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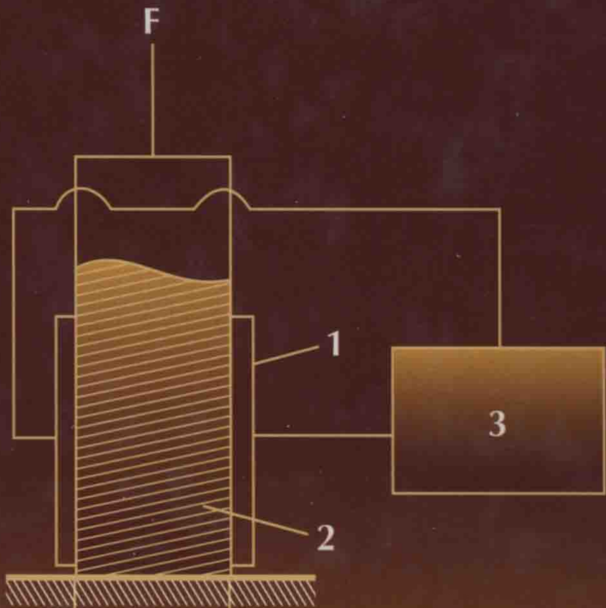
PHYSICS of STRENGTH and FRACTURE CONTROL

Adaptation of Engineering Materials and Structures



Author
Anatoly A. Komarovsky
Scientific Editor
Viktor P. Astakhov

Materials Science

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Physics of Strength and Fracture Control: Adaptation of Engineering Materials and Structures introduces a new physical concept in the science of the resistance of materials to external effects, a concept that opens completely new avenues for improving the strength and safety of engineered objects. Based on a thermodynamic equation of state of solids derived by the author, the approach provides a general methodology for treating all the physical and mechanical properties of materials, regardless of their nature and physical state. The author shows that this approach enables the control of the stressed-deformed state both to prevent failures and fractures and to promote them for easier shaping of materials. He uses this methodology to present and discuss non-traditional but practical ways of solving real-world problems.

Of enormous theoretical and practical significance, this groundbreaking work ushers in a new stage in the science of material strength. It opens the door to systematic ways to design materials, control their operating properties, and predict their behavior under specific operating conditions.

FEATURES

- Presents a breakthrough approach that leads to a fundamental understanding of the relationship between materials structure, processing, and properties
- Theoretically formulates and experimentally proves new concepts for controlling deformation and fractures
- Derives the thermodynamic equation of state of solids and uses it to propose new theoretical and practical concepts, methods, and design techniques
- Shows that the equation of state can explain all phenomena related to deformation and fracture processes and will lead to new methods for predicting and controlling material operating properties

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Komarovsky
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PHYSICS of STRENGTH and FRACTURE CONTROL

Adaptation of Engineering Materials and Structures

Preface

Modern engineering materials and structures operate on the ground, under the water, and in space, at normal, high and cryogenic temperatures, in aggressive environments, and under conditions of intensive radiation. Requirements for their strength, reliability, and durability continuously increase.[1,2] Engineering and applied sciences try to solve multiple problems associated with these requirements using mechanical–mathematical methods rather than physical methods.[3,4] This practice imposes substantial limitations on the level of technogenic safety of engineering objects already achieved and does not lead to improvements in many technological processes associated with engineering materials.

Although the prospects for developing engineering materials are correlated to solid-state physics,[5] the related aspects of this science are insufficiently elaborated.[6,7] As a result, the gap grows between improving the durability of engineering materials and structures and increasing requirements for their safety and reliability, and the corresponding scientific and technical support to meet these challenges. Developed at a time when only invariable or slowly varying force fields were considered, many existing concepts of the physical nature of resistance of solids to different combinations of external effects are obsolete.[3]

According to data presented by Kluev,[3] technogenic accidents and catastrophes resulting in economic losses amounting to $2 billion occur every 10 to 15 years on average; those with losses of up to $100 million occur every 14 to 15 days. Technical progress and inadequacy of traditional methods for ensuring reliable service conditions lead to a 10 to 30% increase in these losses annually. Moreover, for critical objects, they are aggravated by environmental, moral, and social consequences.

From today's standpoint, this means that standard methods of ensuring strength, reliability, and durability have already exhausted their potential. The development of these methods follows a curve with negative first and second derivatives. The time when a qualitatively new stage in the development of design methods should be introduced to support technical progress has passed. Because existing methods and concepts have no reserves left, qualitatively new principles of ensuring technogenic safety need to be introduced.

This book demonstrates that the advances in modern physics that became evident in the mid-20th century form a reliable and sufficient ground for revising common notions of the nature of resistance of solids to diverse external fields (force, thermal, radiation, etc.) and aggressive environments. The book formulates, and then theoretically and experimentally proves, new concepts to control deformation and fracture. It offers methods for inhibition of fracture and reconditioning of damaged structures; a number of nontraditional methods are developed and applied to solve typical practical problems.

This book introduces a new physical concept in the development of the science of resistance of materials to external effects. At its core, the proposed approach has the thermodynamic state of solids equation derived by the author. The book demonstrates that the system of ensuring reliability and durability of engineering structures commonly used today is at an embryonic stage of its development and thus still passive and uncontrollable. The current system is not able to provide corrections or replenishments to the used part of the service life of engineering materials and structures. As a result, failures of engineering materials and structures can be neither predicted nor avoided, thus leading to "unpredictable" accidents and catastrophes. In contrast to this existing system, the concept suggested in the book allows controllability of the stressed–deformed state of materials and structures by activating or preventing undesirable deformations and fractures.

This work develops a new stage in the science of materials strength and provides an introduction to the theory of adapting materials and structures to operating conditions based on physical principles of leading-edge technologies. It introduces new avenues for industries dealing with advanced technologies and products for the improvement of technogenic safety of engineering objects, as well as for the reduction of power consumption of special technological processes. It also discusses practical, but nontraditional, methods of solving many typical problems.

The book is intended for a wide range of readers specializing in the fields of solid-state physics, statistical physics, thermodynamics, materials science, manufacturing technology and processing of structural materials, technology for production and processing of mineral resources, resistance of materials to various external loads, quality of parts and structures, reliability and durability of machines and mechanisms, etc. Thus, all who are directly or indirectly involved in the activation (as in metal cutting) or elimination (engineering structures) of deformation and fracture will find the information useful. It is also very helpful for students because it covers the fundamental aspects of the physics of solids and their resistance to external energy fields and aggressive environments.

Anatoly A. Komarovsky

Preface of the Scientific Editor

Background

To be practical and efficient, materials simulations should be based on proper understanding of the physics of materials; moreover, a way to "convert" such understanding into a mathematical model should be clearly indicated. Unfortunately, this has not yet occurred. Currently, the approach to this problem is to create new materials research centers and laboratories supported by industry and by the National Science Foundation (NSF). The results obtained thus far are not encouraging.

This book explains why solution of actual problems in physics and engineering of materials within the scope of traditional ideas is not possible, regardless of the amount of money granted by NSF or invested by industry. Using numerous examples, this book demonstrates the drawbacks of existing approaches to the mechanics of material and mechanical metallurgy. Attention is drawn to the fact that well-known books on the subject pay little attention to the physics of materials resistance to various external effects (external forces, fields, etc.). Although existing books consider a number of microlevel phenomena, including the property of AM bonds, dislocations, etc., the relation between the microphysics and macrophysics of materials, which defines their actual behavior, is explained qualitatively and thus cannot be used in practice.

Handbooks, reference books, engineering manuals, and standards on the engineering calculations of the strength of parts and structures do not follow advances in materials science. Not one essential property has been added in the last 50 years to the known properties of materials available to a designer. (One can see this on the most popular Web site for materials properties, www.matweb.com.) As a result, design methodology based on failure criteria (largely obtained in the 19th century) and an enormous "safety factor" (that costs billions and "covers" lack of knowledge of materials) prevails in practice.

This book pioneers a new direction in materials science. For the first time, a physical explanation of the strength of materials is offered. The book is multidisciplinary and should be of great interest to all specialists concerned with materials and their properties, design of parts and structures, durability, and reliability.

The Aim of This Book

The ultimate goal of this book is to achieve full understanding of the physics of solid matter through the derived equation of the state of a solid. Using this equation as the basis, this book aims to describe the interaction of a solid with external energy fields. Another essential goal is to suggest new methods to control failure of solids under a full diversity of service conditions.

This book demonstrates that physical–mechanical properties can be controlled from the point of design of a material to the point of fulfilling specific consumer functions, at the stage of solidification and processing, and during service periods of machines and mechanisms. At the first two stages the control functions are performed by passive or materials science methods, whereas at the last stage they are achieved by using active energy methods. Fundamentals of technology for making materials with preset properties in this book will be of interest to materials scientists involved in the development of advanced materials. In addition to solving a direct problem, i.e., control of the structure-formation or destructive processes, the suggested approach allows an inverse problem, i.e., prediction, to be handled successfully.

The book clarifies physical principles of operation and advantages and disadvantages of existing methods of technical diagnostics and nondestructive testing, as well as ways of expanding their capabilities. It also indicates guidelines for development of new, advanced methods for prediction of the technical state of materials and structures. This will be particularly interesting to specialists involved in the development and application of methods of technical diagnostics and nondestructive testing, reliability, and durability of engineering objects and their components. In general, knowing the trends in a specific science and technology area widens the horizons for those working in the area and is very helpful to other specialists.

Why One Needs This Book

This book is essential for understanding how structural materials behave in reality in various external fields and aggressive environments, for understanding how to control the processes of deformation and fracture of solids, and, finally, to build high-reliability engineering objects whose structural components can be adapted to operating conditions. It will not answer all questions about materials, but it will supply knowledge about the physical nature and behavior of materials. Using this knowledge can provide the answers to many theoretical and practical problems.

Viktor P. Astakhov

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I was extremely fortunate that Viktor P. Astakhov kindly agreed to be the scientific editor of this book. As initiator of its publication and a great advisor during the course of its preparation, he made many useful comments and suggestions regarding content, structure, and presentation of major ideas. His incredible engineering sense and broad interdisciplinary knowledge about materials and their technology and about technical physics and applied mathematics helped me enormously in clarifying content. I am deeply grateful to Dr. Zelnichenko for his coordination of the translation of this book into English and to Mrs. T.K. Vassilenko and Ms. Kutianova for their translation. Special thanks are extended to T.Yu. Snegireva and I.S. Batasheva for the clear illustrations.

The Author

Anatoly A. Komarovsky, Ph.D., Dr.Sci., is currently the chief of the Laboratory of Physics of Strength, Scientific and Engineering Center for Non-Traditional Technologies (SALUTA), Kyiv. He received his B.S. and M.E. Mech.E. degrees from Kiev Aviation University (Ukraine) in 1964, his B.S. and M.S. degrees in physics from Kiev National State University (Ukraine) in 1969, and his Ph.D. from the Highest Scientific-Attestation Committee of the U.S.S.R., Moscow, in 1973. Dr. Komarovsky was awarded a Dr.Sci. (Ukraine) designation in 1992 for his outstanding performance and profound impact on science and technology.

After a career in industry with Kiev Civil Engineering Research Institute, where he eventually became the chief of the civil engineering and multidisciplinary research laboratory, Dr. Komarovsky became managing director and professor of Kiev Industrial Technical College. There he taught a number of materials-related courses and continued his study on the physics of materials. After achieving great theoretical results and experimental confirmations, he joined SALUTA in 1991 to further research and implement his results in practice. Dr. Komarovsky has written four books and more than 60 scholarly articles; he holds seven patents.

The Scientific Editor

Viktor P. Astakhov, Ph.D., Dr.Sci., received his B.Eng. in manufacturing from Odessa College of Industrial Automation (U.S.S.R.) in 1972, his M.Eng. from Odessa National Polytechnic University (U.S.S.R.) in 1978, his B.Sc. and M.Sc. in applied mathematics from Mechnicov State University (Odessa, U.S.S.R.) in 1990, and his Ph.D. from Tula Polytechnic University (U.S.S.R.) in 1983. Dr. Astakhov was awarded a Dr.Sci. designation (U.S.S.R.) in 1991 for his outstanding performance and profound impact on science and technology.

Dr. Astakhov's first teaching appointment was in the department of metal cutting and cutting tools at Odessa National Polytechnic University in 1984, where he became a full professor and head of the deep-hole machining industrial center. Dr. Astakhov has served on a number of national scientific and planning committees and has also been a consultant to the machine tool building, and aerospace, nuclear, and gas turbine industries. Currently, he is R&D director of Hypertool Co., a consultant to Ford Motor Co., and adjunct professor at Concordia University (Montreal) and the University of Manitoba (Winnipeg).

Dr. Astakhov's principal research interest is in manufacturing, including the theory of metal cutting, mechanical metallurgy, and physics of fracture. Active in fundamental and industrial research, he has published and edited several books and more than 100 papers, and he holds more than 40 patents. He serves as a board member and frequent reviewer for several international scientific journals.