A STUDY OF DISLOCATION MOBILITY AND DENSITY
IN METALLIC CRYSTALS

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The need for a capability to predict materials behavior under diverse environmental conditions and the need for new and better materials to function under these conditions can best be met when we have an understanding of the fundamental properties of materials. Work under the present contract is directed toward obtaining a more fundamental understanding of the deformation processes which occur in crystalline solids.

Experimental and theoretical studies have demonstrated the central role of dislocation dynamics in the plastic deformation of crystalline solids. While the early theoretical considerations were limited to a treatment of stationary dislocations, more recent studies have demonstrated the importance of the drag force on moving dislocations as it relates to the stress required for plastic deformation to proceed at a finite rate. The study of dislocation mobility and density under this contract is concerned with identification and understanding of the various mechanisms which give rise to a drag on moving dislocations, and with relating these mechanisms to the macroscopic aspects of plastic deformation.

The experimental study of dislocation mobility in single crystals has advanced along two distinct paths: those of the so-called direct and indirect measurements. Historically, the latter preceded the former by about a decade, during which time the quality of single crystals was greatly improved and techniques were developed for observing individual dislocations.
Indirect experiments (which employ macroscopic measurements only) invariably require a dislocation model for the interpretation of measurements, and herein lies the disadvantage of the method, for each model employs presuppositions which can only be affirmed by microscopic observations. Of course, no such restraints are imposed on direct measurements, but the experimental techniques here are generally more difficult to realize.

The direct measurements which have evolved generally employ the following sequence:

1) Dislocations are selectively introduced into a suitable test crystal.
2) Dislocation positions are observed by use of an etchant, or by x-ray topographic methods.
3) A constant amplitude stress is applied to the specimen for a measured period of time.
4) Dislocation positions are again observed, and their displacements measured.

It has been possible to introduce individual, relatively isolated dislocations in some crystals, and to obtain measurements of their mobility as a function of stress and temperature. In crystals of other materials, groups of dislocations are introduced or are generated by the stress pulse, and the motion of the group is observed. The dislocations within the groups (slip bands) interact with each other, so this gives a rather indirect measure of the mobility of individual dislocations (because of uncertainty in the local stress on the leading dislocations).
We have continued, during the current contract period, to develop and exploit our capabilities for direct measurements of dislocation mobilities in FCC, HCP, and BCC crystals. Progress in the several areas of our work is summarized below.

BCC Crystals

The investigation of the influence of stress and temperature on the velocity of dislocations in pure iron single crystals (CALT-767-P3-7) was completed during the past year. As discussed in the report, the experimental results differed significantly from the behavior predicted by theoretical models of dislocation velocity. Since the method used to conduct this study involved the observation of dislocation slip band growth, an investigation was undertaken to attempt to determine if there was an effect of the slip band configuration.

This study involved attempting to observe the motion of individual dislocations in a manner similar to the technique used in the investigations of zinc and copper (CALT-767-P3-4 and 8). Until the present time this study has not been successful because it has not been possible to introduce dislocation into BCC materials such that the dislocations will move on slip planes parallel to the free surface and close enough to the surface to be observed. A study of methods of introducing the required type of dislocations is currently in progress.

In addition to the work on the pure iron crystals, studies are underway on crystals to which small amounts (10 - 100 ppm) of carbon have been added. Crystals have been prepared which contain carbon in the form of C¹⁴ so that the relative impurity contents of the crystals can be
accurately determined from the radio activity. This investigation has progressed to the point that the necessary techniques have been developed. It is expected that the dislocation velocity measurements on the carbon doped crystals will be completed by the end of the contract period.

Measurements of the rate of slip band growth on 112 planes of Mo and Nb have been made at room temperature using the techniques employed for iron. Additional work on Mo and Nb will be deferred until the possibility of making mobility measurements on individual dislocations are explored further.

Non Basal Slip in Zinc

Slip band velocity measurements on the $\{12\bar{1}2\} \langle 1\bar{2}13 \rangle$ slip systems of zinc (CALT-473-26) have been extended to a higher resolved stress range (100-1000 Mdynes/cm$^2$). A new compression impact system has been put into operation for these measurements which produces single stress pulses of duration from 10 to 80 μsec. A tracing of a compressive stress pulse record is shown in Fig. 1. This record was obtained using strain gages which monitor the amplitude and duration of each stress pulse after it passes through the test specimen.

![Fig. 1](image)

**Fig. 1** Tracing of a typical stress pulse produced by the compression impact system (amplitude = 559 Mdynes/cm$^2$, duration = 24 μsec).
Data has been obtained from three tests at room temperature (resolved stresses of the order of 300 Mdynes/cm²) which give the velocity of the leading screw and edge oriented dislocations in slip bands (velocities of the order of 10³ cm/sec). We find that the screw dislocations move faster than the edge dislocations, and that the velocity of both is directly proportional to stress. This linear behavior was also observed at 77°K (CALT-473-26) at stresses of the order of 10 Mdynes/cm² where the velocities were of the order of 10⁻⁶ cm/sec, and the velocity of screw dislocations was also higher. A thermally activated drag mechanism was indicated by the temperature dependence in the range of 77°K - 110°K. At room temperature and in the stress range 8 - 30 Mdynes/cm², edge and screw velocities are the same, and proportional to the 7th or 8th power of the stress. The present data at higher stress may indicate that the Peierls stress has been exceeded, and a viscous phonon drag is limiting the dislocation velocity. Tests are underway to see if the drag decreases at lower temperatures (which would indicate phonon drag) or if the drag increases (which would indicate a thermally activated mechanism of dislocation motion). A new compression impact system is under construction which will produce pulse durations from 100 to 500 μsec. This system will allow us to explore the transition between the low stress behavior (velocity proportional to the 7th or 8th power of stress at room temperature) and the high stress behavior (velocity directly proportional to stress at room temperature).
Slip In Close Packed Structures

The velocity of individual dislocations of edge, screw and mixed orientation on the basal slip system of zinc (CALT-767-P3-4) and of edge dislocations in copper (CALT-767-P3-6) have been measured as a function of stress over a wide range of temperatures. The results have been discussed in detail in the cited reports, and indicate a dislocation-phonon drag mechanism is dominant in the temperature range of \(66^\circ K\) - \(400^\circ K\). A theoretical study of dislocation-phonon interactions has been made (CALT-767-P3-9), and will be continued during the next contract period. Measurements at temperatures down to \(4.2^\circ K\) have been attempted, but failures in bonding agents were experienced. Additional work on suitable bonding agents and test techniques for the lower temperatures is underway.

Preliminary work in an investigation of the quantitative effect of forest dislocations on the mobility of basal dislocations in zinc has begun. Cylindrical specimens have been compressed along their \([0001]\) axes to produce slip on the \([\bar{1}2\bar{1}2]\) \(<\bar{1}\bar{2}13>\) systems while minimizing basal slip. These specimens are being given different annealing treatments. They are then examined to determine the resultant forest dislocation density using an etchant which reveals dislocation intersections on \((0001)\) planes.

Contract Effort, Personnel and Publications

Total expenditures have been somewhat below the rate contemplated in the research proposal due to a shortage of graduate research assistants and to a reduction in the percent effort of a Research Fellow which was charged to the contract. During this contract period, the following staff members and graduate students have contributed to the research
program:

Professor David S. Wood
Professor Thad Vreeland, Jr.
Dr. David P. Pope
Dr. Arthur P. L. Turner
Dr. Kenneth M. Jassby
Dr. J. A. Gorman
Awadh K. Pandey

In addition, seven undergraduate students have worked part time as student assistants. The effort of the principal investigators has considerably exceeded the percentage charged to the contract, and this level of effort will continue to the end of this contract period.

The following publications were issued during the period July 31, 1968 to July 31, 1969:


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<th>Catalog</th>
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Reprints of the following documents which appeared in the literature during this reporting period have been submitted to the San Francisco Operations Office:

- **CALT-767-P3-1** Scripta Met. \textbf{3}, 193 (1969)
- **CALT-767-P3-2** Transactions AIME, \textbf{242}, 2022 (1968)

The following documents have been accepted for publication in the journals cited:

- **CALT-473-30** Acta Met.
- **CALT-767-P3-3** Transactions TMS-AIME