

## Numerical Modeling In Materials Science And Engineering

This book features state-of-the-art contributions in mathematical, experimental and numerical simulations in engineering sciences. The contributions in this book, which comprise twelve chapters, are organized in six sections spanning mechanical, aerospace, electrical, electronic, computer, materials, geotechnical and chemical engineering. Topics include metal micro-forming, compressible reactive flows, radio frequency circuits, barrier infrared detectors, fiber Bragg and long-period fiber gratings, semiconductor modelling, many-core architecture computers, laser processing of materials, alloy phase decomposition, nanofluids, geo-materials and rheo-kinetics. Contributors are from Europe, China, Mexico, Malaysia and Iran. The chapters feature many sophisticated approaches including Monte Carlo simulation, FLUENT and ABAQUS computational modelling, discrete element modelling and partitioned frequency-time methods. The book will be of interest to researchers and also consultants engaged in many areas of engineering simulation. Magnetic Materials and 3D Finite Element Modeling explores material characterization and finite element modeling (FEM) applications. This book relates to electromagnetic analysis based on Maxwell's equations and application of the finite element (FE) method to low frequency devices. A great source for senior undergraduate and graduate students in electromagnetics, it also supports industry professionals working in magnetics, electromagnetics, ferromagnetic materials science and electrical engineering. The authors present current concepts on ferromagnetic material characterizations and losses. They provide introductory material; highlight basic electromagnetics, present experimental and numerical modeling related to losses and focus on FEM applied to 3D applications. They also explain various formulations, and discuss numerical codes. • Furnishes algorithms in computational language • Summarizes concepts related to the FE method • Uses classical algebra to present the method, making it easily accessible to engineers Written in an easy-to-understand tutorial format, the text begins with a short presentation of Maxwell's equations, discusses the generation mechanism of iron losses, and introduces their static and dynamic components. It then demonstrates simplified models for the hysteresis phenomena under alternating magnetic fields. The book also focuses on the Preisach and Jiles–Atherton models, discusses vector hysteresis modeling, introduces the FE technique, and presents nodal and edge elements applied to 3D FE formulation connected to the hysteretic phenomena. The book discusses the concept of source-field for magnetostatic cases, magnetodynamic fields, eddy currents, and anisotropy. It also explores the need for more sophisticated coding, and presents techniques for solving linear systems generated by the FE cases while considering advantages and drawbacks.

June 11-13, 2018 Barcelona, Spain Key Topics : Materials Science and Engineering, Nanomaterials and Nanotechnology, Biomaterials and Medical Devices, Polymer Science and Technology, Ceramics and Composite Materials, Electronic, Optical and Magnetic Materials, Emerging Smart Materials, Materials for Energy and Environmental Sustainability, Physics and Chemistry of Materials, Metals, Mining, Metallurgy and Materials, Mechanics, Characterization Techniques and Equipments, Graphene and 2D Materials,

Composite materials are increasingly used in many applications because they offer the engineer a range of advantages over traditional materials. They are often used in situations where a specified level of performance is required, but where the cost of testing the materials under the extremes of those specifications is very high. In order to solve this problem, engineers are turning to computer Modelling to evaluate the materials under the range of conditions they are likely to encounter. Many of these analyses are carried out in isolation, and yet the evaluation of a range of composites can be carried out using the same basic principles. In this new book the editor has brought together an international panel of authors, each of whom is working on the analysis and Modelling of composite materials. The overage of the book is deliberately wide; to illustrate that similar principles and methods can be used to model and evaluate a wide range of materials. It is also hoped that, by bringing together this range of topics, the insight gained in the study of one composite can be recognized and utilized in the study of others. Professional engineers involved in the specification and testing of composite material structures will find this book an invaluable resource in the course of their work. It will also be of interest to those industrial and academic engineers involved in the design, development, manufacture and applications of composite materials.

This book provides a collection of high-quality peer-reviewed research papers presented at the International Conference of Experimental and Numerical Investigations and New Technologies (CNNTech2018), held in Zlatibor, Serbia from 4 to 6 July 2018. The book discusses a wide variety of industrial, engineering and scientific applications of engineering techniques. Researchers from academia and the industry share their original work and exchange ideas, experiences, information, techniques, applications and innovations in the field of mechanical engineering, materials science, chemical and process engineering, experimental techniques, numerical methods and new technologies.

Porous media are broadly found in nature and their study is of high relevance in our present lives. In geosciences porous media research is fundamental in applications to aquifers, mineral mines, contaminant transport, soil remediation, waste storage, oil recovery and geothermal energy deposits. Despite their importance, there is as yet no complete understanding of the physical processes involved in fluid flow and transport. This fact can be attributed to the complexity of the phenomena which include multicomponent fluids, multiphase flow and rock-fluid interactions. Since its formulation in 1856, Darcy's law has been generalized to describe multi-phase compressible fluid flow through anisotropic and heterogeneous porous and fractured rocks. Due to the scarcity of information, a high degree of uncertainty on the porous medium properties is commonly present. Contributions to the knowledge of modeling flow and transport, as well as to the characterization of porous media at field scale are of great relevance. This book addresses several of these issues, treated with a variety of methodologies grouped into four parts: I Fundamental concepts II Flow and transport III Statistical and stochastic characterization IV Waves The problems analyzed in this book cover diverse length scales that

range from small rock samples to field-size porous formations. They belong to the most active areas of research in porous media with applications in geosciences developed by diverse authors. This book was written for a broad audience with a prior and basic knowledge of porous media. The book is addressed to a wide readership, and it will be useful not only as an authoritative textbook for undergraduate and graduate students but also as a reference source for professionals including geoscientists, hydrogeologists, geophysicists, engineers, applied mathematicians and others working on porous media.

Mathematical models are used to convert real-life problems using mathematical concepts and language. These models are governed by differential equations whose solutions make it easy to understand real-life problems and can be applied to engineering and science disciplines. This book presents numerical methods for solving various mathematical models. This book offers real-life applications, includes research problems on numerical treatment, and shows how to develop the numerical methods for solving problems. The book also covers theory and applications in engineering and science. Engineers, mathematicians, scientists, and researchers working on real-life mathematical problems will find this book useful.

This specialist work comprises 249 peer-reviewed papers on the "Physical and Numerical Simulation of Materials Processing".

Numerical Modeling in Materials Science and Engineering Springer Science & Business Media

This comprehensive and self-contained, one-stop source discusses phase-field methodology in a fundamental way, explaining advanced numerical techniques for solving phase-field and related continuum-field models. It also presents numerical techniques used to simulate various phenomena in a detailed, step-by-step way, such that readers can carry out their own code developments. Features many examples of how the methods explained can be used in materials science and engineering applications.

Numerical Methods and Advanced Simulation in Biomechanics and Biological Processes covers new and exciting modeling methods to help bioengineers tackle problems for which the Finite Element Method is not appropriate. The book covers a wide range of important subjects in the field of numerical methods applied to biomechanics, including bone biomechanics, tissue and cell mechanics, 3D printing, computer assisted surgery and fluid dynamics. Modeling strategies, technology and approaches are continuously evolving as the knowledge of biological processes increases. Both theory and applications are covered, making this an ideal book for researchers, students and R&D professionals. Provides non-conventional analysis methods for modeling Covers the Discrete Element Method (DEM), Particle Methods (PM), MeshLess and MeshFree Methods (MLMF), Agent-Based Methods (ABM), Lattice-Boltzmann Methods (LBM) and Boundary Integral Methods (BIM) Includes contributions from several world renowned experts in their fields Compares pros and cons of each method to help you decide which method is most applicable to solving specific problems

The scope of this book is to identify and emphasize the successful link between computational materials modeling as a simulation and design tool and its synergistic application to experimental research and alloy development. The book provides a more balanced perspective of the role that computational modeling can play in every day research and development efforts. Each chapter describes one or more particular computational tool and how they are best used.

A survey of current research on a wide range of carbide, nitride and boride materials, covering the general issues relevant to the development and characterisation of a variety of advanced materials. Topics include structure and electronic properties, modeling, processing, high-temperature chemistry, oxidation and corrosion, mechanical behaviour, manufacturing and applications. The volume complements more specialised books on specific materials as well as more general texts on ceramics or hard materials, presenting a survey of materials research as a key to technological development. After decades of research, the materials are being used in electronics, wear resistant, refractory and other applications, but numerous new applications are possible. Roughly equal numbers of papers cover theoretical and experimental research in the general field of materials science of refractory materials. Audience: Researchers and graduate students in materials science and engineering.

An original mechanical formulation to treat nonlinear orthotropic behavior of composite materials is presented in this book. It also examines different formulations that allow us to evaluate the behavior of composite materials through the composition of its components, obtaining a new composite material. Also two multiple scale homogenization methods are given, one based on the analytical study of the cells (Ad-hoc homogenization) and other one, more general based on the finite element procedure applied on the macro scale (upper-scale) and in the micro scale (sub-scale). A very general formulation to simulate the mechanical behavior for traditional composite structures (plywood, reinforced concrete, masonry, etc.), as well as the new composite materials reinforced with long and short fibers, nanotubes, etc., are also shown in this work. Typical phenomena occurring in composite materials are also described in this work, including fiber-matrix debonding, local buckling of fibers and its coupling with the overall buckling of the structure. Finally, several numerical examples that evaluates the qualities and capabilities of the general model formulated are offered in this book. This book is intended for graduate engineering students who want to expand their knowledge of composite structures behavior.

This book describes fruitful past collaborations between the mathematical and materials sciences and indicates future challenges. It seeks both to encourage mathematical sciences research that will complement vital research in materials science and to raise awareness of the value of quantitative methods. The volume encourages both communities to increase cross-disciplinary collaborations, emphasizing that each has much to gain from such an increase, and it presents recommendations for facilitating such work. This book is written for both mathematical and materials science researchers interested in advancing research at this interface; for federal and state agency representatives interested in encouraging such collaborations; and for anyone wanting information on how such cross-disciplinary, collaborative efforts can be accomplished successfully.

Recent developments in information processing systems have driven the advancement of numerical simulations in engineering. New models and simulations enable better solutions for problem-solving and overall process improvement. Advanced Numerical Simulations in Mechanical Engineering is a pivotal reference source for the latest research findings on advanced modelling and simulation method adopted in mechanical and mechatronics engineering. Featuring extensive coverage on relevant areas such as fuzzy logic controllers, finite element analysis, and analytical models, this publication is an ideal resource for students, professional

engineers, and researchers interested in the application of numerical simulations in mechanical engineering.

The use of mathematical modeling in engineering allows for a significant reduction of material costs associated with design, production, and operation of technical objects, but it is important for an engineer to use the available computational approaches in modeling correctly. Taking into account the level of modern computer technology, this new volume explains how an engineer should properly define the physical and mathematical problem statement, choose the computational approach, and solve the problem by proven reliable computational approach using computer and software applications during the solution of a particular problem. This work is the result of years of the authors' research and experience in the fields of power and rocket engineering where they put into practice the methods of mathematical modeling shown in this valuable volume. The examples in the book are based on two approaches. The first approach involves the use of the relatively simple mathematical system MathCad. The second one involves the solving of problems using Intel Visual Fortran compiler with IMSL Libraries. The use of other software packages (Maple, MathLab, Mathematica) or compilers (C, C++, Visual Basic) for code is equally acceptable in the solution of the problems given in the book. Intended for professors and instructors, scientific researchers, students, and industry professionals, the book will help readers to choose the most appropriate mathematical modeling method to solve engineering problems, and the authors also include methods that allow for the solving of nonmathematical problems as mathematical problems.

This book summarizes, defines, and contextualizes multiphysics with an emphasis on porous materials. It covers various essential aspects of multiphysics, from history, definition, and scope to mathematical theories, physical mechanisms, and numerical implementations. The emphasis on porous materials maximizes readers' understanding as these substances are abundant in nature and a common breeding ground of multiphysical phenomena, especially complicated multiphysics. Dr. Liu's lucid and easy-to-follow presentation serve as a blueprint on the use of multiphysics as a leading edge technique for computer modeling. The contents are organized to facilitate the transition from familiar, monolithic physics such as heat transfer and pore water movement to state-of-the-art applications involving multiphysics, including poroelasticity, thermohydro-mechanical processes, electrokinetics, electromagnetics, fluid dynamics, fluid structure interaction, and electromagnetomechanics. This volume serves as both a general reference and specific treatise for various scientific and engineering disciplines involving multiphysics simulation and porous materials.

This collection presents contributions on computational fluid dynamics (CFD) modeling and simulation of engineering processes from researchers and engineers involved in the modeling of multiscale and multiphase phenomena in material processing systems. The following processes are covered: Additive Manufacturing (Selective Laser Melting and Laser Powder Bed Fusion); Ironmaking and Steelmaking (Ladle Metallurgical Furnace, EAF, Continuous Casting, Blown Converter, Reheating Furnace, Rotary Hearth Furnace); Degassing; High Pressure Gas Atomization of Liquid Metals; Electroslag Remelting; Electrokinetic Deposition; Friction Stir Welding; Quenching; High Pressure Die Casting; Core Injection Molding; Evaporation of Metals; Investment Casting; Electromagnetic Levitation; Ingot Casting; Casting and Solidification with External Field (electromagnetic stirring and ultrasonic cavitation) Interaction and Microstructure Evolution The collection also covers applications of CFD to engineering processes, and demonstrates how CFD can help scientists and engineers to better understand the fundamentals of engineering processes.

This solutions manual is a companion to the workbook, Practical Numerical Mathematics with MATLAB: A workbook. It is intended for use by individual students independently studying the workbook and provides complete MATLAB code and numerical results for each of the exercises in the workbook and will be especially useful for those students without previous MATLAB programming experience. It is also valuable for classroom instructors to help pinpoint the author's intent in each exercise and to provide a model for graders.

Numerical Modeling in Biomedical Engineering brings together the integrative set of computational problem solving tools important to biomedical engineers. Through the use of comprehensive homework exercises, relevant examples and extensive case studies, this book integrates principles and techniques of numerical analysis. Covering biomechanical phenomena and physiologic, cell and molecular systems, this is an essential tool for students and all those studying biomedical transport, biomedical thermodynamics & kinetics and biomechanics.

Supported by Whitaker Foundation Teaching Materials Program; ABET-oriented pedagogical layout Extensive hands-on homework exercises Numerical Modeling of Masonry and Historical Structures: From Theory to Application provides detailed information on the theoretical background and practical guidelines for numerical modeling of unreinforced and reinforced (strengthened) masonry and historical structures.

The book consists of four main sections, covering seismic vulnerability analysis of masonry and historical structures, numerical modeling of unreinforced masonry, numerical modeling of FRP-strengthened masonry, and numerical modeling of TRM-strengthened masonry. Each section reflects the theoretical background and current state-of-the art, providing practical guidelines for simulations and the use of input parameters. Covers important issues relating to advanced methodologies for the seismic vulnerability assessment of masonry and historical structures Focuses on modeling techniques used for the nonlinear analysis of unreinforced masonry and strengthened masonry structures Follows a theory to practice approach

Demystifying Numerical Models: Step-by Step Modeling of Engineering Systems is the perfect guide on the analytic concepts of engineering components and systems. In simplified terms, the book focuses on engineering characteristics and behaviors using numerical methods.

Readers will learn how the computational aspects of engineering analysis can be applied to develop various engineering systems to a level that is fit for implementation. Provides numerical examples and graphical representations of complex mathematical models Includes downloadable spreadsheets of the numerical tools discussed that allow the reader to gain a hands-on understanding of how they work

Explains the engineering foundations behind the increasingly widespread and complex numerical models

The book presents twelve state of the art contributions in the field of numerical modeling of materials subjected to large strain, high strain rates, large pressure and high stress triaxialities, organized into two sections. The first part is focused on high strain rate-high pressures such as those occurring in impact dynamics and shock compression related phenomena, dealing with material response identification, advanced modeling incorporating microstructure and damage, stress waves propagation in solids and structures response under impact. The latter part is focused on large strain-low strain rates applications such as those occurring in technological material processing, dealing with microstructure and texture evolution, material response at elevated temperatures, structural behavior under large strain and multi axial state of stress.

Mathematics is a universal language. Differential equations, mathematical modeling, numerical methods and computation form the underlying infrastructure of engineering and the sciences. In this context mathematical modeling is a very powerful tool for studying engineering problems, natural systems and human society. This interdisciplinary book cont

Finite element modelling of composite materials and structures provides an introduction to a technique which is increasingly being used as an analytical tool for composite materials. The text is presented in four parts: Part one sets the scene and reviews the fundamentals of composite materials together with the basic nature of FRP and its constituents. Two-dimensional stress-strain is covered, as is laminated plated theory and its limitations. Part two reviews the basic principles of FE analysis, starting with underlying theoretical issues and going on to show how elements are derived, a model is generated and results are processed. Part three builds on the basics of FE analysis and considers the particular issues that arise in applying finite elements to composites, especially to the layered nature of the material. Part four deals with the application of FE to FRP composites, presenting analytical models alongside FE representations. Specific issues addressed include interlaminar stresses, fracture delamination, joints and fatigue. This book is invaluable for students of materials science and engineering, and for engineers and others wishing to expand their knowledge of structural analysis. Covers important work on finite element

analysis of composite material performance Based on material developed for an MSc course at Imperial College, London, UK Covers particular problems such as holes, free edges with FE results compared with experimental data and classical analysis

Describes the basic theory of carrier transport, develops numerical algorithms used for transport problems or device simulations, and presents real-world examples of implementation.

Numerical Modelling of Failure in Advanced Composite Materials comprehensively examines the most recent analysis techniques for advanced composite materials. Advanced composite materials are becoming increasingly important for lightweight design in aerospace, wind energy, and mechanical and civil engineering. Essential for exploiting their potential is the ability to reliably predict their mechanical behaviour, particularly the onset and propagation of failure. Part One investigates numerical modeling approaches to interlaminar failure in advanced composite materials. Part Two considers numerical modelling approaches to intralaminar failure. Part Three presents new and emerging advanced numerical algorithms for modeling and simulation of failure. Part Four closes by examining the various engineering and scientific applications of numerical modeling for analysis of failure in advanced composite materials, such as prediction of impact damage, failure in textile composites, and fracture behavior in through-thickness reinforced laminates. Examines the most recent analysis models for advanced composite materials in a coherent and comprehensive manner Investigates numerical modelling approaches to interlaminar failure and intralaminar failure in advanced composite materials Reviews advanced numerical algorithms for modeling and simulation of failure Examines various engineering and scientific applications of numerical modelling for analysis of failure in advanced composite materials This book provides readers with numerical analysis techniques to model the magnetisation of bulk superconductors based on the finite element method. How to model bulk superconducting materials and their various magnetisation processes are presented along with an in-depth summary of the current state-of-the-art in the field, and example models, implemented in the software package COMSOL Multiphysics(R), are provided so that readers may carry out modelling of their own.

This book deals with the most recent numerical modeling of adhesive joints. Advances in damage mechanics and extended finite element method are described in the context of the Finite Element method with examples of application. The book also introduces the classical continuum mechanics and fracture mechanics approach and discusses the boundary element method and the finite difference method with indication of the cases they are most adapted to. At the moment there is no numerical technique that can solve any problem and the analyst needs to be aware of the limitations involved in each case.

Computational mechanics is a scientific discipline that marries physics, computers, and mathematics to emulate natural physical phenomena. It is a technology that allows scientists to study and predict the performance of various products--important for research and development in the industrialized world. This book describes current trends and future research directions in computational mechanics in areas where gaps exist in current knowledge and where major advances are crucial to continued technological developments in the United States.

Computing application to materials science is one of the fastest-growing research areas. This book introduces the concepts and methodologies related to the modeling of the complex phenomena occurring in materials processing. It is intended for undergraduate and graduate students in materials science and engineering, mechanical engineering and physics, and for engineering professionals or researchers.

In the dynamic digital age, the widespread use of computers has transformed engineering and science. A realistic and successful solution of an engineering problem usually begins with an accurate physical model of the problem and a proper understanding of the assumptions employed. With computers and appropriate software we can model and analyze complex physical systems and problems. However, efficient and accurate use of numerical results obtained from computer programs requires considerable background and advanced working knowledge to avoid blunders and the blind acceptance of computer results. This book provides the background and knowledge necessary to avoid these pitfalls, especially the most commonly used numerical methods employed in the solution of physical problems. It offers an in-depth presentation of the numerical methods for scales from nano to macro in nine self-contained chapters with extensive problems and up-to-date references, covering: Trends and new developments in simulation and computation Weighted residuals methods Finite difference methods Finite element methods Finite strip/layer/prism methods Boundary element methods Meshless methods Molecular dynamics Multiphysics problems Multiscale methods

This is an introduction to molecular and atomistic modeling techniques applied to fracture and deformation of solids, focusing on a variety of brittle, ductile, geometrically confined and biological materials. The overview includes computational methods and techniques operating at the atomic scale, and describes how these techniques can be used to model cracks and other deformation mechanisms. The book aims to make new molecular modeling techniques available to a wider community.

The first section of the book includes the following topics: fusion-based additive manufacturing (AM) processes of titanium alloys and their numerical modelling, mechanism of  $\beta$ -case formation mechanism during investment casting of titanium, genesis of gas-containing defects in cast titanium products. Second section includes topics on behavior of the ( $\alpha$  +  $\beta$ ) titanium alloys under extreme pressure and temperature conditions, hot and super plasticity of titanium ( $\alpha$  +  $\beta$ ) alloys and some machinability aspects of titanium alloys in drilling. Finally, the third section includes topics on different surface treatment methods including nanotube-anodic layer formation on two phase titanium alloys in phosphoric acid for biomedical applications, chemico-thermal treatment of titanium alloys applying nitriding process for improving corrosion resistance of titanium alloys.

Since the 1990s five books on Applications of Computational Mechanics in Geotechnical Engineering have been published. Innovative Numerical Modelling in Geomechanics is the 6th and final book in this series, and contains papers written by leading experts on computational mechanics. The book treats highly relevant topics in the field of geotechnic Instead of presenting the standard theoretical treatments that underlie the various numerical methods used by scientists and engineers, Using R for Numerical Analysis in Science and Engineering shows how to use R and its add-on packages to obtain numerical solutions to the complex mathematical problems commonly faced by scientists and engineers. This practical guide to the capabilities of R demonstrates Monte Carlo, stochastic, deterministic, and other numerical methods through an abundance of worked examples and code, covering the solution of systems of linear algebraic equations and nonlinear equations as well as ordinary differential equations and partial differential equations. It not only shows how to use R's powerful graphic tools to construct the types of plots most useful in scientific and engineering work, but also: Explains how to statistically analyze and fit data to linear and nonlinear models Explores numerical differentiation,

integration, and optimization Describes how to find eigenvalues and eigenfunctions Discusses interpolation and curve fitting Considers the analysis of time series Using R for Numerical Analysis in Science and Engineering provides a solid introduction to the most useful numerical methods for scientific and engineering data analysis using R.

Simulation and modeling using numerical methods is one of the key instruments in any scientific work. In the field of photonics, a wide range of numerical methods are used for studying both fundamental optics and applications such as design, development, and optimization of photonic components. Modeling is key for developing improved photonic devices and reducing development time and cost. Choosing the appropriate computational method for a photonics modeling problem requires a clear understanding of the pros and cons of the available numerical methods. Numerical Methods in Photonics presents six of the most frequently used methods: FDTD, FDFD, 1+1D nonlinear propagation, modal method, Green's function, and FEM. After an introductory chapter outlining the basics of Maxwell's equations, the book includes self-contained chapters that focus on each of the methods. Each method is accompanied by a review of the mathematical principles in which it is based, along with sample scripts, illustrative examples of characteristic problem solving, and exercises. MATLAB® is used throughout the text. This book provides a solid basis to practice writing your own codes. The theoretical formulation is complemented by sets of exercises, which allow you to grasp the essence of the modeling tools.

Major advances, both in modeling methods and in the computing power required to make those methods viable, have led to major breakthroughs in our ability to model the performance and vulnerability of explosives and propellants. In addition, the development of proton radiography during the last decade has provided researchers with a major new experi

The Science of Armour Materials comprehensively covers the range of armor materials from steels and light alloys, through glasses and ceramics, to fibers, textiles, and protective apparel. The book also discusses aspects of analytical and numerical modeling, as well as laboratory-based high-strain rate testing and ballistic testing methodologies. Each chapter is written from an international perspective, including reviews of the current global literature, and incorporates case studies that focus upon real life applications, research outcomes, and lessons learned. The threat spectrum is restricted to small arms ammunition, high velocity fragments, and stab and spike attacks, as well as blast loadings. Features input from an editor who is an expert in his field: Dr. Ian Crouch, the author of over 80 publications in his field, with three patents to his name Provides systematic and comprehensive coverage of armor materials, modeling, and testing Offers a cross-disciplinary approach that brings together expertise in materials science and defense engineering Discusses aspects of analytical and numerical modeling, as well as laboratory-based high-strain rate testing and ballistic testing methodologies

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