

# Sloan Career Cornerstone Center

## Materials Science and Engineering Overview

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Materials Science and Engineering (MSE) is a field of engineering that encompasses the spectrum of materials types and how to use them in manufacturing. Materials span the range: metals, ceramics, polymers (plastics), semiconductors, and combinations of materials called composites. We live in a world that is both dependent upon and limited by materials. Everything we see and use is made of materials: cars, airplanes, computers, refrigerators, microwave ovens, TVs, dishes, silverware, athletic equipment of all types, and even biomedical devices such as replacement joints and limbs. All of these require materials specifically tailored for their application. Specific properties are required that result from carefully selecting the materials and from controlling the manufacturing processes used to convert the basic materials into the final engineered product. Exciting new product developments frequently are possible only through new materials and/or processing. New materials technologies developed through engineering and science will continue to make startling changes in our lives in the 21st century, and people in Materials Science and Engineering will continue to be key in these changes and advances. These engineers deal with the science and technology of producing materials that have properties and shapes suitable for practical use. Activities of these engineers range from primary materials production, including recycling, through the design and development of new materials to the reliable and economical manufacturing for the final product. Such activities are found commonly in industries such as aerospace, transportation, electronics, energy conversion, and biomedical systems. The future will bring ever-increasing challenges and opportunities for new materials and better processing. Materials are evolving faster today than at any time in history. New and improved materials are an "underpinning technology" - one which can stimulate innovation and product improvement. High quality products result from improved processing and more emphasis will be placed on reclaiming and recycling. For these many reasons, most surveys name the materials field as one of the careers with excellent future opportunities.



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### The Field

CD-ROMs, like everything around us, are made of materials. So are dessert plates, basketballs, car engines, telephones, and audiocassettes. Therefore the work done under the heading of Materials Science Engineering has an unprecedented impact on our quality of life. Although the field deals with materials, it encompasses an incredible diversity of topics and problems constituting the four elements of the field -- processing, structure, properties, and performance.

## Materials

History is measured by innovations in materials. Developments in metals like iron and bronze enabled advances in civilization thousands of years ago, a synergy which continues today in the fiber optics that have created the World Wide Web and in the development of biomaterials that mimic living tissue. As you explore the field it may be useful to become familiar with some generic categories of materials.

### Metals

Metals are materials that are normally combinations of "metallic elements". These elements, when combined, usually have electrons that are non-localized and as a consequence have generic types of properties. Metals usually are good conductors of heat and electricity. They are also quite strong but deformable and tend to have a lustrous look when polished.

### Ceramics

Ceramics are generally compounds between metallic and nonmetallic elements and include such compounds as oxides, nitrides, and carbides. Typically they are insulating and resistant to high temperatures and harsh environments.

### Plastics

Plastics, also known as polymers, are generally organic compounds based upon carbon and hydrogen. They are very large molecular structures. Usually they are low density and are not stable at high temperatures.

### Semiconductors

Semiconductors have electrical properties intermediate between metallic conductors and ceramic insulators. Electrical properties are strongly dependent upon small amounts of impurities.

### Composites

Composites consist of more than one material type. Fiberglass, a combination of glass and a polymer, is an example. Concrete and plywood are other familiar composites. Many new combinations include ceramic fibers in metal or polymer matrix.

## Processing

Processing refers to the way in which a material is achieved. Advances in technology have made it possible to create a material atomic layer by atomic layer. There are four general categories which may be useful to know: solidification processing, powder processing, deposition processing, and deformation processing.

### Solidification Processing

Most metals are formed by creating an alloy in the molten state, where it is relatively easy to mix the components. This process is also utilized for glasses and some polymers. Once the proper temperature and composition have been achieved, the melt is cast. Castings can be divided into two types, depending on the subsequent processing steps. The first type is shape casting, which takes advantage of the fluidity of liquid metal to form complex shapes directly. Because of the complexity of their part geometries, these castings generally cannot be worked mechanically to a significant degree. Therefore any changes in microstructure or properties must either be achieved first during solidification or through subsequent heat treatments.

## Powder Processing

Powder processing involves consolidation, or packing, of particulate to form a 'green body'. Densification follows, usually by sintering. There are two basic methods of consolidating powders: either dry powder can be compacted in a die, a process known as dry-pressing, or the particles can be suspended in a liquid and then filtered against the walls of a porous mold in a process known as slip-casting or filter pressing. Bulk ceramics are usually processed in powder form since their high melting points and low formability prohibit other types of processing. Metals and polymers can also be processed from powders.

## Deposition Processing

Deposition processing modifies a surface chemically, usually by depositing a chemical vapor or ions onto a surface. It is used in semiconductor processing and for decorative or protective coatings. Vapor source methods require a vacuum to transport the gaseous source of atoms to the surface for deposition. Common vapor sources are thermal evaporation (similar to boiling water to create steam), sputtering (using energetic ions to bombard a source and create the gas state), or laser light (ablates, or removes, atoms from surface to create the gaseous state). Other sources use carrier media such as electrochemical mixtures (ions in a solution transported by an electrical field to the surface for depositions) or spray coating (ions or small particles transported by gases, liquids, and/or electrical field).

## Deformation Processing

One of the most common processes is the deformation of a solid to create a desired shape. A large force is generally used to accomplish the deformation, and many techniques heat the material in order to reduce the force necessary to deform it. Sometimes a mold is used to define the shape. Forging, an old method that heated the metal and deformed the metal by hammer blows is still used today, albeit with multi-ton hammers. Rolling to reduce the thickness of a plate is another common process. Some glasses when heated can be formed with tools or molds. Other common methods, like drilling to make holes, or milling, are machining versions of the deformation process.

## Structure

Structure refers to the arrangement of a material's components from an atomic to a macro scale. Understanding the structure of a substance is key to understanding the state or condition of a material, information which is then correlated with the processing of the material in tandem with its properties. Understanding these relationships is an intrinsic part of materials science engineering, as it allows engineers to manipulate the properties of a material.

## Properties

Does a material need to be strong and heat-resistant, yet lightweight? Whether you're talking about a fork or the space shuttle, products have specific requirements which necessitate the use of materials with unique properties. Materials engineers must frequently reconcile the desired properties of a material with its structural state to ensure compatibility with its selected processing. Typical properties of interest may be classified into:

**Mechanical Properties:** Tensile strength, fracture toughness, fatigue strength, creep strength, hardness

**Electrical Properties:** Conductivity or resistivity, ionic conductivity, semiconductor conductivity (mobility of holes and electrons)

**Magnetic Properties:** Magnetic susceptibility, Curie Temperature, Neel Temperature, saturation magnetization

**Optical and Dielectric Properties:** Polarization, capacitance, permittivity, refractive index, absorption

**Thermal Properties:** Coefficient of thermal expansion, heat capacity, thermal conductivity

**Environmental Related Properties:** Corrosion behavior, wear behavior

## Performance

The evaluation of performance is an integral part of the field. The analysis of failed products is often used to obtain feedback on processing and its control as well as to assist in the initial selection of the material and in the stages of processing. Testing also ensures that the product meets performance requirements. In many products the control of its processing is closely associated with some property test and/or a structural characterization.

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## Preparation

Preparation for a career in materials engineering can begin as early as high school, and need not be limited to a course of 'materials' study. There are many kinds of programs, degrees, and disciplines that will enable you to pursue a career in the field.

### Pre-College

It is highly recommended that while in high school you take the maximum amount of college preparatory mathematics, laboratory sciences, and English offered. If choices are possible, those courses highly dependent upon knowledge and reasoning should take precedence over courses in which the emphasis is on manual skill. Students should try to take all the physical sciences and mathematics courses offered at their school. In addition, students should take advantage of all available opportunities to develop their communication skills. Study of a language other than English is desirable. Talk to your guidance counselor about requirements at the university of your choice



### College Programs

Most major universities have academic BS degree granting programs in one of the specialty areas of Materials Science and Engineering. The majority of undergraduate programs provide a survey across the spectrum of materials. Other programs focus in one particular class of materials like Ceramics, Metallurgy, or Polymers.

A few universities only have graduate programs. Graduate programs are open to people with bachelors degrees in the field as well as those from other more general areas of science and

engineering. Specific areas of expertise in each program are dependent upon the faculty in that program. The average program is staffed by 15 faculty members. Programs range in faculty size from less than ten members to near forty. No single program covers the entire field due its breadth and the typically modest number of faculty members.

## Accredited Programs

Those interested in a career in materials engineering should consider reviewing engineering programs that are accredited by the Accreditation Board for Engineering and Technology, Inc. (ABET). ABET accreditation is based on an evaluation of an engineering program's student achievement, program improvement, faculty, curricular content, facilities, and institutional commitment. The following is a partial list of universities offering accredited degree programs in materials engineering, including materials, ceramic, and metallurgical programs.

Materials Programs	Ceramic Programs
<ul style="list-style-type: none"> <li>• The University of Akron</li> <li>• University of Alabama at Birmingham</li> <li>• Alfred University</li> <li>• Arizona State University</li> <li>• University of Arizona</li> <li>• Auburn University</li> <li>• Brown University</li> <li>• California Polytechnic State University, San Luis Obispo</li> <li>• University of California, Davis</li> <li>• University of California, Irvine</li> <li>• University of California, Los Angeles</li> <li>• Carnegie Mellon University</li> <li>• Case Western Reserve University</li> <li>• University of Cincinnati</li> <li>• Colorado School of Mines</li> <li>• Cornell University</li> <li>• Drexel University</li> <li>• University of Florida</li> <li>• Georgia Institute of Technology</li> <li>• University of Illinois at Urbana-Champaign</li> <li>• Illinois Institute of Technology</li> <li>• Iowa State University</li> <li>• The Johns Hopkins University</li> <li>• University of Kentucky</li> <li>• Lehigh University</li> <li>• University of Maryland College Park</li> <li>• Massachusetts Institute of Technology</li> <li>• Michigan State University</li> <li>• Michigan Technological University</li> <li>• University of Michigan</li> <li>• University of Minnesota-Twin Cities</li> <li>• Montana Tech of the University of Montana</li> <li>• New Mexico Institute of Mining and Technology</li> <li>• North Carolina State University at Raleigh</li> <li>• Northwestern University</li> <li>• The Ohio State University</li> </ul>	<ul style="list-style-type: none"> <li>• Alfred University</li> <li>• Clemson University</li> <li>• University of Missouri-Rolla</li> <li>• Pennsylvania State University</li> <li>• Rutgers, The State University of New Jersey</li> </ul> <p data-bbox="815 913 1112 945"><b>Metallurgical Programs</b></p> <ul style="list-style-type: none"> <li>• The University of Alabama</li> <li>• Colorado School of Mines</li> <li>• University of Idaho</li> <li>• University of Missouri-Rolla</li> <li>• Montana Tech of the University of Montana</li> <li>• University of Nevada-Reno</li> <li>• The Ohio State University</li> <li>• University of Pittsburgh</li> <li>• South Dakota School of Mines and Technology</li> <li>• University of Texas at El Paso</li> <li>• University</li> </ul>

- **Pennsylvania State University**
- **University of Pennsylvania**
- **University of Pittsburgh**
- **Purdue University at West Lafayette**
- **Rensselaer Polytechnic Institute**
- **San Jose State University**
- **University of Tennessee at Knoxville**
- **University of Texas at El Paso**
- **University of Utah**
- **Virginia Polytechnic Institute and State University**
- **Washington State University**
- **University of Washington**
- **Winona State University**
- **University of Wisconsin-Madison**
- **University of Wisconsin-Milwaukee**
- **Wright State University**

## Coursework

A materials program serves a dual purpose: it provides technical information and instills a thought process characteristic of the engineering discipline. All programs integrate the four elements of the field (properties, structure, processing, and performance) through the several classes of materials (ceramics, electronic materials, metals, polymers, composites). Specialized curricula synthesize one class of materials with the elements of the field, in a Ceramic Engineering or Metallurgical Engineering program, for example. In most programs, however, a core curriculum is incorporated with courses addressing the scientific principles relating to the properties and behavior of materials, as well as the structure (atomic configurations), characterization, and processing of materials. Engineering design courses focus on the performance of materials in applications and emphasize devising new materials, components, systems, or processes to meet particular objectives. Most engineering programs develop from a mathematical base coupled with aspects of chemistry or physics. MST, however, builds almost equally upon chemistry and physics and includes an increasing influence of biology. Communications, social issues, and the humanities are also incorporated in order to provide individuals the requisite breadth to be able to place technical problems in the context of tomorrow's world.



## Concentrations

Degrees are granted in several specializations and concentrations, including materials, metals, minerals, ceramics, and polymers. Within these study programs, one can emphasize areas such as processing, structure-property relationships, electronic properties, and chemical and environmental effects.

## Graduate School

Many students continue their studies to earn an advanced degree, a master's (MS) degree or a doctoral (Ph.D./D.Sc.) degree. They do this either directly after earning the BS degree or after some work experience. An MS degree generally can be earned within two years after the BS degree. The doctoral degree, which typically involves four plus years of study and research beyond the BS degree, is usually completed by those interested in careers in research and/or teaching. Depending on an individual's career goals, the BS degree may also be followed by study in such fields as business administration, management, medicine, and law.

## Study Abroad

Studying abroad can be an exciting and rewarding experience. Materials Science & Engineering careers may take you overseas or at least offer you the opportunity to work with international corporations. Information on studying abroad may be obtained from university counselors. For more information, visit:

- Institute of International Education: [www.iie.org](http://www.iie.org)
- Resource for Study Abroad: [www.studyabroad.com](http://www.studyabroad.com)
- Council of International Educational Exchange: [www.ciee.org](http://www.ciee.org)
- Association for International Practical Training: [www.aipt.org](http://www.aipt.org)



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## Day in the Life

From cellular phones to artificial hip joints to lightweight bicycles, materials engineers work to develop products that improve lives. Materials engineers bring advances in the auto, aerospace, construction, manufacturing, electronics, computer, and telecommunications industries by developing new or improved metals, plastics, ceramics, semiconductors and composites. They work to increase the strength of steel, toughen ceramics, lower the cost of composites and make faster computer circuits. Materials are involved in almost every engineering product, and materials engineers are needed to select the best material, improve its properties, lower its processing cost and increase its durability.

## Career Tracks

There can be many tracks within a career. A materials engineer might begin in a technical area such as manufacturing or research and development, and then move into a management, sales, marketing, or a consulting role, depending on interest and ability.

## Teamwork & Environment

In a manufacturing operation most tasks are conducted by cross-functional teams of people. Materials engineers are generally part of a support group integral to these teams for various functions -- from design concept through manufacturing processes to final product evaluations.













