DETERMINATION OF CONSTITUTIVE RELATIONS
FROM PLANE WAVE EXPERIMENTS

I. INTRODUCTION

The behavior of solids under impact loading at stresses above the linear range of material response has been a subject of study since about 1872.[1] The earliest work and much subsequent work has been done with experimental arrangements that produce conditions of one-dimensional stress, i.e. rod experiments.

Since the Second World War increasing attention has been given to plane waves, in which the strain is accurately one-dimensional. Because of this strain condition deformation of the material takes place under superimposed hydrostatic pressures and, at the higher stress levels, at elevated temperatures resulting largely from adiabatic compression.

The most distinctive feature of plane wave compression, however, is the existence of shock fronts. In these fronts the strain rates can be exceedingly high - in many cases exceeding the resolution capabilities of the recording instrumentation. Nonequilibrium states necessarily exist even in a steady-state shock. Thus, a relatively complete time-dependent and temperature-dependent constitutive relation is required to predict plane-wave propagation; by the same token a wide range of information about material properties can be obtained from plane-wave experiments.

The complexities of shock experiments are mitigated considerably by the accuracy with which the one-dimensional strain boundary condition can be produced. In rod experiments the corresponding one-dimensional stress condition is less easy to verify and has been a difficult and annoying problem in experiments near the impacted end.

The constitutive relation obtained from shock experiments is, however, that pertinent to one-dimensional strain, and it is probably unreasonable to expect that from experiments in this geometry alone one can infer a completely general constitutive relation. Nearly all experimental techniques measure only the stress component in the direction of propagation. The component in the direction tangential to the wavefront can usually only be inferred. Where hydrostatic compression data are available comparison with shock data permits the shear stress behind the shock front to be deduced. Alternatively, measurement of the states obtaining in the relief of stress (via a rarefaction wave) from a shocked state provides much information about the yield stress under shock conditions.

To a considerable degree shock waves have been used as experimental tools for the study of high pressure physical phenomena and several reviews have appeared in recent years which emphasize that aspect of shock wave physics.[2-6] For these studies stress anisotropy and stress relaxation effects are undesired complications and are frequently ignored. Such effects are not negligible at lower pressures or where wave propagation is the principal interest.

In this article we focus on the experimental aspects of nonlinear plane wave propagation in solids. Our attention is thus directed principally to stresses between the elastic yield point and stresses one or two orders of magnitude higher. To predict wave propagation in this regime requires a time-dependent constitutive relation for one-dimensional strain. The converse of this problem, namely how to deduce constitutive relations from observations of wave propagation, is the central theme of the paper. An earlier review of this aspect of shock wave physics has been given by Karnes.[7]

The remainder of this section is devoted to a brief description of some of the most important features of the shock transition. Section II reviews methods for producing plane waves, and describes recent developments in recording techniques for observing wave behavior.