Seventh Edition

Late Professor Emeritus of Engineering of
University of Central Florida

Professor of Ocean and Mechanical Engineering
Florida Atlantic University

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Javad Hashemi is a Professor of Mechanical Engineering at Florida Atlantic University. Javad received his Ph.D. in Mechanical Engineering from Drexel University in 1988. Prior to his tenure at Florida Atlantic University, Javad served as Professor of Mechanical Engineering and Associate Dean of Research for the College of Engineering at Texas Tech University. Over the course of his career, Dr. Hashemi has published over 50 articles in archival journals in the areas of materials, mechanics, and biomechanics. He has taught undergraduate and graduate level courses in materials, structural analysis, design, biomechanics and has developed a materials laboratory course with a variety of experiments.

The late **William F. Smith** was Professor Emeritus of Engineering in the Mechanical and Aerospace Engineering Department of the University of Central Florida at Orlando, Florida. He was awarded an M.S. degree in metallurgical engineering from Purdue University and a Sc.D. degree in metallurgy from Massachusetts Institute of Technology. Dr. Smith, who was a registered professional engineer in the states of California and Florida, taught undergraduate and graduate materials science and engineering courses and actively wrote textbooks for many years. He was also the author of *Structure and Properties of Engineering Alloys,* Second Edition (McGraw Hill, 1993).

he subject of materials science and engineering is an essential course to engineers and scientists from all disciplines. With advances in science and technology, development of new engineering fields, and changes in the engineering profession, today's engineer must have a deeper, more diverse, and up-to-date knowledge of materials-related issues. At a minimum, all materials science and engineering students must have the basic knowledge of the structure, properties, processing, and performance of various classes of materials. This is a crucial first step in the materials selection decisions in everyday rudimentary problems. A more scientific understanding of the same topics is necessary for designers of complex systems, forensic (materials failure) analysts, and research and development engineers/scientists.

Accordingly, to prepare materials scientists and engineers of the future, *Foundations of Materials Science and Engineering* is designed to present diverse topics in the field with appropriate breadth and depth. The strength of the book is in its focus on key concepts in science of materials (basic knowledge) followed by application of scientific principles in selection and engineering of materials (applied knowledge). The basic and applied concepts are integrated through concise textual explanations, relevant and stimulating imagery, detailed sample problems, electronic supplements, and homework problems. This textbook is therefore suitable for both an introductory course in materials at the sophomore level and a more advanced (junior/senior level) second course in materials science and engineering. Finally, the seventh edition and its supporting resources are designed to address a variety of student learning styles based on the well-known belief that not all students learn in the same manner and with the same tools.

With every new edition, it is our intent to improve and complement the explanations of the underlying science of materials. As a result, in this new edition, we have made numerous updates described below:

Chapter 1, a section on the ever important environmental considerations in selection of materials has been added. Life-cycle analysis for materials selection and sustainability (renewable materials and nonrenewable materials) has been introduced. We hope to expand on this topic in future editions.

Chapter 2, the important concept of energy levels for multi electron atoms has been explained in detail. The concept of effective nuclear charge accounting for electron shielding is clarified and Slater's rule used to determine the energy associated with any electron is introduced.

Chapter 3, a more detailed explanation of Bravais lattice, unit cells, the extent of symmetry of a unit cells, and motif is presented.

Chapter 4, the concept of Gibbs free energy is discussed in more detail and the derivation of the critical radius for stable solidification has been updated.

Chapter 5, the relationship between number of vacancies and Gibbs free energy is explained. The theoretical foundation and development of Fick's second law is described.

Chapter 6, the concept of resolved shear stress is explained in more detail.

Chapter 7, theoretical strength, Griffith's theorem, and stress concentration factors are introduced to enhance understanding of brittle fracture of materials. The concept of stress intensity factor is introduced and fracture toughness is explained in more detail.

Chapter 9, the impact of specific alloying elements on properties of steel is discussed.

The end-of-chapter problems have been classified according to the learning/understanding level expected from the student by the instructor. The classification is based on Bloom's Taxonomy and is intended to help students as well as instructors to set goals and standards for learning objectives. The first group in the classification is the Knowledge and Comprehension Problems. These problems will require students to show learning at the most basic level of recall of information and recognition of facts. Most problems ask the students to perform tasks such as define, describe, list, and name. The second group is the Application and Analysis Problems. In this group, students are required to apply the learned knowledge to the solution of a problem, demonstrate a concept, calculate, and analyze. Finally, the third class of problems is called Synthesis and Evaluation Problems. In this class of problems, the students are required to judge, evaluate, design, develop, estimate, assess, and in general synthesize new understanding based on what they have learned from the chapter. It is worth noting that this classification is not indicative of the level of difficulty, but simply different cognitive levels.

Over 150 new problems have been developed, mostly in the synthesis and evaluation category. These problems are intended to make the students think in a more in-depth and reflective manner. This is an important objective of the authors to help instructors to train engineers and scientists who operate at a higher cognitive domain.

The instructors' PowerPoint® lectures have been updated according to the changes made to various chapters. These detailed, yet succinct, PowerPoint lectures are highly interactive and contain technical video clips, tutorials for problem solving, and virtual laboratory experiments. The PowerPoint lectures are designed to address a variety of learning styles including innovative, analytic, common sense, and dynamic learners. Not only is this a great presentation tool for the instructor, it creates interest in the student to learn the subject more effectively. We strongly recommend that the instructors for this course view and test these PowerPoint lecture presentations. This could be especially helpful for new instructors.

Additional resources available through the Instructor Resources are animations; tutorials; and a searchable materials properties database.

Remote proctoring and browser-locking capabilities, hosted by Proctorio within Connect, provide control of the assessment environment by enabling security options and verifying the identity of the student.

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The co-author, Javad Hashemi, would like to dedicate his efforts on this textbook to the eternal-loving memory of his parents Seyed-Hashem and Sedigheh; to his wife, mentor, and friend, Eva; to his sons Evan Darius and Jonathon Cyrus; and last but not least to his siblings (thank you for your ceaseless love and support).

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- Jordan Cunningham, Eastern Washington University

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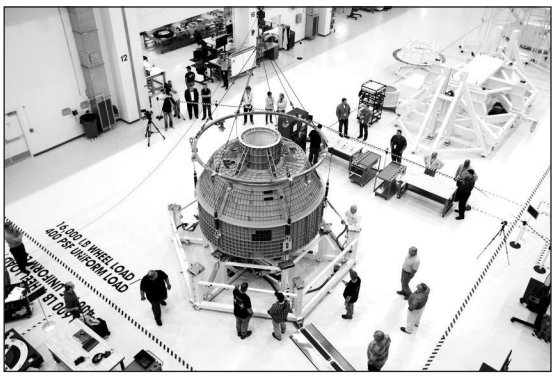
(Source: NASA)



(Source: NASA/Ben Smegelsky)

ne of the most exciting proposed NASA missions is the human journey to Mars by the 2030s. The scientific questions that can be answered by actual human presence on Mars are too numerous and very exciting. A convoy of three NASA orbiters and two active rovers are already functioning on and around Mars to gather more information about the Red Planet in order to pave the way for future manned explorations. NASA engineers, together with U.S. aerospace companies such as Lockheed Martin, are putting together the Space Launch System (SLS) rocket that will take the Orion spacecraft on its manned Mars mission. Consider the technologies and the engineering knowledge needed to build the Orion spacecraft and complete such a mission. Following are some of the engineering and materials-related issues considered by NASA and Lockheed Martin in manufacturing the spacecraft.

Pressure testing: The Orion capsule, called the "birdcage," has an underlying welded metallic structure that must contain the atmosphere for the crew during launch, space travel, reentry, and landing. The capsule will provide living space for the astronauts and must withstand the loads sustained during launch and landing. It is crucial that the structure be able to withstand the maximum internal pressurization needed for the journey. What metal would be suitable for the underlying structure? What properties should it have?

Tile bonding: During reentry, the Orion spacecraft will enter Earth's atmosphere at speeds of 25,000 miles per hour and will be exposed to very high temperatures exceeding 5000°F. The "birdcage" of Orion, discussed above, cannot function at such high temperatures and requires a thermal protection system. NASA will use about 1300 ceramic tiles to protect the capsule in addition to a heat shield. Why use ceramic

LEARNING OBJECTIVES

By the end of this chapter, students will be able to

1. Describe the subject of materials science and engineering as a scientific discipline.
2. Cite the primary classification of materials.
3. Give distinctive features and charactersitics of each group of materials.
4. Name various material from each group. Give some applications of different types of materials.
5. Evaluate how much you know and how much you do not know about materials.
6. Establish the importance of materials science and engineering in the selection of materials for various applications.

tiles? What properties do they possess that makes them attractive as a thermal protection system? What is the heat shield made of? What characteristics should it have?

Flight systems and subsystems: For Orion to function and communicate, it needs its avionics. This includes electrical power storage and distribution, thermal control systems, cabin pressure monitoring, communication command, data handling, guidance, navigation and controls, propulsion, and computers. The slew of sensors and actuators needed for the these operations require the use of advanced electronics materials. What are the applications of electronics materials in space travel? Why are such materials crucial to the success of the mission?

Vibration tests: The Orion spacecraft will encounter vibrations due to interaction with Earth's atmosphere. It is crucial that the spacecraft be able to withstand such vibrations, and all systems, structural or electronic, must function under extreme conditions. NASA tested the Orion capsule using two electromagnetic shakers and exposed it to vibration frequencies ranging from 5 Mhz to 500 Mhz. What strategies for vibration dampening could be used? What materials would be beneficial for dampening vibration?

These are only some of the questions, tests, and considerations that NASA and Lockheed Martin engineers make in manufacturing of this complex system. Can you think of other issues that need be considered? What is the role of materials science and engineering in answering those questions?

Humankind, **materials,** and engineering have evolved over the passage of time and are continuing to do so. All of us live in a world of dynamic change, and materials are no exception. The advancement of civilization has historically depended on the improvement of materials to work with. Prehistoric humans were restricted to naturally