Mbar,[12] and the approximate value of V_0, 0.0025 Mbar, are also shown in the figure. The possible errors in the data at the high stress point are so large that no conclusive inferences can be drawn about functional relationships. However, relationships can be assumed that are consistent with the data; these permit calculations of shock decay to be made that can be usefully compared with experimental attenuation data. Three such relations are represented by the curves in Fig. 10. These are consistent with the model described in Sec. IV-B in that, for example, if Y varies according to curve A in Fig. 10(b), then G varies as curve A in Fig. 10(a). Curves labeled B and curves labeled C in Fig. 10 are also consistent. The basic difference between the three sets of curves is due to the different ways in which Y is assumed to vary with V. The differences in the curves representing the shear modulus are due to a weak coupling which exists in the mathematical model between Y and G.

The curves shown in Fig. 10 actually represent polynomials in μ, which for the curves labeled A are

$$G=0.287+2.99\mu-6.88\mu^2, \tag{16}$$

and

$$Y=0.0025+0.0407\mu-0.043\mu^2. \tag{17}$$

The hydrostat consistent with the above equations and the Hugoniot for aluminum is represented by

$$P=0.764\mu+1.37\mu^2+1.1\mu^3, \tag{18}$$

where $\mu=(V_0-V)/V$, and the units of G, Y, and P are megabars.

Note that the functions for G exhibit a maximum value near $\mu=0.217$ ($V=0.295$ cc/g). The corresponding pressure is about 250 kbar. It would be of considerable interest to better determine experimentally whether the shear modulus possesses such a maximum along the Hugoniot curve, since this would indicate a trend toward true fluid behavior.

D. Flow Calculations for 2024-T351 Aluminum

Results of flow calculations using the assumptions mentioned above are given in Fig. 11 for the lower-velocity case. The (a), (b), and (c) portions of each figure refer to the fits designated similarly in the preceding section and in Fig. 10.

For lower-impact velocities, fit (a) [Fig. 11(a)] shows reasonable agreement but exhibits a stepwise decrease in particle velocity that is not evident in the data. At higher velocities [Fig. 12(a)] this fit compares favorably at five plate thicknesses but falls off too quickly thereafter.

Fit (b) shows less of a step in the decay curve for lower-velocity impact, but falls off too slowly at the greater target thicknesses [Fig. 11(b)]. The agreement for higher impact velocity is quite good [Fig. 12(b)].

The effect of increasing the number of cells in the calculations is shown by the curve labeled "40" in Fig. 11(b). In this calculation the flyer plate was zoned to contain 40 cells rather than 20 as used in all the other calculations. Zoning the flyer plate with only 20 cells places the apparent point of overtaking at $x/x_0=4.5$; with 40 cells this point moves to $x/x_0=5.0$. Presumably, convergence to the experimentally observed value 5.5 would occur with increasingly fine zoning.

The fit shown as curve C in Fig. 10 clearly gives the least satisfactory fit to the decay curves, as shown in Figs. 11(c) and 12(c).

The results of these attempts to fit the decay curves indicate that the elastoplastic theory as formulated is probably too simple. No step in the decay curves can be clearly identified, at least for 2024-T351 aluminum. This implies that there is no pronounced separation of the elastic and plastic rarefaction waves. The most likely explanation for this difference is that a Bauschinger effect tends to spread the elastic rarefaction so that it merges with the following plastic wave. Bauschinger effects have been observed in plane shock waves at much lower pressures.[13,14]

V. CONCLUSIONS

The data show that the initial attenuation of a shock wave in aluminum is caused by a high-speed rarefaction wave. This wave is assumed to be elastic and its velocity can be accounted for by making reasonable assumptions as to the value of the bulk modulus and the shear modulus. Both moduli are assumed to depend on the strain. Data for 2024-T351 aluminum suggest that the shear modulus may have a maximum value when the stress is between 100 and 340 kbar. Effects of temperature were not accounted for in the behavior of either of the moduli.

In addition, the data suggest that 2024-T351 aluminum exhibits a Bauschinger effect. Annealed 1060 aluminum may not exhibit a strong Bauschinger effect. It appears to behave as a more idealized elastoplastic material than does 2024-T351 aluminum.

ACKNOWLEDGMENTS

The authors wish to thank G. R. Fowles, under whose direction the work was performed, J. H. Hannigan, who assembled the experiment, and D. G. Doran, who critically reviewed both the work and the manuscript.

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