1974-05-06

High temperature texture strengthening in zinc

Edwards, G.R.

http://hdl.handle.net/10945/43196

HIGH TEMPERATURE TEXTURE STRENGTHENING IN ZINC

G. R. Edwards[+], T. R. McNelley[++], and O. D. Sherby[+++]
[+] Department of Mechanical Engineering
Naval Postgraduate School, Monterey, California.
[++] Department of Mechanical Engineering
University of Wyoming, Laramie, Wyoming.
[+++] Department of Materials Science and Engineering
Stanford University, Stanford, California.

December 1973

We have investigated the compressive creep behavior of zinc over a wide range of temperatures (0.43 to 0.95 T_m) and strain rates (3×10^{-8} to 3×10^{-2} sec^{-1}) as part of an investigation of zinc-based particulate composites (1-3). Sample material was prepared by a powder metallurgy technique incorporating alternate room temperature rolling and high-temperature extrusions into 3/8" diameter rods. Such processing created a duplex grain structure of elongated grains, 20 to 100 microns wide and 200 to 500 microns long, surrounded by equiaxed grains 5 to 20 microns in diameter. Furthermore, the product possessed a strong crystallographic fiber texture; about 75% of the basal planes were within 5° of being parallel to the extrusion axis (oriented radially to the extrusion axis) and about 50% of the prism planes were within 5° of being perpendicular (or at 60°) to the extrusion axis (1,2,4). Details of the processing technique (3) and the microstructure (5) created by it appear elsewhere. Mechanical testing was performed utilizing a Model TT-C Instron configured for high-temperature compression; a few low stress/high temperature compression creep tests were made using an experimental apparatus and technique described previously (6).

The purpose of this note is to illustrate the large anisotropy in strength observed by us in the textured zinc sample and to compare the results with other high temperature creep data reported for polycrystalline zinc. The salient feature of our results was the following: for the entire range of testing, samples deformed by uniaxial loading parallel to the extrusion axis were consistently 1.5 to 2 times stronger than samples deformed by loads applied parallel to the extrusion axis. These results are shown in Figure 1, where the flow stress at 10% strain is plotted against the absolute temperature.

In spite of the presence of ~1.5% ZnO introduced by sample preparation (1,2,4), longitudinal samples of our extruded zinc rods behaved exactly as predicted by current phenomenological theory for creep of pure metals (7,8). The material exhibited a well-defined power law region, with a stress exponent of 4.5 to 5.0 and creep activation energy near the lattice self-diffusion activation energy, 23,000 cal/mole. In the high stress/low temperature range of the data, a normal power-law breakdown was observed, and the creep activation energy decreased to ~ 14,000 cal/mole. The low activation energy was interpreted by us to represent dislocation pipe diffusion. The activation energy for dislocation pipe diffusion, Q_p, has been shown (9) to be about equal to the activation energy for grain boundary diffusion, $Q_{g.b.}$, and $Q_{g.b.}$ for zinc is

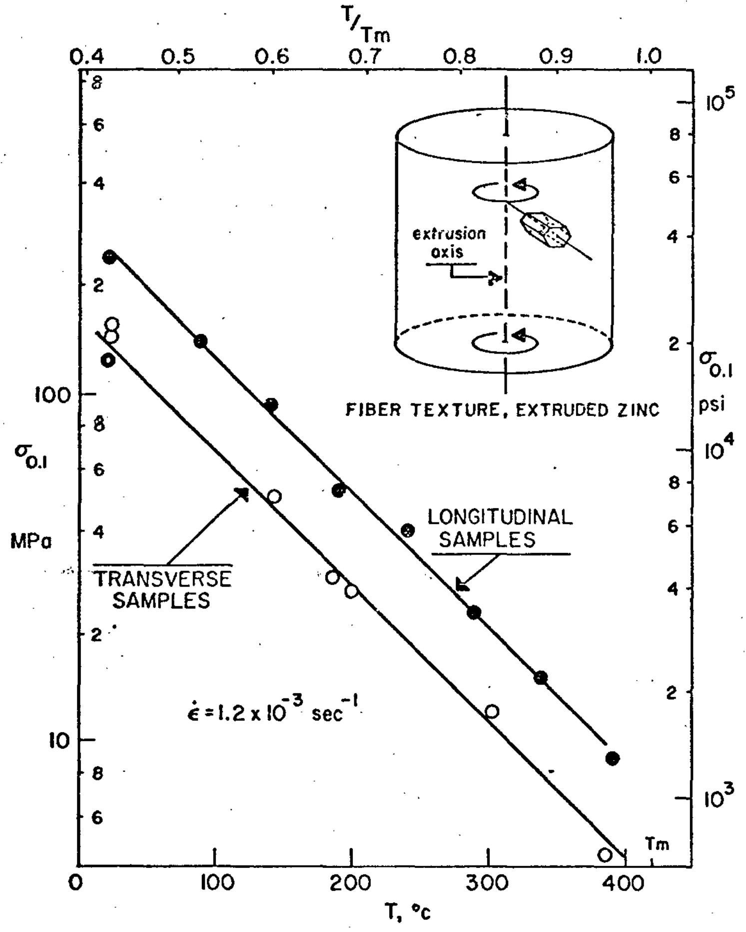

FIG. 1
Influence of texture on the high temperature strength of extruded zinc. A schematic illustration of the fiber texture developed by extrusion is shown.

14,300 cal/mole (10). We therefore analyzed the data over the entire range of testing by introducing an effective diffusion coefficient, in the manner suggested by Robinson et al. (11) and by Armstrong et al. (12). The precise expression employed for D_{eff} (in cm^2/sec) was:

$$D_{eff} = 0.4 \exp \frac{-23,000}{RT} + 11.54\ (\sigma/E)^2 \exp \frac{-14,300}{RT} \quad (1)$$

The result of this analyzis was very satisfactory, as can be seen in Figure 2 (longitudinal samples), where the diffusion-compensated strain rate ($\dot{\varepsilon}/D_{eff}$) is plotted versus modulus-compensated flow stress (σ/E). When transverse data were reduced to a form suitable for Figure 2, transverse creep rates were found to be 50 to 100 times faster than longitudinal creep rates. Such large anisotropic effects have not been previously observed; similar studies of copper (13) and iron-silicon (14) found anisotropic creep effects of only a factor of two or three in creep rate.

We believe that anisotropic creep behavior in our powder metallurgy zinc is a manifestation of its strong preferred crystallographic orientation. The concept of anisotropic mechanical properties resulting from preferred orientation has long been accepted as an important consideration at low temperatures, especially for hcp materials. Crystallographic texture, however, has never been a part of any of the many phenomenological creep theories.

Our observations on the very large anisotropic effects observed in our textured zinc may also

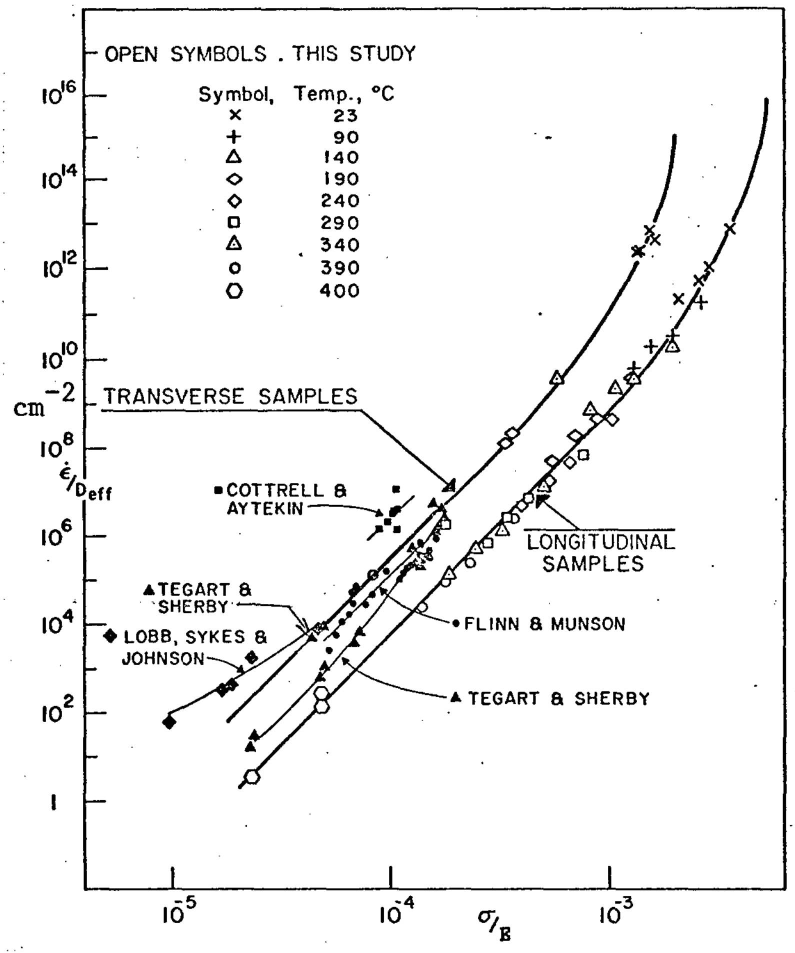

FIG. 2

Influence of texture on the creep strength of zinc, plotted as diffusion-compensated creep rate versus modulus-compensated creep stress. The difference in creep rate noted from various investigations can be attributed to a difference in texture. The values of E were taken from the work of Koster (20).

explain the discrepancies in the creep behavior of zinc which have been reported in the literature. Figure 2 illustrates data taken from several investigations (15-18) using an effective diffusion coefficient to normalize for temperature differences in testing. The data from these various studies are found to fall roughly within the band established by our data.

The creep behavior of close-packed metals can be examined by comparing their flow stress at the same value of diffusion-compensated strain rate ($\dot{\epsilon}/D = 10^7$ cm^{-2}) (7,19). Figure 3 plots these flow stresses against elastic modulus, the one remaining major variable (7,8). The strength of our transverse zinc samples compares favorably with the flow stresses of other close-packed metals; this is reasonable since the transverse samples exhibit a texture more nearly like a random polycrystalline aggregate (a large fraction of the transverse compression sample can deform by basal slip). The marked texture strengthening in our longitudinal zinc samples is very evident in Figure 3. These results would suggest a high potential for high-temperature texture strengthening in such anisotropic materials as α-Zr, α-Ti and α-Be.

We do not yet specifically understand this texture strengthening effect in creep; the effect could possibly be associated with any of at least three anisotropic phenomena: a) a critical resolved shear stress (CRSS) effect, b) a subgrain formation effect, or c) a modulus effect.

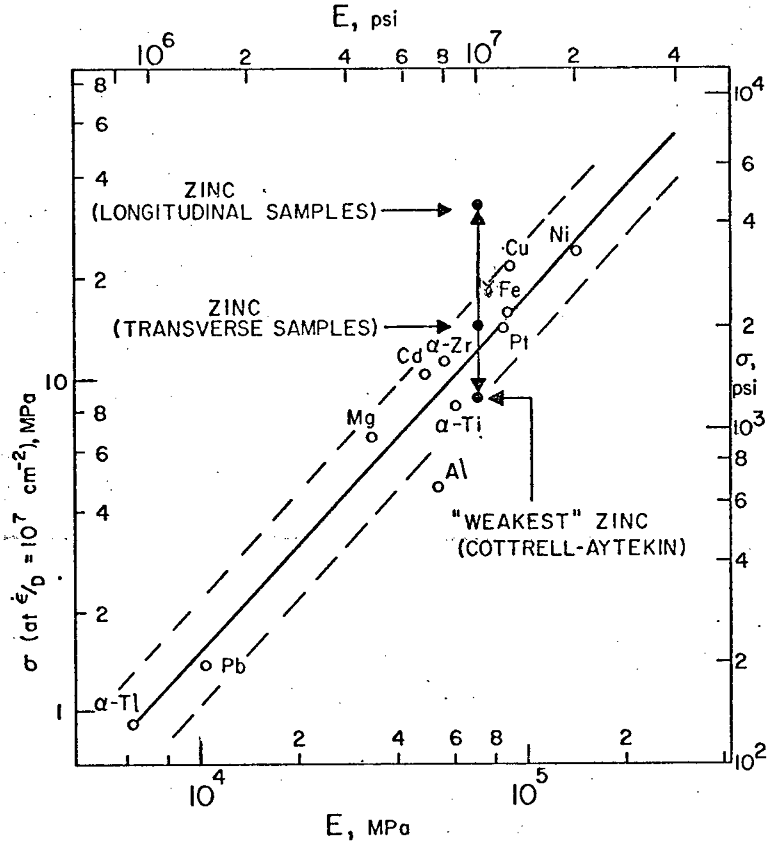

FIG. 3

Relation between high temperature flow stress (at constant strain rate/diffusivity ratio) and elastic modulus for a number of close-packed polycrystalline metals. The effect of texture on the strength of zinc is illustrated; transverse samples of this study are similar in strength to other close-packed metals.

The CRSS effect, a) above, refers to the fact that each slip system of any crystal structure is unique in its ease of activation; if the most facile slip systems are unfavorably oriented with respect to the applied stress because of a strong texture, less easily activated slip systems may be forced to operate to maintain sample integrity. An increased nominal flow stress then will result, even if the nominal flow stress is a creep stress being measured at elevated temperature. As for the subgrain formation effect, the formation of subgrains in textured polycrystalline metals has been shown to be dependent on the direction of applied stress (14, 21). Since considerable evidence now exists that creep rate is strongly subgrain-size dependent (7,22) (recent data indicate $\dot{\varepsilon}$ proportional to λ^3), a change in the axis of loading of highly textured samples could conceivably alter the subgrain formation, and in turn alter the creep behavior. Finally, the anisotropy in elastic modulus may be responsible for anisotropic creep behavior. Elastic modulus has been shown to be an important variable in the analysis of high temperature deformation (7,23,24) as is illustrated in Figure 3. Since zinc exhibits high elastic anisotropy ($E_{\perp c}/E_{\parallel c}$ = 3.5 at high temperature) (25), this factor probably must be taken into account in any successful theoretical explanation of the texture strengthening we have observed in this work.

The authors gratefully acknowledge the financial support of the Office of Naval Research under Project N14-67-A0112-0021, and under the Naval Postgraduate School Foundation Research Grant Program. We wish to thank especially Drs. W. G. Rauch and B. A. MacDonald for their encouragement.

References

1. G. R. Edwards, Ph.D. Dissertation, Stanford University, August, 1971.
2. T. R. McNelley, Ph.D. Dissertation, Stanford University, January, 1973.
3. G. R. Edwards and O. D. Sherby, Intl. J. Powder Met. 7, 21 (1971).
4. W. H. McCarthy, Ph.D. Dissertation, Stanford University, Jan. 1966.
5. G. R. Edwards, J. C. Shyne and O. D. Sherby, Met. Trans. 2, 2955 (1971).
6. O. D. Sherby, Trans AIME 212, 708 (1958).
7. O. D. Sherby and P. M. Burke, Prog. in Mat. Sci. 13, 325 (1968).
8. R. Lagneborg, Intl. Met. Rev. 17, 130 (1972).
9. K. G. Kreider and G. Bruggeman, Trans. AIME 239, 1222 (1967).
10. E. S. Wajda, Acta Met. 2, 184 (1954).
11. S. L. Robinson and O. D. Sherby, Acta Met. 17, 109 (1969).
12. P. E. Armstrong, W. V. Green, O. D. Sherby and E. G. Zukas, Acta Met. 21, 1319 (1973).
13. C. R. Barrett, J. L. Lytton and O. D. Sherby, Trans AIME 239, 170 (1967).
14. J. L. Lytton, Ph.D. Dissertation, Stanford University, April 1962.
15. A. H. Cottrell and V. Aytekin, J. Inst. Met. 77, 389 (1950).
16. W. J. M. Tegart and O. D. Sherby, Phil. Mag. 3, 1287 (1958).
17. J. E. Flinn and D. E. Munson, Phil. Mag. 10, 861 (1964).
18. R. C. Lobb, E. C. Sykes and R. H. Johnson, Met. Sci. J. 6, 33 (1972).
19. S. L. Robinson, Ph.D. Dissertation, Stanford University, Dec., 1972.
20. W. Koster, Z. Metallk. 39, 1 (1948).
21. J. L. Lytton, C. R. Barrett and O. D. Sherby, Trans AIME 233, 1399 (1965).
22. S. L. Robinson, C. M. Young and O. D. Sherby, J. of Mat. Sci., in press.
23. J. Weertman, Trans ASM 61, 681 (1968).
24. J. E. Bird, A. K. Mukherjee and J. E. Dorn, Quantitative Relation Between Properties and Microstructures, p. 255. Israel Universities Press (1969).
25. G. Reinacher and E. Scheil, Z. Metallk. 39, 231 (1948).

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

UNCLASSIFIED

1. ORIGINATING ACTIVITY *(Corporate author)*

Stanford University
Stanford, California 94305

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

High Temperature Texture Strengthening in Zinc

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Report

5. AUTHOR(S) *(First name, middle initial, last name)*

G. R. Edwards, T. R. McNelley and O. D. Sherby

6. REPORT DATE

December 1973

7a. TOTAL NO. OF PAGES

5

7b. NO. OF REFS

25

8a. CONTRACT OR GRANT NO.

N00014-67-A0112-0021

b. PROJECT NO. NR 031-715

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

Distribution of report is unlimited. Reproduction in whole or in part is permitted for any purposes of the United States Government.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

U. S. Office of Naval Research

13. ABSTRACT

It is shown that the high temperature creep strength of polycrystalline zinc is a strong function of the texture developed in the material. Powder metallurgy extruded zinc exhibits creep rates that are about 50 to 100 times slower in longitudinal samples than in transverse samples in the temperature range from 0.45 to 0.95 T_m. Such large anisotropic effects have not been previously observed and the results obtained suggest a high potential for elevated temperature texture strengthening of such materials as α-Ti, α-Zr and α-Be. The large texture strengthening effect observed in polycrystalline zinc may arise from (1) a direct orientation effect (i.e. one may only need to resolve the proper shear stress and thus obtain an effective stress which controls the creep rate), (2) a subgrain size effect if size of subgrains are dependent on texture and (3) a modulus effect if anisotropy of elastic constants are important in creep of polycrystals. Creep hardening by control of texture in polycrystalline solids has not been considered in contemporary creep theories.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Zinc Powder Metallurgy Creep High Temperature Strength Anisotropy Texture Hexagonal close-packed metals						