MATERIALS SCIENCE AND ENGINEERING

Graduate Studies

The Materials Science and Engineering Department offers three graduate degree programs representing a range of opportunities for advanced study. While they share several common features, the programs are designed to serve students with a variety of academic backgrounds, technical interests, and career aspirations. In all three programs, it is expected that our graduate students will acquire fundamental understanding of the structure, properties, processing, and performance of materials, underpinned by the foundational pillars of thermodynamics and kinetics and manifested by the immense landscape of engineered materials and the broad range of physical, chemical, and mechanical functionalities that may be realized in them. Our degree programs include a combination of classroom instruction, seminars, laboratory training, guided teaching experiences, individually mentored independent study, and various forms of materials research experiences, all intended to serve students with a wide range of educational goals. Students are admitted with undergraduate or prior graduate qualifications in a variety of technical areas, and each program of study is tailored to meet the needs of the individual student. The accomplishments of our alumni demonstrate that our graduate training enables a wide range of career paths, but certain types of technical employment opportunities are targeted by the specific components within each degree program, as summarized below.

The Master of Engineering (M. Eng.) program in Materials Science and Engineering is a coursework-only degree program intended to provide broad knowledge related to materials processing, structure, properties, and performance, coupled with an understanding of the various materials challenges associated with existing and emerging technologies and industry/business sectors. The program is delivered mainly through classroom-based instruction but may also include laboratory-based courses and/or online courses. The curriculum combines a core of fundamental coursework with a highly flexible set of electives, which may include MSE courses and courses from other fields of study. This flexible coursework-only degree option is intended to provide advanced knowledge of fundamental and contemporary issues in Materials Science and Engineering relevant to a broad range of career paths.

The Master of Science (M.S.) program in Materials Science and Engineering is an intensive advanced degree program combining graduate coursework and project-based research. The program is intended to provide broad-based knowledge related to materials processing, structure, properties, and performance, coupled with an understanding of the various materials challenges associated with existing and emerging technologies and industry sectors. The program is delivered mainly through classroom-based instruction but may also include laboratory-based courses and/or online courses. The curriculum combines a core of fundamental coursework and a complement of MSE and non-MSE electives.

Two program options are available, and students enrolled in the MS degree program will select either the *Research Thesis* track or the *Research Portfolio* track. Both tracks include a substantial research component but with different focus.

- The *Research Thesis* track provides an opportunity for the student to complete a full-scale research project from beginning to end, including literature review, project design, planning, laboratory and/or computational investigation, data analysis, decision-making, formulation of conclusions, and appropriate reporting of outcomes. The research, culminating in a thesis document, will be conducted under the supervision of a major professor. In this track, the research efforts are aimed at making an identifiable contribution toward solving a relevant problem in a selected area of science and/or engineering. Project success is judged on the scientific soundness of the contribution and the quality with which it is presented in the Thesis document and in a final oral presentation/examination.
- The *Research Portfolio* track provides an opportunity for the student to complete several separate research projects involving multiple selected topics and methods of experimental and/or computational investigation in accordance with the student's interests. In this track, research is conducted through a sequence of three 3-credit project-based courses, each supervised by a specific faculty member and focused on a different area of research and related methods and analysis techniques. Each project has specific scientific objectives, but the focus of the overall portfolio is for the student to develop expertise in a targeted set of laboratories and/or computational research skills. Assessment is based on practical examinations and documented research results associated with each project. The program also requires a comprehensive presentation and oral examination covering all of the student's project work. Each student's overall program is overseen by a major professor.

The Doctor of Philosophy (Ph.D.) degree is the highest academic credential in the field. ISU's robust multi-faceted program is intended to develop state-of-the-art competencies in academic scholarship, enabling graduates to make high-level career-based contributions in fields related to Materials Science and Engineering. The Ph.D. program combines graduate coursework with intensive and specialized project-based research expected to result in significant reportable scientific contributions in one or more selected areas, as evidenced by publication in peer-reviewed journals, industry standards, patents, or other forms of recognizable technical contributions.

The MSE 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, the Critical Materials Institute, and the Sensitive Instruments Facility. These laboratories provide excellent resources for our graduate students in advanced materials research.

Graduate Majors

The Materials Science and Engineering Department offers three graduate degree programs:

- *Master of Engineering* in Materials Science and Engineering
- *Master of Science* in Materials Science and Engineering
- *Doctor of Philosophy* in Materials Science and Engineering

Eligibility: Enrollment in a graduate degree program requires prior* completion of an undergraduate curriculum in Materials Science and Engineering or any discipline of engineering, physical science, or biological science. 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.

Requirements: Program requirements include:

- Required core and elective coursework
- Research (M.S. and Ph.D. only)
- Research proposal (M.S. and Ph.D. only)
- Qualifying examination (Ph.D. only)
- Preliminary oral examination (Ph.D. only)
- Thesis/dissertation (M.S. and Ph.D. only)
- Final oral examination (M.S. and Ph.D. only

Specific requirements for each degree program are specified in the MSE Graduate Handbook and Graduate College Handbook.

Minor: 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 5100, MSE 5200, MSE 5300, and MSE 5400. In addition, the minor program requires that the POS committee includes at least one member of the MSE Graduate Faculty.

* Qualified students enrolled in the undergraduate materials engineering program at Iowa State University are eligible to apply to the Graduate College for admission to the concurrent enrollment program, where students may simultaneously pursue undergraduate and graduate degrees.

Courses primarily for graduate students, open to qualified undergraduates:

MSE 5010: Fundamentals of Materials Science and Engineering I
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
An examination of structure-property-process relationships in materials, focusing on control and measurement of end-use performance characteristics. Materials design fundamentals are discussed as they pertain to various critical industries, applications, and manufacturing technologies. Offered on a satisfactory-fail basis only. (Typically Offered: Fall)

MSE 5020: Fundamentals of Materials Science and Engineering II
Credits: 1. Contact Hours: Lecture 1.
Repeatable, maximum of 1 credits.
An examination of the physical behavior of materials, as underpinned by multiphase multicomponent thermodynamics, transport phenomena, interfaces, defect structures, the kinetics of phase transformations, and the mechanistic origins of structure-property-processing relationships in various types of materials. Offered on a satisfactory-fail basis only. (Typically Offered: Fall)

MSE 5030: Fundamentals of Materials Science and Engineering III
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
Directed study of advanced topics in Materials Science and Engineering. Fundamental principles and relationships connecting structure, chemistry, stability, physical behavior, properties, and processing response are reviewed. Experimental and computational methods for materials research are emphasized. Offered on a satisfactory-fail basis only. (Typically Offered: Summer)

MSE 5100: Fundamentals of Structure and Chemistry of Materials
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Fall)

MSE 5190: Magnetism and Magnetic Materials
(Dual-listed with EE 4190/ MATE 4190). (Cross-listed with EE 5190).
Credits: 3. Contact Hours: Lecture 3.
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 phenome. 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. Offered odd-numbered years. (Typically Offered: Fall)

MSE 5200: Thermodynamics and Kinetics in Multicomponent Materials
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Fall)

MSE 5210: Mechanical Behavior and Manufacturing of Polymers and Composites
(Cross-listed with ME 5210).
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Spring)

MSE 5300: Solid State Science
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Spring)

MSE 5320: Microelectronics Fabrication Techniques
(Dual-listed with EE 4320/ MATE 4320). (Cross-listed with EE 5320).
Credits: 4. Contact Hours: Lecture 2, Laboratory 4.
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).

MSE 5370: Electronic Properties of Materials
(Dual-listed with EE 4370/ MATE 4370). (Cross-listed with EE 5370).
Credits: 3. Contact Hours: Lecture 3.
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, biomedical applications of magnetism, magnetic evaluation of materials. (Typically Offered: Spring)

MSE 5400: Mechanical Behavior of Materials
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Spring)

MSE 5500: Nondestructive Evaluation
(Cross-listed with EM 5500).
Credits: 4. Contact Hours: Lecture 3, Laboratory 2.
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. (Typically Offered: Spring)

MSE 5510: Characterization Methods in Materials Science
Credits: 3. Contact Hours: Lecture 2, Laboratory 3.
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. (Typically Offered: Spring)

MSE 5520: Scanning and Auger Electron Microscopy
(Dual-listed with MATE 4520).
Credits: 3. Contact Hours: Lecture 2, Laboratory 2.
Characterization of materials using scanning electron microscopes (SEM) and variants thereof, including electron microprobe, Auger spectrometer, and DualBeam focused ion beams (FIB)/SEMs). Compositional determination using energy and wavelength dispersive x-ray and Auger spectroscopies. Orientation determination using electron backscattered diffraction. Specimen preparation. Laboratory covers SEM operation. (Typically Offered: Fall)

MSE 5530: Physical and Mechanical Properties of Polymers
(Dual-listed with MATE 4530).
Credits: 3. Contact Hours: Lecture 2, Laboratory 3.
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. (Typically Offered: Fall)

MSE 5540: Polymer Composites and Processing
(Dual-listed with MATE 4540).
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Spring)

MSE 5560: Biomaterials
(Dual-listed with BME 4560/ MATE 4560).
Credits: 3. Contact Hours: Lecture 3.
Presentation of the basic chemical and physical properties of biomaterials, with special emphasis on metallic, ceramic, polymeric, and composite biomaterials, as they are related to their manipulation by the engineer for incorporation into living systems. Role of microstructure and properties needed to select and design biomaterials used in medical devices, artificial organs, implants, and prostheses. Overview of medical science vis-à-vis materials science. (Typically Offered: Fall)

MSE 5570: Chemical and Physical Metallurgy of Rare Earth Metals
(Dual-listed with MATE 4570).
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Spring)

MSE 5640: Fracture and Fatigue
(Cross-listed with AERE 5640/ ME 5640/ EM 5640).
Credits: 3. Contact Hours: Lecture 3.
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. Offered even-numbered years. (Typically Offered: Fall)

MSE 5690: Mechanics of Composite and Combined Materials
(Cross-listed with AERE 5690/ EM 5690).
Credits: 3. Contact Hours: Lecture 3.
Prereq: EM 3240
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. Offered even-numbered years. (Typically Offered: Spring)

MSE 5800X: Introduction of Project Management for Thesis Research
(Cross-listed with CHE 5800X/ IE 5800X).
Credits: 1. Contact Hours: Lecture 1.
Tools and skills of Project Management (PM) adapted from industry to improve efficiency in thesis research. Project charter initiation for thesis, timeline and meeting scheduling tools, expectation management, and communication with advisors. Practice of the PM skills using student's own thesis. Presentation of a project charter. Demonstration of knowledge of related PM skills and the ability of utilizing these skills for thesis research. Sharing thesis ideas and learning experience in the Graduate for Advancing Professional Skills (GAPS) learning community. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring)

MSE 5810: Computational Modeling of Materials
(Dual-listed with MATE 4810).
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Fall)

MSE 5880: Eddy Current Nondestructive Evaluation
(Dual-listed with EE 4880/ MATE 4880). (Cross-listed with EE 5880).
Credits: 3. Contact Hours: Lecture 3.
Electromagnetic fields of various eddy current probes. Probe field interaction with conductors, crack 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. Offered odd-numbered years. (Typically Offered: Fall)

MSE 5900: Special Topics
Credits: 1-30. Repeatable.
Prereq: Instructor Permission for Course
(Typically Offered: Fall, Spring, Summer)

MSE 5990: Creative Component
Credits: 1-30. Repeatable.
Prereq: Instructor Permission for Course
(Typically Offered: Fall, Spring, Summer)

Courses for graduate students:

MSE 6010: Materials Seminar
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
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. (Typically Offered: Fall, Spring)

MSE 6200: Fundamentals of Phase Transformations
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Spring)

MSE 6300: Physical Properties of Solids
Credits: 3. Contact Hours: Lecture 3.
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.

MSE 6510: Powder Diffraction Methods
Credits: 3. Contact Hours: Lecture 3.
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. (Typically Offered: Spring, Summer)

MSE 6520: Transmission Electron Microscopy
Credits: 3. Contact Hours: Lecture 2, Laboratory 3.
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. (Typically Offered: Spring)

MSE 6900: Advanced Topics in Materials Science
Credits: 1-30. Contact Hours: Lecture 30.
Repeatable.
Prereq: Instructor Permission for Course
(Typically Offered: Fall, Spring, Summer)

MSE 6970: Engineering Internship
Credits: Required. Repeatable.
One semester and one summer maximum per academic year professional work period. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

MSE 6990: Research
Credits: 1-30. Repeatable.
Prereq: Instructor Permission for Course
(Typically Offered: Fall, Spring, Summer)