# MATERIALS SCIENCE AND ENGINEERING

## Graduate Study

Built on a foundation of thermodynamics, kinetics of phase transformations, mechanical behavior, physical properties, solid state science, and the structure and chemistry of materials, the graduate program offers advanced studies in many areas of materials science and engineering, including the design and control of materials for structural, electronic, photonic, magnetic, optical, and biological functionality. Graduates of the program have a fundamental understanding of the critical aspects of the field and how they are applied to real materials systems. The program is highly flexible and research-oriented, where students work carefully with their major professor in tailoring the various academic and research components to meet their interests.

With the ability to address complex problems in materials science while considering the various constraints inherent to both academic and industrial environments, our graduates are well prepared for a wide range of academic and research-related careers. They are skilled in carrying out independent and collaborative research, able to communicate effectively in formal and informal settings, and are proficient at writing persuasive technical articles and grant proposals.

The department boasts excellent facilities for academic materials research, maintaining a wide range of faculty laboratories across the ISU campus. In addition, departmental research is highly integrated with the operation of several Research Centers, such as the Ames Laboratory, the Center for Nondestructive Evaluation, the Microelectronics Research Center, the Center for Advanced Nonferrous Structural Materials, the Caloric Materials Consortium, and the Critical Materials Institute. These laboratories offer excellent resources and opportunities for graduate student research.

## Graduate Majors

The department offers work toward the following advanced degrees: Master of Engineering in Materials Science and Engineering, Master of Science in Materials Science and Engineering and Doctor of Philosophy in Materials Science and Engineering.

Prerequisite to major graduate work is completion of an undergraduate curriculum in physical science, biological science, or engineering discipline. Graduate students from disciplines other than materials science and engineering may expect that supplemental coursework will be needed, in addition to the required graduate coursework. Well qualified students (juniors) enrolled in the undergraduate materials engineering program at Iowa State University can apply to the Graduate College for admission to the concurrent enrollment program, where students may simultaneously pursue both master of science and bachelor of science degrees.

The requirements for the M. Eng., M.S. and Ph.D. degrees are established by the student's program of study (POS) committee within the established guidelines of the Graduate College. Minimum requirements include coursework, research (M.S. and Ph.D. only), proposal (M.S. and Ph.D. only), preliminary oral examination (Ph.D. only), dissertation (M.S. and Ph.D. only), and a final oral examination (M.S. and Ph.D. only).

Academic requirements include 30 credits for the M.Eng. degree, 33 credits for the M.S. degree (18 credits of coursework, 3 credits of professional development, 12 credits of research), and 72 credits for the Ph.D. degree (27 coursework, 6 professional development, 36 credits of research, 3 additional course or research). The MSE Department offers a graduate minor in Materials Science and Engineering. The graduate minor requires 12 credits of MSE graduate coursework, including 6 credits selected from MSE 510, 520, 530, and 540. In addition, the minor program requires that the POS committee includes at least one member of the MSE Graduate Faculty. There are no foreign language requirements for any of the graduate degrees administered by the Department of Materials Science and Engineering.

**Courses primarily for graduate students, open to qualified undergraduates:**

**M S E 510: Fundamentals of Structure and Chemistry of Materials**
(3-0) Cr. 3. F.
*Prereq: MATH 165, PHYS 221, and CHEM 167*
Geometric and algebraic representations of symmetry. Pair distribution function. Structure, chemistry, and basic properties of covalent, ionic, and metallic solids, glasses and liquids, and polymers. Interactions of materials with particles and waves. Relationships between direct and reciprocal spaces. The kinematical theory of diffraction, with an introduction to the dynamical theory.

**M S E 519: Magnetism and Magnetic Materials**
(Dual-listed with MAT E 419). (Cross-listed with E E). (3-0) Cr. 3. F.
*Prereq: E E 311 or MAT E 317 or PHYS 364*
Magnetic fields, flux density and magnetization. Magnetic materials, magnetic measurements. Magnetic properties of materials. Domains, domain walls, domain processes, magnetization curves and hysteresis. Types of magnetic order, magnetic phases and critical phenomena. Magnetic moments of electrons, theory of electron magnetism. Technological application, soft magnetic materials for electromagnets, hard magnetic materials, permanent magnets, magnetic recording technology, magnetic measurements of properties for materials evaluation.

**M S E 520: Thermodynamics and Kinetics in Multicomponent Materials**
(3-0) Cr. 3. F.
*Prereq: MAT E 311 or CHEM 321, MATH 266 or MATH 267*
A review of the fundamental principles of heat, work, basic thermodynamic relations, and criteria for equilibrium. Analytical treatments for the thermodynamic description of multicomponent chemical solutions and reacting systems are developed and employed to predict phase equilibria in materials systems. Builds on the thermodynamic construction to treat the kinetics of chemical reactions and phase transformations. Topics include general first order and second order transitions, along with chemical diffusion. Detailed examples involving nucleation and diffusion limited growth, spinodal decomposition, martensitic transformations, magnetic and electric transitions, and glass formation will be considered.

**M S E 521: Mechanical Behavior and Manufacturing of Polymers and Composites**
(Cross-listed with M E). (3-0) Cr. 3. S.
*Prereq: M E 324 or MAT E 272 and E M 324*
Effect of chemical structure and morphology on properties. Linear viscoelasticity, damping and stress relaxation phenomena. Structure and mechanics of filler and fiber reinforced composites. Mechanical properties and failure mechanisms. Material selection and designing with polymers. Processing of polymer and composite parts.

**M S E 530: Solid State Science**
(3-0) Cr. 3. S.
*Prereq: MAT E 334 or E E 332 or PHYS 322*
Development of a quantitative description of the electronic structure of solids starting with fundamentals of atoms, atomic bonding, basic crystallography, and band theory of solids. Continuum properties of solids in response to electromagnetic fields and thermal gradients. Quantitative description of the atomistic properties of solids through electron-electron interactions, electron-phonon interactions, and dipole interactions.

**M S E 532: Microelectronics Fabrication Techniques**
(Dual-listed with MAT E 432). (Cross-listed with E E). (2-4) Cr. 4.
*Prereq: PHYS 222; Mat E majors: MAT E 317; CprE and EE majors: E E 230*
Techniques used in modern integrated circuit fabrication, including diffusion, oxidation, ion implantation, lithography, evaporation, sputtering, chemical-vapor deposition, and etching. Process integration. Process evaluation and final device testing. Extensive laboratory exercises utilizing fabrication methods to build electronic devices. Use of computer simulation tools for predicting processing outcomes. Recent advances in processing CMOS ICs and micro-electro-mechanical systems (MEMS).

**M S E 537: Electronic Properties of Materials**
(Dual-listed with MAT E 437). (Cross-listed with E E). Cr. 3. S.
*Prereq: E E 332 or MAT E 317 or PHYS 322*
Review of classical and quantum mechanical descriptions of electrons in solids, band theory, metallic conduction, lattice vibrations, semiconductors, semiconductor devices, dielectrics, polarization, dielectric relaxation, crystal anisotropy, ferroelectricity, piezoelectricity, superconductivity, magnetism, device applications.

**M S E 540: Mechanical Behavior of Materials**
(3-0) Cr. 3. S.
*Prereq: MAT E 418, MATH 266 or MATH 267*
Mechanical behavior of materials with emphasis on micromechanics of deformation in three generic regimes: elasticity, plasticity, and fracture. A materials science approach is followed to understand and model the mechanical behavior that combines continuum mechanics, thermodynamics, kinetics, and microstructure. Some topics include elastic properties of materials, permanent deformation mechanisms at different temperatures (e.g., via dislocation motion and creep), and fracture in ductile and brittle materials. Specific classes of materials that are studied: metals, ceramics, polymers, glasses and composites.

**M S E 550: Nondestructive Evaluation**
(Cross-listed with E M). (3-2) Cr. 4. S.
*Prereq: E M 324, MATH 385*
Principles of five basic NDE methods and their application in engineering inspections. Materials behavior and simple failure analysis. NDE reliability, and damage-tolerant design. Advanced methods such as acoustic microscopy, laser ultrasonics, thermal waves, and computed tomography are analyzed. Computer-based experiments on a selection of methods: ultrasonics, eddy currents, x-rays are assigned for student completion.

**M S E 551: Characterization Methods in Materials Science**
(2-3) Cr. 3. Alt. S., offered odd-numbered years.
*Prereq: MAT E 214*
Characterization of ceramic, metal, polymer and glassy materials using modern analytical techniques. Spectroscopic (IR, Raman, UV/VIS/NIR, and NMR), thermal (DSC, DTA/TGA, and DMA) methods, mechanical and rheological testing, magnetic and electrical characterization, and powder characterization.

**M S E 552: Scanning and Auger Electron Microscopy**
(Dual-listed with MAT E 452). (2-3) Cr. 3. F.
*Prereq: PHYS 222*
Characterization of materials using scanning electron microscope (SEM), electron microprobe, and auger spectrometer. Compositional determination using energy and wavelength dispersive x-ray and Auger spectroscopies. Specimen preparation. Laboratory covers SEM operation.

**M S E 553: Physical and Mechanical Properties of Polymers**
(Dual-listed with M S E 453). (2-3) Cr. 3. F.
*Prereq: MAT E 351*
Overview of polymer chemical composition, microstructure, thermal and mechanical properties, rheology, and principles of polymer materials selection. Intensive laboratory experiments include chemical composition studies, microstructural characterization, thermal analysis, and mechanical testing.

**M S E 554: Polymer Composites and Processing**
(Dual-listed with MAT E 454). (3-0) Cr. 3. S.
*Prereq: MAT E 351*
Basic concepts in polymer composites, blends, and block copolymers. Phase separation and miscibility, microstructures and mechanical behavior. Fiber reinforced and laminated composites. Viscosity, rheology, viscoelasticity of polymers. Polymer melt processing methods such as injection molding and extrusion; selection of suitable processing methods and their applications.

**M S E 556: Biomaterials**
(Dual-listed with MAT E 456). (3-0) Cr. 3. F.
*Prereq: CHEM 178 and MAT E 216 or MAT E 273 or MAT E 392*
Presentation of the basic chemical and physical properties of biomaterials, including metals, ceramics, and polymers, as they are related to their manipulation by the engineer for incorporation into living systems. Role of microstructure properties in the choice of biomaterials and design of artificial organs, implants, and prostheses.

**M S E 557: Chemical and Physical Metallurgy of Rare Earth Metals**
(Dual-listed with MAT E 457). (3-0) Cr. 3. Alt. S., offered even-numbered years.
*Prereq: MAT E 311 or CHEM 325*
Electronic configuration, valence states, minerals, ores, beneficiation, extraction, separation, metal preparation and purification. Crystal structures, phase transformations and polymorphism, and thermochemical properties of rare earth metals. Chemical properties: inorganic and organometallic compounds, alloy chemistry, nature of the chemical bonding. Physical properties: mechanical and elastic properties, magnetic properties, resistivity, and superconductivity.

**M S E 564: Fracture and Fatigue**
(Cross-listed with AER E, E M, M E). (3-0) Cr. 3. Alt. F., offered even-numbered years.
*Prereq: E M 324 and either MAT E 216 or MAT E 273 or MAT E 392. Undergraduates: Permission of instructor*
Materials and mechanics approach to fracture and fatigue. Fracture mechanics, brittle and ductile fracture, fracture and fatigue characteristics, fracture of thin films and layered structures. Fracture and fatigue tests, mechanics and materials designed to avoid fracture or fatigue.

**M S E 569: Mechanics of Composite and Combined Materials**
(Cross-listed with AER E, E M). (3-0) Cr. 3. Alt. S., offered even-numbered years.
*Prereq: E M 324*
Mechanics of fiber-reinforced materials. Micromechanics of lamina. Macromechanical behavior of lamina and laminates. Strength and interlaminar stresses of laminates. Failure criteria. Stress analysis of laminates. Thermal moisture and residual stresses. Joints in composites.

**M S E 581: Computational Modeling of Materials**
(Dual-listed with MAT E 481). (3-0) Cr. 3. Alt. F., offered odd-numbered years.
*Prereq: MATH 265 and MAT E 311 or CH E 381 or CHEM 325 or PHYS 304*
Introduction to the basic methods used in the computational modeling and simulation of materials, from atomistic simulations to methods at the mesoscale. Students will be expected to develop and run sample programs. Topics to be covered include, for example, electronic structure calculations, molecular dynamics, Monte Carlo, phase-field methods, etc.

**M S E 588: Eddy Current Nondestructive Evaluation**
(Dual-listed with MAT E 488). (Cross-listed with E E). (3-0) Cr. 3. Alt. F., offered odd-numbered years.
*Prereq: MATH 265 and (MAT E 216 or MAT E 273 or MAT E 392 or E E 311 or PHYS 364)*
Electromagnetic fields of various eddy current probes. Probe field interaction with conductors, cracks and other material defects. Ferromagnetic materials. Layered conductors. Elementary inversion of probe signals to characterize defects. Special techniques including remote-field, transient, potential drop nondestructive evaluation and the use of Hall sensors. Practical assignments using a 'virtual' eddy current instrument will demonstrate key concepts.

**M S E 590: Special Topics**
Cr. arr. Repeatable.
*Prereq: Permission of instructor*

**M S E 599: Creative Component**
Cr. arr. Repeatable.

**Courses for graduate students:**

**M S E 601: Materials Seminar**
(1-0) Cr. 1. Repeatable. F.S.
*Prereq: MSE Graduate Student Status*
Seminar course - presentations given on a weekly basis by leading U.S. and International researchers that are experts in their respective fields closely related to Materials Science. Offered on a satisfactory-fail basis only.

**M S E 620: Fundamentals of Phase Transformations**

(3-0) Cr. 3. Alt. S., offered even-numbered years.

*Prereq: M S E 520*

Explores various advanced theoretical treatments of the energetics and kinetics of multicomponent materials. Topics include analytical and computational descriptions of thermodynamic quantities, experimental measurement of essential physical properties, analytical and computational treatments of kinetic processes, and the use of theoretical predictions of phase equilibria and evolution in materials systems.

**M S E 630: Physical Properties of Solids**

(3-0) Cr. 3. Alt. F., offered odd-numbered years.

*Prereq: M S E 530*

Advanced course in the behavior of solids within the framework of solid state physics and chemistry. Includes magnetic, dielectric, transport, and optical phenomena in solids. Influence of phase transformations and crystal symmetry on the physical properties.

**M S E 651: Powder Diffraction Methods**

(3-0) Cr. 3. Alt. S., offered odd-numbered years.

*Prereq: M S E 510*

Advanced structural characterization of materials using powder diffraction. Production of X-ray and neutron radiation. Review of symmetry, group and kinematical theories of diffraction. Mathematical and computational backgrounds of powder diffraction data. Introduction to single crystal diffraction methods, origin of powder diffraction pattern, history of the technique. Modern powder diffraction methods. Indexing of powder diffraction patterns, figures of merit, precise lattice parameters. Phase problem, determining crystal structures from symmetry and geometry, Patterson, direct and Fourier methods. Rietveled method, precise crystal structures: atomic parameters, qualitative and quantitative phase identification, preferred orientation, grain size, strain, residual stress, order-disorder. Powder diffraction at non-ambient conditions. Applications of powder diffraction: data bases, phase transformations, phase diagrams, local structures, magnetism.

**M S E 652: Transmission Electron Microscopy**

(2-3) Cr. 3. Alt. S., offered odd-numbered years.

*Prereq: M S E 510*

Theory and application of transmission electron microscopy to inorganic materials. Specimen preparation, selected area and convergent beam electron diffraction, bright field/dark field/high resolution imaging. Compositional analysis using X-ray and electron energy loss spectroscopy.

**M S E 690: Advanced Topics in Materials Science**

Cr. arr. Repeatable.

*Prereq: Permission of instructor*

**M S E 697: Engineering Internship**

Cr. R. Repeatable. F.S.SS.

*Prereq: Permission of department, graduate classification*

One semester and one summer maximum per academic year professional work period. Offered on a satisfactory-fail basis only.

**M S E 699: Research**

Cr. arr. Repeatable.