JOURNAL OF APPLIED PHYSICS VOLUME 38, NUMBER 13 DECEMBER 1967

Attenuation of Shock Waves in Aluminum*

J. O. ERKMAN† AND A. B. CHRISTENSEN‡

Poulter Laboratory, Stanford Research Institute, Menlo Park, California

(Received 30 March 1967; in final form 19 July 1967)

Targets of 2024-T351 aluminum were shocked to approximately 110 kbar and 340 kbar by flyer plates having velocities of 0.12 and 0.32 cm/μsec, respectively. Free-surface velocities were determined as a function of target thickness by recording the time of flight across known distances of thin shims which were originally in intimate contact with the surfaces of the samples. The experimental data are believed to be more accurate than any obtained previously. In earlier work it appeared that the free-surface velocity decreased in a stepwise manner as the target thickness was increased. The new data do not show a stepwise decrease, so the simple elastoplastic relations cannot be used to predict attenuation. Some improvement in the predictions was obtained by using a variable shear modulus. The relation between the shear modulus and the strain was obtained from the results of the attenuation experiments. Further improvement may be obtained by the inclusion of the Bauschinger effect in the calculations. Some data were obtained for annealed 1060 aluminum at 110 kbar. The response of 1060 aluminum appears to differ significantly from that of the hard aluminum.

I. INTRODUCTION

The work reported here is an extension of earlier work in which the decay of shock waves in several solids was observed and compared with predictions based on various assumptions concerning the pressure-release curves.[1–3] This earlier work showed the rigidity is significant in several materials studied at pressures up to at least 100 kbar. Agreement between experiment and theory was improved in most cases by assuming an elastoplastic model (in place of a hydrodynamic model) and a particular functional dependence of the yield stress and the shear modulus on the pressure.

Recent studies on aluminum were aimed toward obtaining more explicit information on the variation of the shear modulus and the yield stress at high pressures, and toward obtaining more accurate knowledge of the shape of the pressure-release curve in the immediate vicinity of the shocked state. In this region the elastic and plastic relief waves are most distinctly separated so that the shear modulus and yield stress might be determined. The major portion of the work was performed with 2024-T351 aluminum in the as-received condition. Some work was also performed on type 1060 aluminum to determine whether the high-pressure behavior depends significantly on the initial condition.

Shock waves were produced in specimens of the test materials by impacting them with aluminum plates that had been accelerated to a high velocity by charges of high explosive. The velocities of the plates were determined either optically by means of a streak camera, or electronically by the use of contact pins.

II. EXPERIMENTAL TECHNIQUES

A. Shim Technique for Free-Surface Velocity Measurements

The free-surface velocity of a shock-loaded sample can be determined by several different methods.[4] One of the simplest is to record the time of flight of the free surface across a gap. This method has the disadvantage that it gives an average velocity in those cases in which the shock is not a uniform shock, i.e., the pressure profile is not flat-topped. What is wanted from the measurement is the velocity of the surface at the instant of reflection of the shock wave. The measurement can be made more accurately if a thin (with respect to the stress gradient behind the shock front) shim is held in contact with the specimen. Because the shim is made of the same material as the specimen, it acquires the same velocity as the free surface. If there is any attenuation of the shock, the surface of the specimen is decelerated but the shim continues at uniform velocity. The reflectivity of an aluminum shim changes sufficiently when it is accelerated by a shock so that its initial motion can be detected on a streak camera record (see line *A-A* in Fig. 1). The gap is defined by a glass witness plate (which may be partially coated with gold) set at a known distance from the original position of the shim. When the shim collides with the witness plate, another change of reflectivity occurs, so the arrival can be observed in the record (line *B-B* in Fig. 1). The elastic precursor wave in as-received 2024-T351 aluminum does not change the reflectivity of the shim sufficiently for the precursor to be observed. The gap closure caused by the

* This work was suponsored in whole by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, under contract No. AF 29(601)-6734.

† Present address: U.S. Naval Ordnance Laboratory, Silver Spring, Maryland.

‡ Present address: University of Denver, Denver, Colorado.

[1] D. R. Curran, J. Appl. Phys. **34,** 2677–2685 (1963).

[2] J. O. Erkman, "Hydrodynamic Theory and High Pressure Flow in Solids," Stanford Research Institute Project No. PGU-3712, Final Report, Contract No. DA-49-146-X2-095, 15 July 1963.

[3] J. R. Rempel and J. O. Erkman, "Shock Attenuation in Solid and Distended Materials," Stanford Research Institute Project No. GSU-4613, Final Report, Contract No. WLTR 64-119, 31 August, 1965.

[4] G. E. Duvall and G. R. Fowles, in *High Pressure Physics and Chemistry,* R. S. Bradley, Ed. (Academic Press Inc., New York, 1963), Chap. IX.