four $\frac{1}{2}$ $[10\bar{1}]$ screw dislocations on the $(1\bar{1}1)$ slip plane have interacted with two intersecting dislocations that lie in $(\bar{1}11)$. The plane of the drawing is (101) or any other plane in the $[10\bar{1}]$ zone. The $\frac{1}{2}$ $[10\bar{1}]$ dislocations of one sign form attractive junctions with the intersecting dislocations while those of the opposite sign are repelled. However, the latter are attracted by the former and will, therefore, be held against the intersecting dislocations. An element of dislocation tangle like that shown in Fig. 1 will become unstable if dislocations of the same Burgers vector are introduced that are split on (111) instead of on $(1\bar{1}1)$. Therefore, multiplication of dislocations on (111) will result in annihilaton of metastable arrangements of screw dislocations like that shown in Fig. 1.

An edge dislocation in a tangle is frequently stabilized by being close to another edge dislocation of opposite sign that lies on a different glide plane. As a simple example suppose that a joged screw dislocation has moved leaving behind two dipoles; a section through the two dipoles is represented by Fig. 2.a. The dislocations A and B lie on the same glide plane, they are of opposite sign and would glide together and annihilate except that they are stabilized by dislocations A' and B'. If it is assumed that these two dipoles have the same Burgers vector as the newly active system, and if $\frac{D}{d} < \frac{d}{b}$ where D is the distance between dipoles and d is the spacing between dislocations in the dipoles then A and B can be annihilated by intersection cross slip[4] as shown in the sequence of Fig. 2 (b,c). In this way some dislocations of the intersecting forest will be destroyed.

The particular cases illustrated by Figs. 1 and 2 involve annihilation of antiparallel pairs of dislocations in the dislocation tangles that have the same Burgers vector as that for the newly active system. Some of these should almost always be present. However similar events can take place when the antiparallel pair has a different Burgers vector from that of the new system. In these cases the result is recombination rather than annihilation. Intersection cross slip[4] should facilitate these recombinations. The length of dislocation destroyed is then generally only about half as great as for the cases described.

Although the actual interactions that will take place must usually be more complex than the simple cases that can be conveniently described, it seems likely that multiplication of dislocations on a new system will always partially destroy the stability of dislocation tangles that have developed under different deformation conditions. If a few intersecting forest dislocations and parallel screw segments near an active glide plane are destroyed by these mechanisms it will lead to rearrangements of other connecting segments of the dislocation tangle resulting in further shortening of the total length of dislocation line. Therefore a natural explanation is provided for the tendency of slip to cluster into heavy slip bands. If the dislocation density is reduced in the regions to either side of an active glide plane then the next active slip plane should tend to develop close to a previous one. The local annihilation probably extends to a distance that is a function of the dislocation density. The higher the average dislocation density the smaller will be the width of the zone within which the forest density is reduced but the larger will be the magnitude of the decrease; making the tendency for clustering of slip increasingly pronounced.

A prediction of this model is that the greatest instability should occur when the prestrain has taken place on a single system and the new system is one of those involving the cross slip plane; particularly the one having the same Burgers vector as the previously active system.

Although these suggestions apply particularly well to the case where the active glide plane has been changed we believe they are more general. Even when a crystal is deformed from the start under conditions of "single slip" the dislocation tangles that develop in stage II and III of the stress strain curve contain many different Burgers vectors. It seems likely that passage of a group of dislocations across a previously inactive glide layer will generally promote some annihilation and rearrangement by the mechanisms suggested here. The only effect of changing the active plane of glide is to make the effect more pronounced.

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Figure Captions

FIGURE I Metastable array containing screw dislocations of opposite sign Average plane of array is (101). Dislocations b_1 are $\frac{1}{2}$ [$\bar{1}$01] dissociated in (1$\bar{1}$1), b_2 are $\frac{1}{2}$ [0$\bar{1}$1] dissociated in ($\bar{1}$11), and b_3 are $\frac{1}{2}$ [1$\bar{1}$0] sessile dislocations lying along [110].

FIGURE 2 Annihilation of dipoles by intersection cross slip - (a) metastable pair of dipoles (b,c) successive stages in the annihilation of dislocations A and B when intersected by moving dislocation which has the same Burgers vector. Brcken lines show segments of A and B that have been eliminated.

References

1. Z.S. Basinski and P.J. Jackson, Phys. Stat. Sol. 9, 805 (1965)

2. J. Washburn and G. Murty, University of California L.R.L. Report # 16551

3. H. W. Paxton and A.H. Cottrell, Acta Met. 2 , 3 (1954)

4. J. Washburn, Appl. Phys. Letters 7 183 (1965)

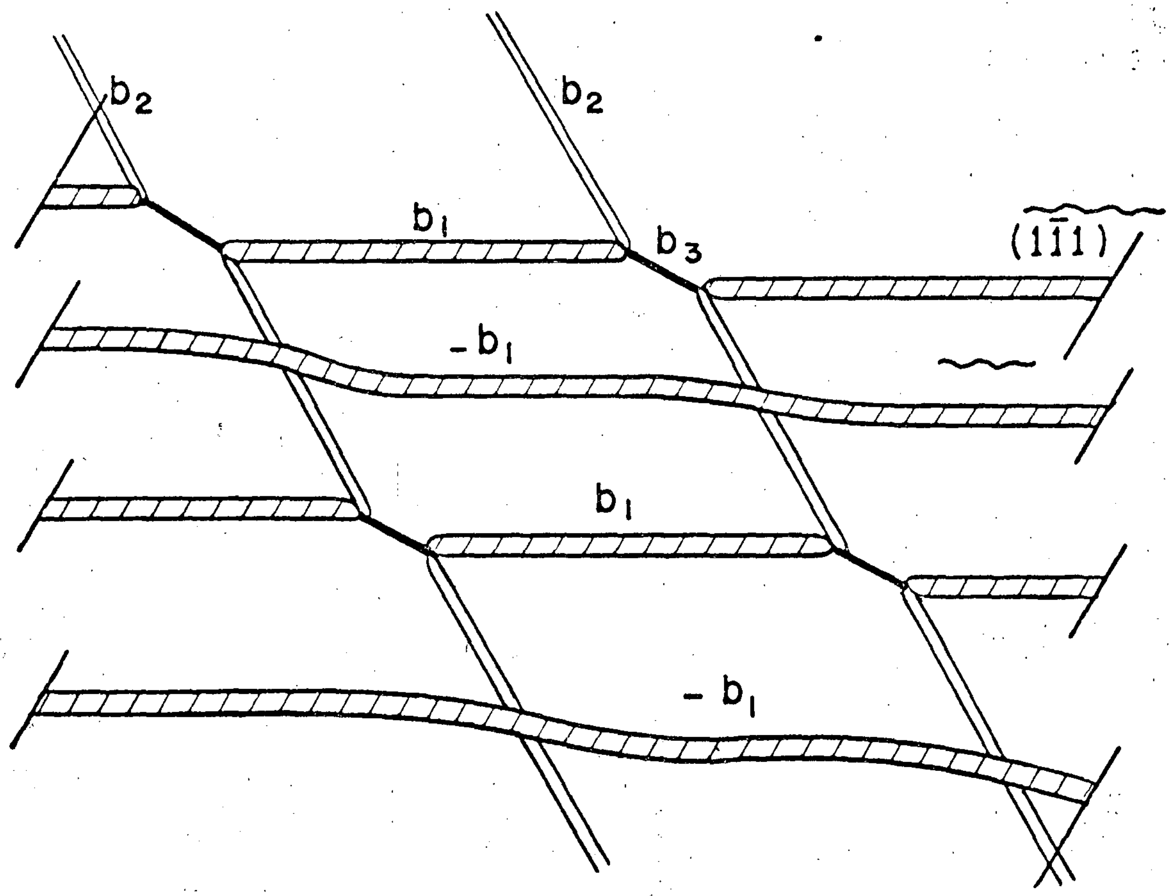

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Fig. 1

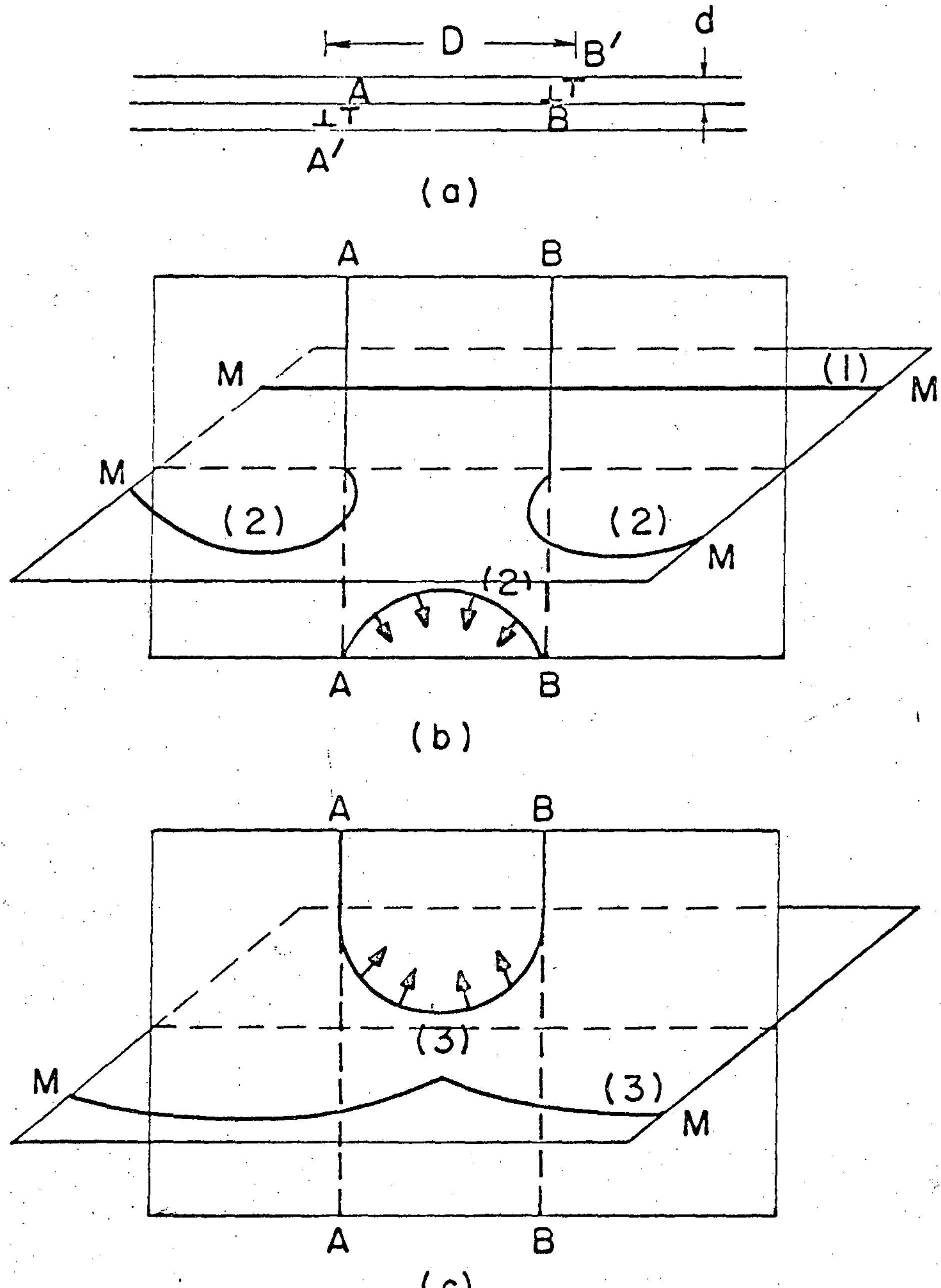

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Fig. 2.