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MATERIAL RESPONSE UNDER IMPULSIVE LOADING

2 days, 3 instructors

OVERALL OBJECTIVE:

This graduate-level course emphasizes the material science and mechanics of the effect of high-strain-rate and shock loading upon inert materials such as metals and unreacted explosives in terms of changes in microstructure and mechanical properties. Characteristics of the load produced by the stimulus driving the shock, typically plate impact or contact with detonating explosive, will be described. Split Hopkinson bar, Taylor cylinder, shock loading and shock recovery techniques and results that describe dynamic response of materials will be shown, with the aim of introducing the student to the basis and utility of data that are available. Experimentally generated data have been used as the basis to recognize and calibrate phenomena such as constitutive behavior, including strain-rate sensitivity and strain-hardening for strength models that are incorporated into multidimensional wave-propagation codes, for example EPIC and CTH. Examples of the differences between strength models such as Johnson-Cook, Zerilli-Armstrong, and the Mechanical Threshold Strength for various materials will be detailed. Students will be shown how this has been done, so that they may undertake such efforts themselves or make proper use of models that are already available in wave codes. The course goal is that students will understand how these multi-faceted strength and damage problems can be approached both experimentally and computationally.

LEARNING OBJECTIVES

At course completion student should be able to:

- Sketch shock waveshapes driven into a target material by plate impact and by contact detonation of explosives
- Diagram in the P-u plane how a detonation front interacts with a stiff or soft material
- Explain how shocks attenuate with propagation distance in inert materials
- Describe how tensile states and potential damage are produced by rarefaction waves that follow the shock front driven by contact detonation
- Explain the mechanism of fragment formation in a fragmenting tubular munition, and factors that control fragment size

- Recognize circumstances in which the Gurney model of explosive output could help you analyze material response issues
- Understand fundamental factors that define the state of stress in a deforming material
- Give an example of how crystal structure, or lack of it, affects mechanical behavior of a material.
- Describe the split Hopkinson bar method for measuring the mechanical response of solids to dynamic loading and understand its limitations
- Understand how Taylor cylinder testing is used as a validation tool for material strength models
- Understand how shock-loading affects the mechanical behavior of materials
- Appreciate the influence of material microstructure and stress state on dynamic failure / spallation / fragmentation processes
- Define what a constitutive relation for a solid is, and give two examples of behaviors described by constitutive relations
- Explain microscopic behaviors that may cause changes in mechanical properties when a material is prestrained (as by shock loading) before undergoing large deformation
- Describe a method for measuring the response of a material to shock-wave loading
- Understand how the conservation equations are used to analyze shocks and deformations computationally
- Explain how deformation may lead to material damage and failure
- Explain Eulerian and Lagrangian coordinates, and strengths and weaknesses of each system and when each should be applied to obtain the most accurate result
- Describe mixed-mode damage, material bifurcation and failure for complex materials (anisotropic)
- Describe simple to complex approaches to the modeling of material failure

<u>IMMEDIATE BENEFITS:</u>

Each student who completes this course will gain an understanding of links between material microstructure (crystallinity, grain size, texture, etc.) and mechanical properties, as well as experimental techniques for measurement of the mechanical response of metals and unreacted energetic materials under dynamic loading, especially shock-wave loading. He/she will recognize ways to incorporate those behaviors into wave-propagation codes and will be able to read, with understanding, technical papers reporting results and models describing these behaviors. Students should be able to select material models that are well-suited for problems they analyze.

<u>INSTRUCTORS:</u>

Instructors for this graduate-level class will be Dr. George T. (Rusty) Gray III of LANL, Dr. Paul Maudlin, retired from LANL and Dr. Jim Kennedy of HERE, LLC. All are internationally established experts in their subject areas. Dr. Kennedy has over 40 years experience in explosives work, mostly at Sandia and Los Alamos National Laboratories.

In this course, he will address the behavior of shock waves in solids, emphasizing loads that are produced by impact and by detonation of explosives in contact with a solid material. Dr. Gray is a Lab Fellow at Los Alamos National Laboratory, Fellow of the American Physical Society, and serves on several committees of the National Academy advising government on structure/property material behavior. He will describe deformation mechanisms in materials that control dynamic / shock behavior and their effects on mechanical behavior, constitutive modeling and validation to support strength models, the role of material microstructure in shock-induced damage evolution, as well as experimental techniques used to quantify the high-strain-rate and shock responses of materials. Dr. Maudlin has over 30 years experience and 200 publications in computational sciences and has addressed the modeling of nuclear reactor safety problems and simulation of conventional and nuclear weapon systems. He has led projects and pursued research involving constitutive modeling of dynamic material behavior with mixed-mode damage, axial and shear loadings, and anisotropic material response, all for the purpose of ultimate incorporation into 3D simulation codes. He will describe constitutive model implementation in existing hydrocodes, both Lagrangian and Eulerian, and discuss in detail the challenges of such implementations, including addressing problem instabilities.