## 1. Introduction

The introduction of a plane shock wave into a solid body provides a means for subjecting it to large, carefully controlled compression. Study of the effects of this compression, and the ensuing decompression, has formed the primary objective of the research to be reviewed here. Plane shock compression is accompanied by shear, so the shear strength of the material and its inelastic response are additional important considerations. Finally, shock compression is accompanied by heating attributable to both compression and dissipation and effects of this heating must be taken into account.

In typical experiments, loading is accomplished by impact or explosion. In some cases shock loading has been used to produce compressions as small as a fraction of one per cent while, in others, the density of the solid has been increased more than fourfold. The shock heating causes increases in temperature ranging from negligible amounts for weak shocks to values as high as several electron volts (several tens of thousands of kelvins) for the strongest shocks examined experimentally.

On a macroscopic scale, a shock-compression experiment comprises a precise, orderly, and comprehensible sequence of events. However, this sequence evolves rapidly. The shock itself may rise to full amplitude in a time not exceeding a few nanoseconds and a typical experiment runs its entire course in only about a microsecond. It is during this period, while the substance is in a thermodynamic state that is difficult or impossible to produce by other means, that interesting physical phenomena present themselves for examination. Unfortunately, one cannot terminate a completed experiment in the same orderly fashion in which it was conducted. The aftermath imprinted in our human experience is often a violent explosion accompanied by much rending of metal, splintering of wood, and emission of light and sound. With this experience in mind, it is difficult for many to appreciate the underlying orderly process. Indeed, Duvall [63D2]* has found it necessary to point out that the rapidity and violence of an explosion do not vitiate Newton's laws, nor those of thermodynamics, chemistry, or quantum mechanics. They do, however, force matter into states quite different from those with which we customarily deal. These states provide a stringent testing ground for some of our favorite assumptions about the bulk properties of matter.

Research on plane shock compression of solids began during World War II. In the early investigations, materials were compressed by plane detonation of a contacting block of high explosive. The compressions achieved in metals by this means were generally in the range of 10 to 30 per cent and correspond to compressive stresses of from 10 to 50 GPa.**

These stresses so exceeded the yield strength of the metals that shear stresses were neglected entirely and the state of the solid characterized just as if the material were fluid. Values of pressure, specific volume, and internal energy density in states of compression achieved by shocks of various strengths were measured and additional information such as temperature was inferred theoretically.

The first review of the field, that prepared by Rice, McQueen and Walsh [58R1] some twenty years ago, was devoted entirely to their work on measurement of the compressibility of metals in the pressure range that can be achieved by contact detonation. This review was instrumental in

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* References are arranged at the end of the review by year of publication, within which they are alphabetized by the first author's surname and assigned a serial number within that letter grouping.

** $1\ \text{GPa} \equiv 10^9\ \text{N/m}^2 = 10\ \text{kbar} = 145\,038\ \text{lb/in}^2$.

demonstrating the scientific potential of studies of solids under shock compression and it remains the most widely cited work in the field.

In the years that have passed since this early work, the limits to the pressure range investigated experimentally have been extended some one-hundredfold both upward and downward. The low-pressure portion of this range now overlaps that accessible to investigation by a variety of static techniques, but the higher pressures are the unique province of shock-compression research. The range of phenomena considered has grown to include at least some aspect of most subjects treated in textbooks on solid-state physics, physical metallurgy, and continuum mechanics.

Military applications originally motivating research in this field continue to provide an important stimulus, but the subject has developed into one of scientific interest in its own right and has found application in other areas of physics, geophysics, and metallurgy. Shock and static-high-pressure studies are mutually supportive. Nonmilitary technological application of the methods or results of shock-compression research have been slow to materialize, although there have been several notable successes. Metal parts are now routinely shaped, joined, and welded with explosive loading methods and these applications of shock waves have been found economically advantageous in many instances [71E1]. Diamonds suitable for use as industrial abrasives have been synthesized from graphite. Some of the first sandwich coins minted in the United States were made from explosively-laminated metal and miniaturized explosive bonding is used to repair electronic microcircuits.

The field under review remains in its infancy. Only a few laboratories are involved in this work, but their number has steadily increased and interest in the subject is worldwide. Workers tend to think of themselves as specialists in "shock-wave physics" rather than as investigators of particular physical phenomena. This, too, is changing, but interpretation of the effects of the unique conditions of a shock-compression experiment still imposes a certain requirement of specialized knowledge. Early work required rather special facilities where large amounts of high explosive could be detonated. The advent of technology for controlled projectile impact has made it possible to conduct shock-wave experiments in more conventional laboratory settings, however, and with finer control over appropriate variables. Improvements in instrumentation, primarily the result of advances in electronics and optics, are making it possible to conduct experiments on a smaller scale than was previously possible. These two developments would seem to open the way for more widespread application of the method than has heretofore been possible.

The basis of research on shock compression of solids is firmly experimental and is so presented in this review. One cannot doubt the influence of theoretical developments, and quantitative interpretation and generalization of observations is the goal of most work. The relative importance of theoretical research is increasing as experimental investigations have been successful in delineating the physical nature of shock processes.

We have attempted to provide a concise, critical review of the status of investigations of the properties of shock-compressed solids and have provided adequate reference to original and review sources. We emphasize studies directed toward underlying physical phenomena and the relationship among results from diverse areas of investigation. Repetition of work summarized in recent reviews has been avoided and original material has been added in a few instances.