High-Pressure Shock Compression of Condensed Matter

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High-Pressure Shock Compression of Condensed Matter

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High-Pressure Shock Compression of Solids VI

Old Paradigms and New Challenges

With 138 Illustrations

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Preface

It is increasingly recognized that some phenomena associated with high-pressure shock compression of solids are fundamentally different from those explained by conventional macroscopic descriptions based on the concept of laminar motions. The evidence for this arises from both experimental and theoretical investigations and the phenomenological differences are manifest at the mesoscale, a spatial and temporal scale between the atomic and the continuum levels. Important features that emerge at such mesoscopic (grain diameter) levels are, for example, fluctuating particle velocities and transient eddies, as well as the formation of a hierarchy of dissipative structures such as non-uniformly distributed lattice defects, residual stresses, and inelastic deformation fields. These phenomena are obviously controlled by the interactions of shock waves with local material properties, microstructure, and internal material interfaces.

The subject of inhomogeneity and stress fluctuation has long played an important role in the physics of fluid motion and is not new in the study of solid response under high pressure. Nevertheless, the dynamical issue of heterogeneous and non-equilibrium shock processes occurring on the mesoscale has largely been ignored despite the fact that they must strongly influence phenomena such as plastic flow, fracture, and phase transformation. Field quantities averaged over many grains are obviously inadequate for describing physical processes occurring at the grain level. A steady, plane shock wave at the macrolevel is neither steady nor plane at the mesolevel. Stochasticity raises its ugly head.

This book is an outgrowth of invited talks given during two meetings: the pre-conference workshop on "Shock Dynamics and Non-Equilibrium Mesoscopic Fluctuations in Solids," and the special, plenary session, "What is a Shock Wave?" held during the 12th American Physical Society Topical Conference on Shock Compression of Condensed Matter. Both meetings were held during June 23–29, 2001 in Atlanta. The topical conference was attended by about 450 scientists and engineers from 18 countries, and 25 specialists from the United States, Russia, and China participated in the workshop. The theme of both the workshop and the plenary session of the topical conference was re-evaluation of the paradigm(s) underlying our understanding of shock phenomena, examination of basic assumptions, and presentation of new calculations, measurements, and theories that challenge these assumptions. The key questions addressed during the meetings were

1. What experimental data are available and what are their implications?
2. Are there new mesoscale theories of shock dynamics?
3. How do the theories affect the existing fracture and phase transition paradigms?
4. What kind of new computational and material response models are needed?

The chapters of this book concern the themes of these meetings, but they go far beyond the level of lectures that could be presented during the technical meetings or covered in conference proceedings. These articles expose many underlying and unresolved questions, and illustrate that they can no longer be dismissed simply as "small or minor effects." Successful fitting of experimental data by itself does not guarantee that the model used is a physically correct model, particularly at the micro- and mesolevels. A case in point is the fact that many models, even those that we know work well for, say, looking at stress gauge records and/or free surface velocity data, are not adequate when viewed from the perspective of stress rate and velocity rate (acceleration) [R. A. Graham, private communication]. We hope that this book will inspire and challenge its readers and set them on a path to discover a deeper, more fundamental understanding of shock wave phenomena in solid materials.

The first chapter of the volume, by Lee Davison, presents the most traditional view of the subject of shock phenomena in solids. It is the shortcomings of this theory that motivate the research discussed in the remainder of the book. In the second chapter, by Jim Asay and Lalit Chhabildas, conventional experimental observations not satisfactorily explained by traditional theories of the response of elastoplastic continuua are discussed. This is followed with a chapter by John Lee in which observations of structure and turbulence in shock and detonation waves are discussed. Brad Holian discusses molecular-dynamic calculations of shock phenomena and the understanding that they bring to micro- and mesoscale aspects of shock propagation in atomic lattices. This is followed by chapters by Yuri Mescheryakov and Tatyana Khantuleva, respectively, in which measurements of mesoscale fluctuations in shock-induced flow fields in solids are presented and a new theory to explain the observed phenomena is described. Yilong Bai et al. then present a discussion of the effects of random defects in material bodies on mechanical behavior, pointing out that the interaction of these defects with mesoscopic heterogenieties and stress fluctuations helps explain damage localization and fracture and the sometimes surprising sensitivity of mechanical responses to small differences in the initial defect state of materials. In the following chapter, Jack Gilman discusses the different mechanisms of elastic and plastic deformation and suggests that the kinematical aspects of these differences are not properly captured in conventional theories of elastoplasticity. This is followed by a chapter in which Ron Rabie comments on various mechanisms underlying the development of structure in plane laminar shocks and presents some new data on the structure of very strong shocks. Finally, Craig Tarver extends the previous discussions of non-reactive solids to include consideration of the effects of shock-induced chemical reactions.

We express our sincere thanks to all the authors for their effort to expand their talks and make timely materials available in its present form. We specially thank Prof. Y.L. Bai who could not attend the meetings due to a bureaucratic policy, but was still willing to contribute an article that summarizes his and his colleagues' important contributions to the subject of dynamic fracture.

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Contents

Preface v

Contributors xiii

CHAPTER 1
Traditional Analysis of Nonlinear Wave Propagation in Solids 1
Lee Davison
1.1. Introduction 1
1.2. Mechanical Principles 2
1.3. Analysis of Shocks 14
1.4. Thermodynamic Behavior of Compressible Fluids 19
1.5. Analysis of Smooth Waves 25
1.6. Steady Detonation Waves 42
1.7. Concluding Remarks 51
References 54

CHAPTER 2
Paradigms and Challenges in Shock Wave Research 57
James R. Asay and Lalit C. Chhabildas
2.1. Introduction 58
2.2. Basic Assumptions 63
2.3. Specific Examples 71
2.4. Closure 106
Acknowledgments 108
References 108

CHAPTER 3
The Universal Role of Turbulence in the Propagation of Strong Shocks and Detonation Waves 121
John Lee
3.1. Introduction 121
3.2. Turbulent Structure of Gaseous Detonations 124
3.3. Turbulent Structure in Condensed Phase Detonations 128
3.4. Turbulent Structure of Non-Reacting Shocks 131
3.5. Why Shocks Have a Turbulent Structure 137
3.6. Conclusion 143
Acknowledgments 144
References 144

CHAPTER 4
What is a Shock Wave? —The View from the Atomic Scale........................ 149
Brad Lee Holian
4.1. Introduction.. 149
4.2. Tricks of the NEMD Trade 153
4.3. NEMD Shock Simulation Results... 157
4.4. What the Hell is MD Good For, Anyway?................................. 163
4.5. Fulture Challenges and Opportunities.. 165
Acknowledgments... 166
References.. 166

CHAPTER 5
Meso–Macro Energy Exchange in Shock Deformed and Fractured Solids... 169
Yuri I. Mescheryakov
5.1. Introduction.. 169
5.2. Mesoscopic Scale Level.. 170
5.3. Velocity Distribution Function and Its Statistical Moments 172
5.4. On the Propagation of a Plane Shock Wave in a Heterogeneous Medium 182
5.5. The Stochastic Approach to Change of Strain Kinematics 187
5.6. Experiments on Dynamic Plasticity.. 193
5.7. Kinetics of Mesostructure and Dynamic Strength 200
5.8. Multiscale Energy Exchange and Dynamic Strength.................. 208
5.9. Conclusions.. 212
References.. 212

CHAPTER 6
The Shock Wave as a Nonequilibrium Transport Process............................ 215
T.A. Khantuleva
6.1. Introduction.. 215
6.2. Generalization of Classical Hydrodynamics 216
6.3. Self-Consistent Non-Local Models for High-Rate Transport in Media 221
6.4. Non-local Generalization of the Maxwell Model for a Medium with Internal Structure 226
6.5. Shock-Wave Propagation in a Relaxing Medium....................... 234
6.6. Nonequilibrium Thermodynamics of High-Rate Processes........ 236
6.7. Non-Steady Waveforms in the Dynamical Equilibrium 246
6.8. General Scheme of the Problem.. 249
6.9. Conclusions.. 250
References.. 252

CHAPTER 7
Non-Equilibrium Evolution of Collective Microdamage and Its Coupling with Mesoscopic Heterogeneities and Stress Fluctuations 255
Y.L.Bai, M.F. Xia, Y.J. Wei, and F.J. Ke
7.1. Introduction 255
7.2. Two Approaches to Non-equilibrium Evolution in Heterogeneous Media and Stress Redistribution Models 257
7.3. Statistical Microdamage Mechanics 259
7.4. Catastrophe Transition in Stress Redistribution Models with Stress Fluctuations 268
7.5. Concluding Remarks 276
Acknowledgment 276
References 277

CHAPTER 8
Responses of Condensed Matter to Impact 279
John J. Gilman
8.1. The Impact Process 279
8.2. Weak to Mild Impact 282
8.3. Elastic Strain and Plastic Deformation 283
8.4. Mechanical Equation of State 287
8.5. Debris Production 287
8.6. Heat Production 288
8.7. Nonpropagation of Plastic Deformation 289
8.8. Fluctuation–Dissipation Theorem 289
8.9. Shear-Induced Instabilities 290
8.10. Shear at Strong Shock Fronts 291
8.11. Diagnosis of Shock Fronts 293
8.12. Relaxation Times (Liquds, Solids, and Plastic Materials) 294
8.13. Limiting Speeds of Dislocations 294
References 295

CHAPTER 9
The Discontinuous Shock—Fact or Fancy? 297
Ronald L. Rabie
9.1. Introduction 297
9.2. Beginnings 298
9.3. The Nature of the Shock 307
9.4. Some Experimental Notes 313
9.5. Recent Experimental Findings in Shock Structure 314
9.6. Conclusion 319
Acknowledgments 320
References 320

CHAPTER 10
What Is a Shock Wave to an Explosive Molecule? 323
Craig M. Tarver
10.1. Introduction 323
10.2. Non-Shock Impact Ignition 324
10.3. The Ignition and Growth Reactive Flow Model 325
10.4. Weak Shock Compression 328
10.5. Homogeneous Explosives 328
10.6. Heterogeneous Explosives 333
10.7. Future Research 336
10.8. Summary 338
Acknowledgments 339
References 339

Author Index 341

Subject Index 349

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