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A Proposal to the
Office of Naval Research
for Extension
of

Experimental Research on Plastic Deformation

Contract N6 ori 071 (54)

Expires August 31, 1955

Department of Physics
University of Illinois
Urbana, Illinois

Approved

F. W. Loomis.
Head, Physics Department

Approved

Dean, Engineering College

A. Proposed Research

I. Dislocation Production on Various Glide Systems

Recent research in our laboratory (see technical report no. 10 for this contract) indicates that even though a single crystal of a face centered cubic material may appear to deform macroscopically by single slip, on a microscopic scale several slip systems may be active. It is proposed that X-ray evidence be obtained on single crystals of aluminum and copper to test this hypothesis. If the deformation involves the production of many dislocations in the active glide system alone then one should find that certain Bragg reflections are broadened whereas others suffer little or no broadening. It may be that during the "easy glide" which occurs at the beginning of the stress strain curve generation only takes place in the active slip system whereas at higher strains generation occurs in many slip systems as suggested by Lange and Lucke.⁽¹⁾

II. Distinction Between Ductile and Brittle Materials

At present there exists no successful way to understand the fact that some materials are brittle whereas others are ductile. For example, it cannot be claimed that brittle materials do not contain dislocations since all bulk materials examined thus far have been found to contain dislocations. The supposition that brittle materials contain cracks which give rise to stress concentrations thus causing fracture does not give a satisfactory solution to the problem because experimentally it is found that fracture occurs at such large stresses that one would expect the existing dislocations to glide and thus relieve the stresses.

It appears therefore that in some way the dislocations are anchored. Orowan⁽¹²⁾ has suggested that in certain perfect crystals the stress required to move a dislocation through one atomic distance is very large in certain materials. It seems difficult to understand on this basis why rock salt is brittle at room temperature and silver chloride which has the same lattice and essentially the same kind of binding is quite ductile. We have suggested⁽³⁾ that brittle materials contain "hollow" dislocations while ductile materials contain "solid" dislocations. In the case of a "hollow" dislocation the axis of the dislocation is a region where the atomic or ionic density is much lower than it is in the perfect crystal. Theoretical calculations indicate that ionic crystals are much more likely to contain "hollow" dislocations than metals.

We would like to seek experimental evidence for "hollow" dislocations. It is possible, if a high density of dislocations can be introduced and if the radius of the "hollow" is sufficiently large that measureable density changes would be associated with "hollow" dislocations. The dislocations would be introduced by deformation at high temperature where the ionic crystals are ductile. The material would then be annealed to allow climb of the edge dislocations thus producing the "hollows"; then the specimen would be slowly cooled. If 3×10^{10} edge dislocations per cm^2 can be retained and if only one ion is missing per atomic length of dislocation in rock salt then the density decrease would be about one part in 10^5 which is just measureable. We are at present searching for crystals which have larger "hollows". Carborundum is such a crystal, but simpler crystal structures would be preferred.

Once a measureable density decrease has been obtained, a scattering experiment using sound or light waves would be done to determine the shape of the regions of low ionic density. This is necessary because deformation also produces vacancies which may cluster to produce voids.

It is also planned to obtain deformation data on rock salt and silver chloride single crystals of various orientations at various temperatures. Such data would be used to check calculations made by Dr. Robb Thompson⁽³⁾ of our laboratory who predicts that at low temperatures in rock salt the glide plane will be the 110 plane whereas at high temperatures the 100 plane may become active.

It is also possible that the velocity of a moving dislocation can be measured by stressing an ionic crystal between crossed Nicol prisms. Schmid and Boas in their book show pictures which demonstrate the sudden appearance of double refraction along the slip lines which form in rock salt and in K Cl. To date little is known either theoretically or experimentally about dislocation dynamics.

The birefringence data will also be useful to test Lange and Lucke's⁽¹⁾ contention that during easy glide dislocation generation only occurs on one slip system whereas they believe that in the later stages of deformation generation occurs on all possible glide systems.

III. Twinning

Blewitt, Coltman and Redman⁽⁴⁾ have demonstrated that copper will produce deformation twins under large stresses at liquid helium temperature. The experiment indicates that the

mechanism of twinning in this case is not that suggested by Cottrell and Bilby⁽⁵⁾. We would like to attempt to produce deformation twins in aluminum at helium temperature. This may not be possible because the energy of a twin interface is much larger in aluminum than it is in copper

IV.

Jamison and Blewitt⁽⁶⁾ have shown that the yield stress of a brass decreases rapidly with increasing temperature in the temperature region below room temperature where diffusion of either zinc or copper is negligible. This can be understood by assuming, as Mott⁽⁷⁾ did, that dislocations zig and zag so as to pass through impurities. Mott did not calculate the influence of temperature on the phenomena. However it is clear that as the temperature increases the thermal fluctuations will pull the most loosely held dislocation loops free thus reducing the yield stress. We would like to calculate the temperature dependence of the yield stress using this model.

V. Damping and Elastic Constants

In an effort to measure in a vibrating crystal the energy dissipation and the amount of motion to be associated with a single dislocation loop two experiments are proposed. First, using X-ray techniques, measure the dislocation density. Then from the decrement and the Young's modulus data at various strain amplitudes the damping per cm and the amount of motion per loop can be found.⁽⁸⁾

These results can be checked by making measurements on a crystal which contains a small angle grain boundary (in which the dislocation density is known from the angle between the two grains).

The damping and modulus contributions of the interior of the grains can be found by arranging matters so that a stress node occurs at the grain boundary. The contribution of the boundary can then be evaluated from measurements made when a maximum in the stress occurs at the boundary. Measurements on tilt and on twist boundaries should reveal the relative effectiveness of edge and screw dislocations.

A. Personnel

The chief investigator would be Professor J. S. Koehler who would devote one quarter of his time to the supervision of this contract and to an O.O.R. contract which also involves plastic deformation. Professor Seitz would be available for brief consultation. Mr. Koehler will spend the remainder of his time on an A.E.C. Radiation Damage Contract. The research problems dealt with on the two contracts concerned with deformation are different.

B. Publications

1. J. S. Koehler, On the Nature of Work Hardening, Phys. Rev., April, 1952.
2. J. S. Koehler and F. Seitz, Dislocations in Ideal Crystals. Article to be published in a book on dislocations (A.S.M.).
3. P. Neurath and J. S. Koehler, Plastic Deformation of Pure Single Crystals of Lead and Copper, J. App. Phys. 22, p. 621 (1951)
4. J. S. Koehler, On the Production of Large Tensile Stresses by Dislocations, Phys. Rev., February 15, 1952.
5. J. Marx and J. S. Koehler, Decrement and Young's Modulus Measurements on Single Crystals of Copper and Lead, Pittsburgh Symposium on Elastic Deformation, p. 171 (1950).

6. T. H. Blewitt and J. S. Koehler, The Lamellar Nature of Slip and Its Implications, Pittsburgh Symposium on Plastic Deformation, p. 77 (1950).
7. M. Peach and J. S. Koehler, The Forces Exerted on Dislocations and the Stress Fields Produced by Them, Phys. Rev. 80, p. 436 (1950)
8. J. S. Koehler, The Influence of Dislocations and Impurities on the Damping and Elastic Constants of Metal Single Crystals, article in book on Imperfections in Crystalline Solids, Wiley (1952).
9. J. S. Koehler, A. Calculation of the Changes in the Conductivity of Metals Produced by Cold-Work, Phys. Rev. 75, p. 106 (1949).
10. J. S. Koehler and F. Seitz, Proposed Experiments for Further Study of the Mechanism of Plastic Deformation, J. App. Mech. 14, p. 217 (1947).
11. J. S. Koehler, Work Hardening in Face Centered Substitutional Alloys, Acta Met, 1, p. 508 (1953).
12. J. Weertman and J. S. Koehler, Internal Friction and Youngs Modulus of Cold-Worked Copper Single Crystals, J.A.P. 24, 624 (1953).
13. E. Salkovitz and J. Koehler, Energy Absorption and X-Ray Studies of Kink Formation in Zinc Single Crystals, Acta Met, 1, p. 552 (1953).

C. Training of Students.

It is anticipated that two graduate students in physics will do their thesis research in connection with this project.

D. Facilities Available.

Equipment is at present under construction for stress-strain tests and electrical resistance measurements down to liquid helium temperature. Three vacuum furnaces are available for the growth of metal single crystals. X-ray apparatus is available for the orientation and the examination of specimens. Two RCA electron microscopes are available on the campus. An active low temperature

group exists. Liquid helium is produced in a Collins cryostat. Excellent shops, glass blowers, and electronic technicians aid in research work.

E. Cost Estimate and Duration.

It is proposed that the contract run for 1 year starting September 1, 1954 to August 31, 1956. A financial summary is given below which requests support from the Office of Naval Research in the amount of \$10,000 for the one year period.

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Proposed Budget for the Period

September 1, 1955 - August 31, 1956

Direct Charges

A. Salaries and Wages

1. Two (2) half-time research assistants at \$160. per month for 10 months	\$3,200.
2. Two (2) full-time research assistants at \$320. per month for two months	1,280.
3. Wages at \$75. per month	900.

Sub Total, Salaries and Wages \$5,380.

B. Expense and Equipment at \$175. per month 2,100.

C. Travel, Telephone and Telegraph 314.

D. Workmen's Compensation insurance at 2.0%
of salaries and wages 108.

Total, Direct Charges \$7,902

Indirect Costs

Overhead at 39% of salaries and wages 2,098.

Grand Total \$10,000.

References:

1. See A. H. Cottrell, Dislocations and Plastic Flow in Crystals
p 157 et seq Oxford (1953)
K. Lucke and H. Lange, Zeit. Metallk 43, p. 55 (1952)
2. E. Orowan, Dislocations in Metals, p. 126, A.I.M.E. (1954)
3. R. Thompson, H. B. Huntington, unpublished work
4. T. H. Blewitt, Phys. Rev. 91, p. 1115 (1953)
5. A. H. Cottrell, Dislocations and Plastic Flow in Crystals,
p 87 Oxford (1953)
6. See footnote in reference 4.
7. N. F. Mott, Imperfections in Nearly Perfect Crystals p. 179
Wiley (1952)
8. J. S. Koehler, Imperfections in Nearly Perfect Crystals
p. 197 Wiley (1952)

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