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A Model for Dislocation Generation in Shock-wave Deformation

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ABSTRACT

A model for dislocation generation in shock-wave deformation is described. Contrary to earlier models proposed by Smith(1958) and Hornbogen(1960), this model does not require the dislocations to move with the shock front; therefore no supersonic dislocations are needed. Dislocations are homogeneously nucleated at the shock front by the deviatoric component of the applied stress pulse; after generation, they are left behind, organizing themselves into more stable arrangements. Dislocation generation may also take place at the rarefaction part of the wave; however the mechanism is thought to be the conventional multiplication mechanism in this part of the wave. Dynamical considerations for nickel show that dislocations moving at velocities higher than the transverse sound velocity would lead to exceedingly high temperatures; experiments show that such is not the case. What renders the proposed model especially attractive is that, for the first time, quantitative predictions of residual dislocation densities are made possible. Accordingly, calculated dislocation densities are compared to observed densities for nickel reported in the literature.

THE SMITH(1958) AND HORNBOGEN(1962) PROPOSALS

The metallurgical effects associated with the passage of shock waves through metals have been extensively investigated over the past twenty years (Dieter,1962;Leslie, 1973). However, the number of attempts to explain the generation of dislocations has been small (Smith,1958; Hornbogen,1962; Harris and Jacobs,1963; Cowan,1965). And these attempts yielded only one physical model, the one by Smith(1958), and its modification, proposed by Hornbogen(1960).

Figure 1 shows an idealized simple cubic structure being elastically distorted by an elastic wave. Once the amplitude of the wave rises, the deviatoric strains have to be accomodated; this is shown in the sequence displayed in Figure 1. Interfacial dislocations recompose the cubicity of the distorted lattice. That is, in essence, the Smith interface. Smith(1958) proposed that this interface propagated with the shock front. In order to account for the residual substructure found in shock loaded iron--mainly straight screw dislocations--Hornbogen(1962) proposed that the shock front promoted the expansion of dislocation loops, whose edge segments composed the shock interface, leaving behind the trailing screw portions. However, Hornbogen's(1962) proposal overlooked one distinct feature of shock-loaded substructures; that they show a strong resemblance to low-temperature substructures culated results were obtained is given by Meyers(1978). It should be emphasized that this is the first model that allows quantitative predictions of dislocation densities. The divergence between calculated and observed results can be greatly narrowed down by introducing corrections for the (a)-(d) aforementioned items.

(a) Residual shear stresses. These stresses will be, of course, non-homogeneous. In the surrounding of a dislocation they will be smaller. It will be assumed that the average shear stress will be just below the stress required to homogeneously nucleate a dislocation.

(b) Dislocation motion. Under the influence of the residual stresses, dislocations can move at high velocities. Above the 1 GPa level, this velocity can be assumed, for simplicity, to be equal to the shear wave velocity (See Figure 7). The acceleration rates being very high, this velocity is assumed to be reached instanteously. Figure 9 shows the direction of motion of these dislocations under the applied stresses indicated on the sides. The shear stress along two planes have been indicated. Dislocations move both towards and away from the shock front. This will effectively increase the distance d_1.

(c) Dislocation annihilation. It can very easily be seen from Figure 9 that the motion of dislocation of opposite signs in opposite directions favors annihilation; this is thought to occur during the application of the pulse.

(d) Dislocations formed in the attenuation part of the wave. The rate of decay of the stress will be low enough for dislocation motion and "stretching" to accomodate the shear stresses. No homogeneous nucleation is thought to take place. What is meant by "stretching" is the following: dislocations move until they encounter "forest" dislocations. Then, segments "bow out" between the forest, if jogs that cannot move conservatively are formed. These loops can stretch to large distances, increasing in the process the overall dislocation length and density. Alternatively, sources similar to Frank-Read sources might be activated.

The four factors above contribute to changes in residual dislocation density. One could, therefore, express the overall dislocation density as:

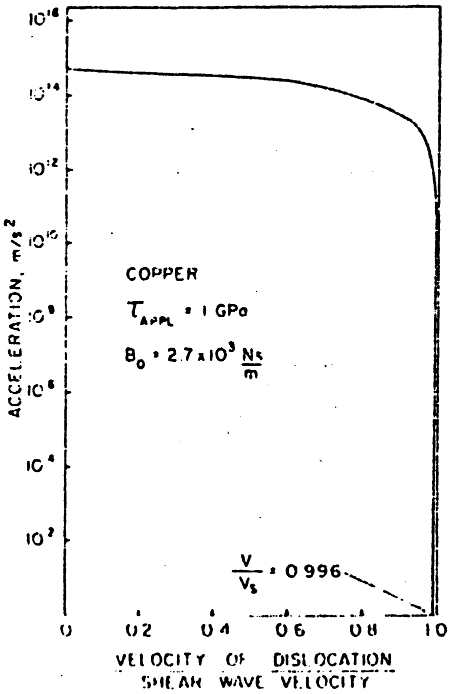

Fig. 7. Acceleration of dislocation when subjected to a 1 GPa shear stress.

$$\rho_{corr} = \rho_{calc} + \Delta\rho_{shear} + \Delta\rho_{mot} + \Delta\rho_{ann} + \Delta\rho_{att}$$

If numerical values were attached to these $\Delta\rho$, calculated and observed densities could be brought to a closer correlation.

CONCLUSIONS

A) By means of dislocation dynamical considerations, it is shown that the model proposed by Smith(1958) for shock-induced dislocations is not realistic.

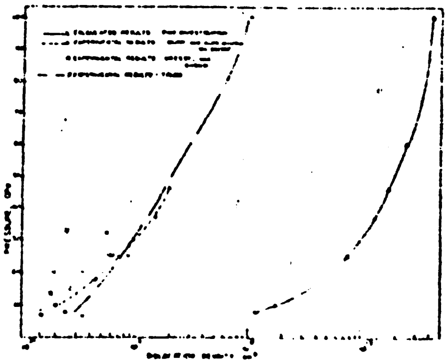

Fig. 8. Comparison between calculated and observed dislocation densities.

B) A model is proposed that does not require supersonic dislocation motion. Dislocations are homogeneously nucleated at the shock front by the action of the shear stresses; they are left behind. Once the shear stresses at the shock front reach again values high enough for homogeneous dislocation generation, new interfaces are formed.

C) This model allows quantitative predictions, which are compared with experimental results. Agreement is not very good, but the introduction of four factors--dislocation motion, residual shear stresses, dislocation annihilation, dislocation multiplication at the rarefaction part of the wave--can bring model and results into superposition.

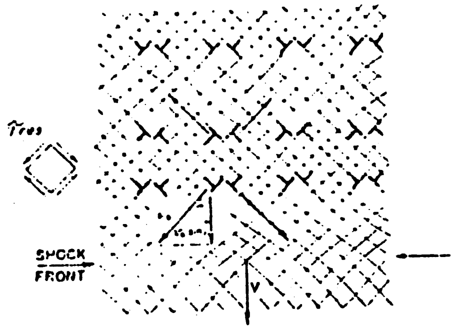

Fig. 9. Movement of dislocations generated at front.

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