BARK-LM 64-0022

JOURNAL OF APPLIED PHYSICS VOLUME 35, NUMBER 4 APRIL 1964

Dynamic Response of Aluminum*

L. M. BARKER AND C. D. LUNDERGAN
Sandia Corporation, Albuquerque, New Mexico

AND

WALTER HERRMANN
Division of Sponsored Research, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received 12 November 1963)

The dynamic stress–strain relation of aluminum was measured in compression to a stress of 22 kbar using plate impacts to induce uniaxial strain. The results were compared to a uniaxial strain curve constructed from elastic moduli and quasistatically determined stress–strain curves. The dynamically determined stress–strain relation was not unique in that it varied as a function of the magnitude of the induced stress and was offset from the quasistatic curve. These small deviations are attributed to strain rate effects. The rate effects were further demonstrated by observing the transmission of an elastic compression stress wave in aluminum after the aluminum was dynamically stressed beyond the yield point and held at constant strain for a period of approximately 2 μsec.

The dynamic stress–strain relation was measured upon the release of a shock induced compressive stress of 10.5 kbar to a tension of −9 kbar by observing the effects of tensile stress waves. The deviation of the unloading stress–strain relation from that predicted by simple elastic–plastic theory is attributed to strain rate and Bauschinger effects.

INTRODUCTION

THE locus of states that can be attained by a solid when it is subjected to compressive shock loading is referred to as the dynamic stress–strain relation. The model used to describe the response of the medium to shock loading depends upon the magnitude of the induced stress relative to the yield stress. In the high-pressure region, where the induced stress greatly exceeds the stress which can be supported by the rigidity of the medium, a hydrodynamic model has been used.[1–3] For the lower stress region, where rigidity effects are not negligible, an elastic–plastic model has been assumed.[4,5]

Nearly all problems in which a knowledge of the loading behavior is important would be aided by a knowledge of the unloading behavior of the material; i.e., the family of stress–strain paths followed during the release of stress from the various points on the loading curve. At present, however, only a few experiments have been reported which provide some insight into the form of the reverse-strain paths. Al'Tshuler *et al.*,[6] have observed elastic release waves propagating in material precompressed by a plane shock of the order of 400 kbar. Curran[7] has observed substantial premature attenuation of a 200-kbar shock in aluminum by a following rarefaction wave which he attributed to an unexpectedly large amplitude elastic release wave preceding the plastic rarefaction wave. The magnitude of the elastic release indicates that rigidity effects are probably more important at high pressures than formerly considered. In the low-pressure region, only one point, the residual strain point at zero longitudinal stress, has been measured on the reverse strain path.[8]

The results of our one-dimensional plate impact experiments were used to deduce a complete dynamic stress–strain path for aluminum, and include the reverse straining from a compressive stress of 10.5 kbar into the tension region to the incipient spall threshold (−9 kbar[9]), in order to further clarify the characteristics of the release paths from states of low plastic strain. In essence, the reverse strain path was obtained by observing the propagation characteristics of rarefaction waves; i.e., by knowing an input wave shape at one point in the specimen and by observing the wave shape after a lapse of time. Since the rarefaction wave originates with the reflection of a compressive wave at a free boundary, an accurate determination of the compressive wave shape, and hence the dynamic stress–strain relation, was an important part of the study. The precision measurements of the loading curves of aluminum up to 22 kbar clearly show the effects of a small strain rate sensitivity in one-dimensional strain shock loading. This behavior is discussed in some detail because of its own sugnificance.

* This work was supported in part by the U. S. Atomic Energy Commission and, under contract AF 29(601)-4601, by the Air Force Weapons Laboratory, USAF. Reproduction in whole or in part is permitted for any purpose of the U. S. Government.

[1] J. M. Walsh and R. H. Christian, Phys. Rev. **97**, 1544 (1955).

[2] M. H. Rice, J. M. Walsh, and R. G. McQueen, *Solid State Physics*, edited by F. Seitz and D. Turnbull (Academic Press Inc., New York, 1958), Vol. 6, p. 1.

[3] L. V. Al'Tshuler, A. A. Bakanova, and R. F. Trunin, Zh. Eksperim. i Teor. Fiz. **42**, 91 (1962) [English transl.: Soviet Phys.—JETP **15**, 65 (1962)].

[4] G. R. Fowles, J. Appl. Phys. **32**, 1475 (1961).

[5] C. D. Lundergan and W. Herrmann, J. Appl. Phys. **34**, 2046 (1963).

[6] L. V. Al'Tshuler, S. B. Kromer, M. I. Brazhmik, L. A. Vladimirov, M. P. Speramskaya, and A. I. Funtikov, Zh. Eksperim. i Teor. Fiz. **38**, 1061 (1960) [English transl.: Soviet Phys.—JETP **11**, 766 (1960)].

[7] D. R. Curran, J. Appl. Phys. **34**, 2677 (1963).

[8] W. F. Hartman (unpublished).

[9] B. M. Butcher, L. M. Barker, D. E. Munson, and C. D. Lundergan, Am. Inst. Aeron. Astron. J. (to be published).