6 C. R. Kennedy, W. O. Harms, and D. A. Douglas, "Multiaxial Creep Studies on Inconel at 1500 Deg F," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, vol. 81, 1960, p. 599.

7 A. M. Wahl, "Effects of the Transient Period in Evaluating Rotating Disk Tests Under Creep Conditions," ASME Paper No. 62—Met-10.

8 Yu N. Rabotnov, *Plasticity*, Pergamon Press, Oxford, 1960, p. 338.

9 E. M. Smith, "Axial Deformation in Thick Tubes Creeping Under Internal Pressure," *Journal of Mechanical Engineering Science*, 1964, vol. 6, p. 418.

10 "Creep of Thick-Walled Tubes Subjected to Internal Pressure," Technical Report No. 2, Mechanical Engineering Research Annexe, University of Glasgow, 1962.

11 R. H. King, "Creep of Thick-Walled Cylinders Under Internal Pressure," PhD thesis, University of Glasgow, 1964.

12 R. H. King, "The Prediction of the Creep Behavior of Thick-Walled Tubes Subjected to Internal Pressure," Technical Report No. 17, Mechanical Engineering Research Annexe, University of Glasgow, 1966.

13 D. N. Allen and D. G. Sopwith, "The Stresses and Strains in a Partly Plastic Thick Tube Under Internal Pressure and End Load," *Proceedings of the Royal Society*, Series A, vol. 205, 1951, p. 69.

14 R. W. Bailey, "The Utilization of Creep Test Data in Engineering Design," *Proceedings of the Institution of Mechanical Engineers*, London, 1935, vol. 131, p. 131.

15 C. D. Weir, "Creep of Thick Tubes Under Pressure," *Journal of Applied Mechanics*, vol. 24, TRANS. ASME, vol. 79, 1957, p. 464.

16 J. F. Traexler, "The Design of Pressurized Cylinders for High Temperature Applications," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, Vol. 82, 1960, p. 477.

17 I. Finnie, "Steady-State Creep of a Thick-Walled Cylinder Under Combined Axial Load and Internal Pressure," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, vol. 82, 1960, p. 689.

18 P. J. Rimrott, "Creep of Thick-Walled Tubes Under Internal Pressure," *Journal of Applied Mechanics*, vol. 26, TRANS. ASME, vol. 81, Series E, 1959, p. 271.

19 A. E. Johnson, J. Henderson, and B. Khan, "Behavior of Metallic Thick-Walled Cylindrical Vessels or Tubes Subject to High Internal or External Pressures at Elevated Temperatures," *Proceedings of the Institution of Mechanical Engineers*, vol. 175, 1961, p. 1043.

20 H. Poritsky and F. A. Fend, "Relief of Thermal Stresses Through Creep," *Journal of Applied Mechanics*, vol. 25, TRANS. ASME, vol. 80, Dec., 1958, pp. 589–597.

21 A. Mendelson, M. H. Hirschberg, S. Manson, "A General Approach to the Practical Solution of Creep Problems," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, vol. 81, 1959, p. 585.

22 E. M. Smith, "Analysis of Creep in Cylinders, Spheres, and Thin Disks," *Journal of Mechanical Engineering Science*, vol. 7, 1965, p. 82.

23 I. Berman and D. H. Pai, "A Theory of Anisotropic Steady-State Creep," *Int. J. Mech. Sciences*, vol. 8, 1966, pp. 341–352.

DISCUSSION

D. H. Pai[2]

The authors are to be commended for their careful work on creep of thick-walled cylinders. Their emphasis on the influence of material anisotropy on creep behavior of structures subjected to complex stress states is correctly placed.

Based on a special case of the general model presented in reference [23] of the authors' paper, this writer has analyzed the thick-walled cylinder problem in a subsequent paper.[3] It is shown therein that material creep anisotropy does indeed have a great effect on the radial displacement rates (hence diametral strains as measured in the authors' experiments) in a thick-walled cylinder. It was also shown that for the particular case of a thick-walled cylinder under internal pressure, the difference in creep rates between tension and compression under identical environments can also contribute greatly to errors in the usual isotropy assumption. In reference [23] of the authors' paper, this type of behavior was also classified as material anisotropy and some examples were cited as references [10, 11, and 12] in the said paper. This type of material creep anisotropy is probably a general rule rather than an exception and it should be accounted for in creep analysis under multiaxial stress states as well as the conventional sense of material anisotropy (i.e.; direction preference as exhibited in tensile specimens taken from different directions).

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[3] Pai, D. H., "Steady State Creep Analysis of Thick-Walled Orthotropic Cylinders," *International Journal of Mechanical Sciences*, Vol. 9, June 1967, pp. 335–348.

Authors' Closure

The authors would like to thank Dr. Pai for his interesting comments on the anisotropic behavior of materials at elevated temperatures, and for the references to his recent paper on the relevance of this problem to a thick-walled cylinder. They agree with him that the material behavior under compressive stress as well as in tension must be determined before the form of the creep-rate/stress relations as used in the present analysis can be accepted but suggest that the problems of experimental technique involved in such an investigation would render an approach of such precision impracticable. This raises the important point of whether a complex highly detailed analysis of the type employed by the authors (and found to an increasing extent in the literature on deformation at elevated temperature) is justifiable at the present time in light of the many ill-defined aspects of material behavior mentioned both in Dr. Pai's contribution and in the authors' Introduction. The answer to this question will only be found after careful experiment rather than by profound theoretical discourse.