Preface

This book is the first of several *Solids* volumes in the *Shock Wave Science and Technology Reference Library.* These volumes are primarily concerned with high-pressure shock waves in solid media, including detonation, high-velocity impact, and penetration.

This volume contains eight articles. The first three describe recent, exciting advances in three experimental areas: ultrashort shock dynamics at the atomic and molecular scale, very-high pressure equations of state measurements using the Z accelerator, and failure waves associated with impact failure of brittle solids. The subsequent four chapters are foundational, covering equations of state, elastic–plastic shock waves, continuum plasticity, and numerical methods. The final article describes recent progress in mesoscale modeling of heterogeneous reactive solids.

The articles are each self-contained, and can be read independently of each other, though, of course, they are thematically interrelated. They offer a timely reference, for beginners as well as professional scientists and engineers, covering both the foundations and new viewpoints of shock waves in solids, and include burgeoning developments. The following are supplementary comments on some of the outstanding issues described in this volume.

For many decades the primary significance of shock wave research in solids has been the determination of high-pressure equations of state (EOS) for weapons analysis, geophysics and astrophysics applications, as well as materials science focusing on the synthesis of ultra-hard materials such as diamond. It was once remarked, in jest, by a famous physicist that a shock wave for him is nothing but a "point" on an equilibrium thermodynamic surface. Such an extreme view aptly reflects a past interest with emphasis on EOS in shock wave research. Interestingly, shock measurements are still the only means of calibrating static high-pressure measurements. So it is no surprise that even today the subject of EOS occupies a good portion of papers presented at world-wide shock wave conferences on condensed matter.

The three experimental articles by Knudson, Moore et al., and Bless and Brar, describe exciting new developments in three separate areas: isentropic compression experiments (ICE) and magnetically driven flyer-plate shock experiments, laser shock dynamics experiments, and dynamic failure of brittle materials under impact loading.

In ICE, magnetic pressures approaching 400 GPa are achieved, and velocities as high as 32 km/s is measured in the flyer plate experiments. These values far exceed the range of gas-gun technologies, which have been the standard bearer of shock wave research in solids over the last fifty years. Currently, ICE experiments and the new flyer plate technology are opening windows into the regime of high pressures and temperatures, which hitherto have not been accessible to controlled experimental observations. The first dramatic achievement of the flyer technique is seen in the shock compression of deuterium over a pressure range up to 120 GPa, establishing a peak compression of the Hugoniot of about 4.3. Other achievements include the Hugoniot data for aluminum up to 830 GPa. The achievements of ICE are no less spectacular. They include the measurement of an unreacted response of an explosive to a stress of 17 GPa, the detection of phase transitions in zirconium with differing purity level, and the discrimination of dynamic response for defect concentration as low as 0.4%, covering strain rates of from about 10^5 to 10^7 1/s.

In addition, the Knudson article shows that EOS is still a focus of research. However the field is breaking out of old molds, with research focus increasingly shifting toward the investigation of difficult issues, such as non-equilibrium thermodynamics and anisotropic structure effects at the grain and atomic scales. There is speculation that the consideration of these highly heterogeneous, stochastic effects may require a reformulation of the basic equations for the conservation of mass, momentum and energy. It is hoped that the articles in the *Solids* volumes will not only serve as an authoritative reference on shock wave research in solids, but also convey to the readers some sense of excitement, thus triggering the impetus for joining in such an endeavor.

The main focus of laser-driven shocks has been to generate very high pressures in the context of fusion research. But the work described in the article by Moore et al., is primarily concerned with bench-top systems for investigation of a material's response behavior at the atomic scale. If ICE represents a march into the new domain in thermodynamic space, then laser shock experiments are breaking barriers at the atomic and molecular scale, gaining fundamental understanding of the shock processes. They probe the question "What is a shock wave to an atom or a molecule in solids". So far, results are not as eye-catching as ICE, but nonetheless they have begun to yield fundamental data. Examples are optical properties of metallic thin films at shock loading, electron excitation in dielectric substrates, time-resolved spectroscopic studies of shock induced chemical reactions in energetic solids on picosecond timescale, just to name a few.

The article by Bless and Brar is a status report on the controversial subject of failure waves in glass and ceramics. In metals, when shock stress exceeds the elastic limit of the material (Hugoniot elastic limit, HEL), the material relaxes toward an equilibrium state by means of plastic deformation (as discussed in both the Menikoff and Brannon articles), and this process "propagates" or carries the materials to whatever the terminal state imposed by the driving shock. However, in the case of failure waves in glass or ceramic materials, the existence of a distinct irreversible process (or processes) has not been well established as plasticity. This is not surprising, because even in the case of plastic deformation, the use of the phrase "plastic waves" has been problematic, because plastic deformation is a dissipative process, and no conservative potential can be associated with such a process. That is, plastic waves cannot exists any more than "opacity waves" or "resistance waves" can. However, if the mechanism of propagating "failure" is found to be the transfer of elastic shear strain energy to dilatant strain energy due to microcracking, the term "failure waves" may indeed be described as "waves".

The article on EOS by Menikoff is a thermodynamic examination of the prevailing practice of using empirical equations of state in analytical forms. Examples include stiffened gas EOS, Mie-Gruniesen EOS, and Hayes EOS. The article discusses the limits and pitfalls of Hugoniot data reduction, not only from a thermodynamic point of view, but also from the condition of shock stability. The article also suggests some improvements in the creation of tabular forms of EOS. Sections on porous materials contain a fresh look at the P-α model that is useful not only for porous metals, but also for polymers and molecular crystals.

The second article by Menikoff discusses a new framework for the formulation of elastic–plastic shock waves using hyperelasticity and conservative forms of flow equations. Hyperelasticity is well suited to describe shock waves in three dimensions. The combined formulation is not found in a standard text on elastic–plastic shock waves in solids. It requires a familiarity with tensor notation in order to follow the discussions. Readers who are not conversant with tensor analysis may start with Brennon's article, which contains an excellent heuristic discussion of tensors in plasticity with geometric aids.

Unlike many of the existing theories of elastic–plastic shocks, Menikoff's article offers a new, rigorous framework in which three dimensional shocks can be examined in a thermodynamically consistent fashion with a known order of approximation. As typical of his thorough analysis, the limitation of the theory is also addressed in dealing with strong overdriven shocks.

The article by Brannon is not concerned with shock wave propagation per se, but it offers a heuristic review of plasticity models as they are practiced in shock wave calculations. It compliments the Menikoff article and offers insight to the physical meaning of plasticity models, as well as to the domain of applicability with emphasis on geometrical interpretation of the governing equations. Tutorials on tensor notation and terminology, and the careful development of the governing equations are a valuable guide for beginners. The comments on prevailing misconceptions should be warning even to seasoned researchers.

The article by D. Benson is a concise bird's eye view of the major topics in numerical methods for treating shocks in solids. It covers not only finite differences and finite element methods, but also other methods such as SPH and material point methods. Shock wave problems in solids, when compared with those in gases and liquids, have a unique set of computational issues. They include, for example, problems associated with contacting interfaces, multi-materials, and a complex range of materials and materials behavior where shear response can be as dominant as that of pressure. Also, shocks in solids are mostly transient ranging in time typically from picoseconds to seconds. The spatial scale may vary from nanometers to even hundreds of meters for geological structures.

Numerical methods for shocks in solids share many similarities with those for gases and liquids, but they have evolved via different paths, typically starting as a part of nuclear weapons development after WWII. Today, the codes are used for a variety of problems ranging from shock effects on materials as well as structures, craters by meteor impact, the explosive formation of metals, to the disintegration of kidney stones by shock waves. Recent trends in fundamental applications are heavily influenced by the availability of computing powers, and follow the directions of either large scale, first principle calculations using tens of millions of particles (molecular dynamics will be covered in the second volume), or high-fidelity, continuum-based modeling of complex heterogeneous media with the hope of improving its predictive capability. The latter is discussed in the article by Baer.

Baer's article discusses one of the most exciting developments in understanding shock waves in complex, heterogeneous media with chemical reactions. Thanks to massive parallel computing powers, we can now simulate inert as well as chemically reactive solids in terms of physical processes that occur at the microscale and mesoscale (grain scale). At the grain scale solids exhibit microstructure unique to solids that critically controls their behavior. The mesoscale response also enslaves atomic as well as macroscopic behaviors. At this scale, some phenomena associated with high-pressure shock compression of solids are found to be fundamentally different from those explained by conventional macroscopic descriptions based on the concept of laminar motions. Plane shock waves are no longer "plane", and the wave front acquires a fractal-like appearance. Interactions of shock waves with anisotropic grains and grain boundaries cause stress and particle fluctuations, and flow fields exhibit chaotic patterns. Thus, macroscopic quantities averaged over many grains are inadequate for describing physical processes occurring at the grain level. As discussed in the article, new ideas and directions are being pursued to understand the mesodynamics of shock waves with the aid of experimental diagnostics, but they are still in an early stage of development from both the theoretical and experimental viewpoints.

The editors express sincere thanks to all authors for their willingness to prepare and make available their timely and authoritative materials to a wide audience.

Yasuyuki Horie
AFRL/MNME,
Eglin AFB, FL 2006

http://www.springer.com/978-3-540-22364-1

Shock Wave Science and Technology Reference Library,
Vol. 2
Solids I
Horie, Y. (Ed.)
2007, XV, 369 p., Hardcover
ISBN: 978-3-540-22364-1