Seismic depth estimates arrived at do not take into consideration the possible presence of low velocity layers which are not unlikely in the area as revealed by some of the boreholes.

ACKNOWLEDGEMENTS

The author is indebted to all his colleagues without whose sincere co-operation it would have not been possible to carry out the work. The author is thankful to Shri. Y. R. Bhanumurthy, Superintending Geophysicist, for his guidance and encouragement during the course of survey. It is a pleasure to acknowledge Shri A. G. B. Reddi, Superintending Geophysicist for the valuable discussions the author had in bringing out this paper. The author is thankful to the Director-General, Geological Survey of India, for his kind permission to publish this paper. The author is thankful to the O.N.G.C. authorities for making available the lithological logs of the boreholes under 'Shallow Drilling Programme' in the Pondicherry area.

1. Kailasam, L. N., *A Preliminary Report on the Gravity and Magnetic Surveys in the South Aroct District, Madras State*, Unpublished report of G.S.I., 1956.
2. Hawkins, L. V., "Nomograms for determining maximum errors and limiting conditions in seismic refraction survey with blind zone problem," *Geophysical Prospecting*, 1962, 9.
3. Subrahmanyam, B., Mukherji, B. B. and Ramarao, M. S. V., *Report on the Geophysical Investigations for Groundwater in Pondicherry State and Adjoining Parts of South Arcot District, Tamil Nadu*, Unpublished report of G.S.I., 1970.

DEFORMATION BEHAVIOR OF POLYCRYSTALLINE ZINC AT 4·2° K

Y. V. R. K. PRASAD* AND N. M. MADHAVA**

Engineering Materials Group, and Department of Mechanical Engineering, University of Maryland, College Park, Md. 20742, U.S.A.

A STUDY of the deformation characteristics of metal at very low temperatures is of considerable interest in view of the restricted occurrence of thermally activated slip processes. This is particularly so in hexagonal close packed (h.c.p.) metals because of the existence of only a limited number of operative slip systems. Several h.c.p. metals such as Be, Zn and Mg are brittle at low temperatures[1] and therefore their deformation behavior upto a reasonable magnitude of strain can be studied only under compression. In this study the nature of plastic deformation of polycrystalline zinc including strain rate effects under compression at 4·2° K is reported.

Cylindrical specimens with 5 mm diameter and 13·6 mm height were machined from hot rolled zinc material (99·98%) and were annealed at 150° C for one hour in a paraffin oil bath. The resulting average grain diameter was 0·036 mm. Compression testing was carried out on an Instron machine employing a compression jig which uses spherical ball bearings for the axial application of load to the specimen. The tests at 4·2° K and 77° K were conducted by surrounding the specimen with liquid helium and nitrogen, respectively, contained in suitable cryostats.

The force *versus* cross-head displacement curves recorded for the zinc material at 4·2° K and 77° K are shown in Fig. 1. After the material was deformed to some plastic strain, the cross-head speed and chart speed were changed by one order of magnitude with a view to examining the effect

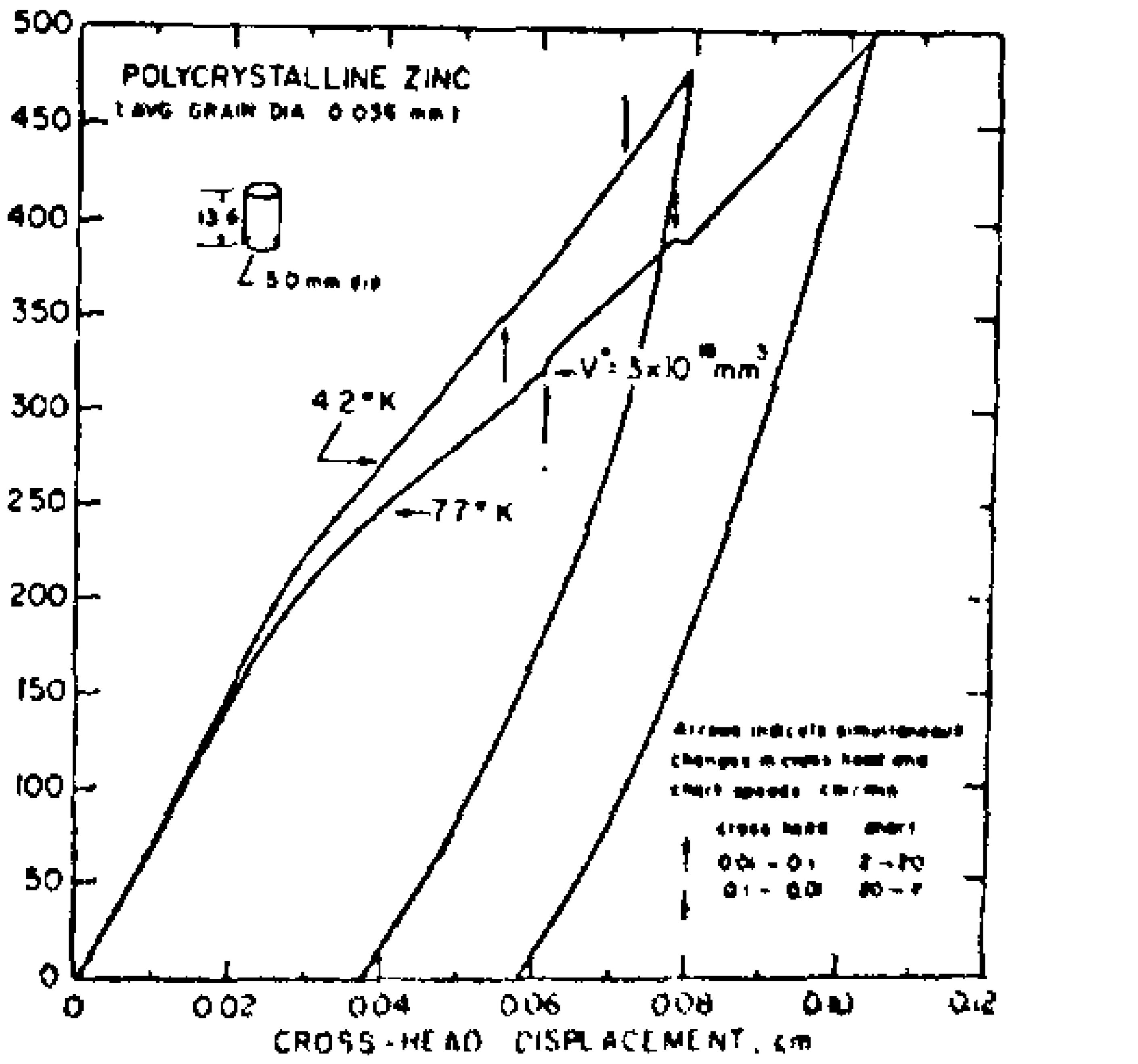

FIG. 1. Load *versus* cross-head displacement curves recorded on polycrystalline zinc material deformed at 4·2° K and 77° K under compression.

* On leave from Department of Metallurgy, Indian Institute of Science, Bangalore.

** On leave from Materials Science Division, National Aeronautical Laboratory, Bangalore.

of a strain rate change. The load—displacement curves show the following striking features:

(*i*) The apparent work hardening rate of the material is very large, being larger at 4·2° K ($\approx$ 340 kg/mm²) than at 77° K ($\approx$ 240 kg/mm²), and is about one-tenth of the shear modulus of zinc material.

(*ii*) The strain rate sensitivity of the flow stress at 4·2° K is nearly zero, in spite of the high work hardening rate. This implies that the activation volume, v^*, given by:

$$v^* = m\,(\Delta\, ln\,\dot{\epsilon}/\Delta\sigma)_r\,RT, \qquad (1)$$

which is a parameter commonly used to express the effect of strain rate ($\dot{\epsilon}$) on the flow stress (σ) at constant temperature (T), is therefore nearly zero at 4·2° K. In equation (1), R is the gas constant and m is an orientation factor approximately equal to 6·5. The activation volume from measurements at 77° K, was calculated to be, 3×10^{-18} mm³.

(*iii*) The stress at which permanent deformation occurs at 4·2° K is nearly the same as at 77° K.

These features clearly indicate that the deformation process occurring at 4·2° K is essentially athermal in nature and hence the occurrence of mechanisms based on thermally-activated slip processes can be ruled out. Alternately, deformation twinning and/or cracking are to be considered. At these low temperatures, mechanical twinning occurs in competition to slip since the resolved shear stress for slip is large under these conditions. Moreover, because of the restricted number of slip systems, mechanical twinning is an important mode of deformation in h.c.p. metals at low temperatures. It is known, in fact, that $(10\bar{1}2)$ $[\bar{1}011]$ twins occur in zinc even at relatively higher temperatures[2]. As deformation twinning is a shear process involving cooperative movement of atoms through a material volume within microseconds, the temperature and strain rate do not appear to have an appreciable influence on the flow stress and hence the deformation caused by twinning can be considered as an essentially athermal process. This appears to be a good possibility of accounting for the apparent zero activation volume observed in the present investigation. In addition to the twinning process, it is also possible that the yielding of this material under compression is associated with the nucleation and growth of cracks which are again normally taken to be athermal processes. The propagation of cracks is thought to be rather slow under compression as a result of which the material exhibits reasonable ductility before fracture. Thus twinning as well as cracking processes might be responsible for the apparent athermal nature of deformation of this material at 4·2° K.

It is perhaps interesting to compare the deformation behavior of zinc material with that of another h.c.p. metal deformed at 4·2° K, namely, titanium. Madhava and Armstrong[3] have observed that polycrystalline titanium exhibits discontinuous deformation at 4·2° K in a somewhat similar manner to that found by Madhava, Worthington and Armstrong[4], in steel material. Deformation twinning was suggested by these workers as the probable mechanism for this observation. In zinc material, however, the occurrence of cracking is an added consideration besides deformation twinning.

The authors are thankful to Professor R. W. Armstrong under whose supervision this work was conducted. Acknowledgement is given for the support of this research at the University of Maryland by the United States Office of Naval Research, Contract N 00014-67-A-0239-0011, NR 031-739.

1. Armstrong, R. W., *Acta Met.*, 1968, **16**, 347.
2. Bell, R. L. and Cahn, R. W., *Proc. Roy. Soc.*, 1957, **239 A**, 494.
3. Madhava, N. M. and Armstrong, R. W., Submitted to *Met Trans.*
4. —, Worthington, P. J. and Armstrong, R. W., *Phil. Mag.*, 1972, **24**, 519.