Materials and Metallurgical Engineering
Professors: Hirschfeld, Inal, Majumdar, McCoy (chair of the Department)
Associate Professors: Burleigh, Fuierer
Asst. Professor: Kalugin
Adjunct Faculty: Browning, Curro, Doughty, Hockensmith, Jacobson, Lowe, Ravi, Romig, Sickafus, M. Smith
Emeritus Professor: G. Bond

Degrees Offered: B.S. in Materials Engineering, Materials Engineering with Metallurgical Engineering option; M.S. and Ph.D. in Materials Engineering

Web site: http://infohost.nmt.edu/~mtls/

Department Mission Statement
•To educate our students so that they are prepared to obtain and succeed in the best positions in industry, government laboratories, and graduate schools.
•To advance the frontiers of materials science and engineering.
•To serve the public of New Mexico through outreach and expanded education.

Program Educational Objective
Our objective is to produce practicing professionals who:
1. Demonstrate competence in the fundamentals of materials science and engineering, across the sub-disciplines of metals, ceramics, polymers and composites (undergraduate program) or expertise in a specialized area of materials engineering (graduate programs).
2. Solve problems in their chosen profession.

Undergraduate Program *(ABET accredited)*
The design and application of materials rest upon the relationship of structure, properties, and processing at all length scales from sub-atomic to nano- to micro- and ultimately, macro-materials. At the atomic level, structure and property interactions are characterized using techniques such as x-ray scattering, spectroscopy, atomistic computer modeling, atomic force and electron microscopy. At the micron length scale structures are evaluated using, for example, both optical and electron microscopy and characterized using techniques such as micro-hardness then are related to macroscopic properties, e.g., strength, toughness, and thermal conductivity. An understanding of how processing methods affect the performance of the material is also considered. For example, the performance of an as-cast metal component is very different from the same component that was forged even though both are made of the same material.

These ideas are developed and expanded upon throughout the undergraduate curriculum. The introductory materials engineering courses familiarize students with the general ideas and terminology. Three instrumentation-intensive courses on methods and analysis specifically address the observational basis of the materials and metallurgical engineering discipline. Four classes target the theories used to understand the relations between processing and microstructure as well as those between microstructure and macroscopic properties in the areas of metals, ceramics, polymers, and composites. Upper-level elective materials courses chosen from a rotating selection investigate more specialized topics such as electronic- and nano-materials. The senior design sequence emphasizes the synthesis of skills and ideas as well as providing experience in teamwork and practical design.

Research experience for the students is available and encouraged through part-time employment in the broad range of Materials research projects that are on-going in the department and also in the Energetic Materials Research and Testing Center, New Mexico Bureau of Geology and Mineral Resources, and Petroleum Recovery Research Center. Departmental collaborations with scientists and engineers at Los Alamos and Sandia National Laboratories provide another avenue for student involvement in research projects. Many of our undergraduate students pursue graduate degrees either at New Mexico Tech or elsewhere while others seek employment directly.

The Materials and Metallurgical Engineering Department operates and maintains a broad range of instrumentation for characterization and testing. A full list of instrumentation resources is available on the department's web site. Of particular note is the broad range of microscopy capabilities available for research and instruction, including light microscopes, scanning electron microscopes and a scanning probe (atomic force) microscope.

Bachelor of Science in Materials Engineering
Minimum credit hours required—131
In addition to the General Degree Requirements (page 54), the following courses are required:
- MATH 231 (4), 335 (3)
- ES 110 (2), 111 (3), 201 (3), 302 (3), 332 (3) or EE211 (3)
- MATE 101L (1), 202 & 202L (4), 235 & 235L (4), 301 (3), 310 (3), 311 (3), 314 (3), 350 (3), 351 (3), 410 (3), 445 (3), 481 (3), 482 (3)
- METE 327 (3)
- Advanced basic science (3): CHEM 311, 331, 333 or MATE 452 are recommended.
- Technical electives (12): Approved upper level MATE and METE courses. Up to 3 credit hours can be completed outside the department with the consent of the department.
- Electives to complete 131 credit hours

Credit for trigonometry or college algebra is not allowed for engineering students.

All engineering majors are required to take the Fundamentals in Engineering (FE) exam as a requirement for graduation.

Sample Curriculum for the Bachelor of Science in Materials Engineering

Semester 1
1 MATE 101L (Intro. Materials Lab)
3 ENGL 111 (College English 1)
4 MATH 131 (Calculus 1)
4 CHEM 121 & 121L (General Chemistry 1)
3 Social Science
2 ES 110 (intro. to Engineering)
17 Total credit hours

Semester 2
3 ENGL 112 (College English 2)
4 MATH 132 (Calculus 2)
4 CHEM 122 & 122L (General Chemistry 2)
3 ES 111 (Computer Programming)
3 Social Science
17 Total credit hours

Semester 3
4 MATE 202 & 202L (General Materials 1)
4 MATH 231 (Calculus 3)
5 PHYS 121 & 121L (General Physics 1)
3 Humanities
16 Total credit hours

Semester 4
3 MATH 335 (Applied Analysis)
5 PHYS 122 & 122L (General Physics 2)
4 MATE 235 & 235L (General Materials 2)
3 ES 201 (Statics)
3 Social Science
18 Total credit hours

Semester 5
3 METE 327 (Metals)
3 Humanities/Social Science
3 ES 302 (Mechanics of Materials)
3 MATE 350 (Materials Thermodynamics)
3 MATE 310 (Processing and Microstructure)
15 Total credit hours

Semester 6
3 ENGL 341 (Technical Writing)
3 ES 332 or EE 211 (Electrical Engineering)
3 MATE 301 (Ceramics)
3 MATE 351 (Polymers)
3 MATE 314 (Transport Processes)
3 MATE 311 (Thermal and Mechanical Properties)
18 Total credit hours

Semester 7
3 Technical Elective*
3 Technical Elective*
3 MATE 445 (Composites)
3 MATE 481 (Senior Design 1)
3 MATE 410 (Microstructural Characterization)
15 Total credit hours

Semester 8
3 Technical Elective*
3 Technical Elective*
3 Advanced Basic Science Elective*
3 MATE 482 (Senior Design 2)
3 Humanities
15 Total credit hours

** Electives must be approved by the student's advisor.*

Bachelor of Science Degree in Materials Engineering with Metallurgical Engineering Option

Minimum credit hours required—131
In addition to the General Degree Requirements (page 54), the following courses are required:
- MATH 231 (4), 335 (3)
- ES 110 (2), 111 (3), 201 (3), 302 (3), 332 (3) or EE211 (3)
- MATE 101L (1), 202 & 202L (4), 235 & 235L (4), 310 (3), 311 (3), 314 (3), 326(3), 350 (3), 410 (3), 431(3), 435(3), 481 (3), 482 (3)
- METE 326 (3), 327 (3)
- Advanced basic science (3): CHEM 311, 331, 333 or MATE 452 are recommended.
- Technical electives (12): Approved upper level MATE and METE courses. Up to 3 credit hours can be completed outside the department with the consent of the department.
- Electives to complete 131 credit hours

Credit for trigonometry or college algebra is not allowed for engineering students.

All engineering majors are required to take the Fundamentals in Engineering (FE) exam as a requirement for graduation.

Sample Curriculum for the Bachelor of Science in Materials Engineering with Metallurgical Engineering Option

Semester 1
1 MATE 101L (Intro. Materials Lab)
3 ENGL 111 (College English 1)
4 MATH 131 (Calculus 1)
4 CHEM 121 & 121L (General Chemistry 1)
3 Social Science
2 ES 110 (Intro. to Engineering)
17 Total credit hours

Semester 2
3 ENGL 112 (College English 2)
4 MATH 132 (Calculus 2)
4 CHEM 122 & 122L (General Chemistry 2)
3 ES 111 (Computer Programming)
3 Social Science
17 Total credit hours

Semester 3
4 MATE 202 & 202L (General Materials 1)
4 MATH 231 (Calculus 3)
5 PHYS 121 & 121L (General Physics 1)
3 Humanities
16 Total credit hours

Semester 4
3 MATH 335 (Applied Analysis)
5 PHYS 122 & 122L (General Physics 2)
4 MATE 235 & 235L (General Materials 2)
3 ES 201 (Statics)
3 Social Science
18 Total credit hours

Semester 5
3 METE 327 (Metals)
3 Humanities/Social Science
3 ES 302 (Mechanics of Materials)
3 MATE 350 (Materials Thermodynamics)
3 MATE 310 (Processing and Microstructure)
15 Total credit hours

Semester 6
3 MATE 311 (Thermal and Mechanical Properties)
3 MATE 314 (Transport Processes)
3 METE 326 (Process Metallurgy)
3 ES 332 or EE 211 (Electrical Engineering)
3 ENGL 341 (Technical Writing)
3 Humanities
18 Total credit hours

Semester 7
3 Technical Elective*
3 Technical Elective*
3 MATE 431 (Manufacturing Processes)
3 MATE 481 (Senior Design 1)
3 MATE 410 (Microstructural Characterization)
15 Total credit hours

Semester 8
3 Technical Elective*
3 Technical Elective*
3 Advanced Basic Science Elective*

3 METE 482 (Senior Design 2)
3 MATE 435 (Mechanical Behavior)
15 Total credit hours

* Electives must be approved by the student's advisor.

Minor in Materials Engineering

Minimum credit hours required—17
The following courses are required:
•MATE 202 and MATE 235 (6+).
• Approved Technical Electives (to yield total of 17).

Minor in Polymer Science

Minimum credit hours required—19
The following courses are required:
•CHEM 334 (3), 446 (3)
•MATE 202 & 202L (4) or 235 & 235L (4)
•MATE 351 (3)
•Approved Technical Electives (6)

Graduate Programs
Master of Science in Materials Engineering

The student's course of study must be approved by the student's advisory committee and must fulfill the general requirements for the master's degree and must include MATE/METE 591 (thesis). No more than three credit hours of directed study can be used to satisfy the course work requirements.

Students must take MATE 592 each semester offered if the student is in residence. Distance-education students will be required to document conference participation in lieu of this requirement. Only one credit of MATE 592 may be used to fulfill degree requirements.

Master of Science in Materials Engineering, Independent Study Option

A student may petition the department with the approval of the faculty to pursue a Master of Science degree with an independent option must complete a minimum of 30 credit hours of which 3 credit hours must be independent study and a minimum of 18 credit hours must be 400-500 level Materials or Metallurgical Engineering courses. The student's course of study must be approved by the student's advisor committee and must fulfill the other requirements of the MS degree with the exception of the 6 credit hours of thesis.

Five Year Bachelor/Master Degree Program

The degrees of MS and BS in Materials Engineering may be achieved in five years by fulfilling the requirements for a BS degree and a MS degree in the following year upon satisfying the requirements for either the Thesis or Independent Study Option. A minimum of 161 credit hours are required to complete both degrees. To be considered for this program students typically apply at the end of their sophomore year. Admission is contingent upon their having a 3.0 GPA and the acceptability of their proposed course of study. Students with upper division standing may apply but acceptance will be conditional. Students in the 5-year program must apply for graduate standing, normally in their 6th semester. Graduate admission will be contingent upon adherence to the approved program of study and a 3.0 minimum overall cumulative GPA. Graduate status will be granted upon fulfillment of the requirements for the BS degree.

Doctor of Philosophy in Materials Engineering

The prospective doctoral candidate should develop a good background in materials sciences, chemistry, physics, and mathematics, in addition to achieving a high level of competence in a specialized area of materials. Programs are arranged by the prospective student and the student's advisory committee. Additional information can be found under the Graduate Program (page 34).

In addition to the course requirements specified for the M.S. degree, students seeking the Ph.D. degree in materials are required to take a minimum of 24 credit hours of approved course work, of which at least 12 credit hours must be in 500–level courses; no more than three of these hours should be directed study.
Students must take MATE 592 each semester offered if the student is in residence.
Distance-education students will be required to document conference participation in lieu of this requirement. Only one credit of MATE 592 may be used to fulfill degree requirements.

Dissertation research must also be completed. In order to pursue dissertation research, the student must pass a candidacy examination and a qualifying examination. An oral defense of the completed written dissertation is also required.

Suitable topics for doctoral candidates can be selected from a broad range of materials issues (relating to ceramics, composites, metals, or polymers) that are of current interest to the department's faculty.

Special Programs

Students pursuing an advanced degree in materials may elect to emphasize and develop a background in the general area of materials with research centered around an area of structure-property-processing performance of metals, ceramics, polymers, and composites. This could involve modern microstructural characterization techniques (X-rays and electron microscopy); mechanical and physical property measurements; explosive forming, hardening, and consolidation; performance under conditions of fatigue, high temperatures, and aggressive environments.

Interdisciplinary programs in the areas of materials are encouraged. Joint dissertation supervision is provided by the appropriate departments or divisions. Research facilities not available on the campus may be available through cooperative agreements with the Air Force Weapons Laboratory at Kirtland Air Force Base and Sandia National Laboratories in Albuquerque, and Los Alamos National Laboratory.

Materials Engineering Courses:
MATE 101L, Introductory Materials Engineering Laboratory, 1 cr, 3 lab hrs

Hands-on laboratory experience with some fundamental concepts in materials engineering: classification of solids, gelation processes, particulate dispersions, nucleation and growth of crystals, phase diagrams, magnetic domains, (explosive) welding, and composite design. Course provides a glossary of terms and concepts used in the field of materials science and engineering.

MATE 102L, Introductory Materials Engineering Laboratory, 2 cr, 3 lab hrs

See description for MATE101L with additional emphasis on exploration of career opportunities in Materials Science and Engineerng.

MATE 103L, Introduction to Electron Microscopy, 1 cr, 3 lab hrs

Students will obtain a basic understanding of various

techniques of electron microcopy including Scanning Electron Microscopy (SEM), Transmission Electron Microscopy, Auger Electron Spectroscopy (AES), Secondary Ion Mass Spectroscopy (SIMS), and Atomic Force Microscopy (AFM). Demonstrations of various applications of these techniques will be given.

MATE 104L, Introduction to Electron Microscopy, 2 cr, 3 lab hrs

See description for MATE 103L with additional emphasis on Electron Microscopy across multiple disciplines.

MATE 202, Materials Engineering I, 4 cr,
Corequisite: CHEM 122

Application of the student's background in physical sciences, mathematics, and computer science to the solution of elementary problems in the materials sciences. Introduction to metallurgical techniques and the science of materials. Elementary design problems involving the optimum use of materials.

MATE 202L Materials Engineering I Laboratory, 1 cr, 3 lab hrs
Corequisite: MATE 202

Laboratory experiments addressing elementary design problems involving optimal use of materials. Designed to reinforce principles discussed in Mate 202.

MATE 235 Materials Engineering II, 3 cr, 3 cl hrs
Prerequisites: CHEM 122 and 122L
Corequisite: Phys 122 & 122L

Survey of technologically important materials including ceramics, glasses, semiconductors, polymers and composites. The objective is to understand the chemical composition, structure, processing and property relationships in material systems. The student will obtain a basic understanding of the principles of electronic transport, dielectric, thermal, optical and mechanical properties of engineered solids. Undergraduate students majoring in Materials Engineering must take Mate 235L concurrently.

MATE 235L Materials Engineering II Laboratory, 1 cr, 3 lab hrs
Corequisites: MATE 235

Laboratory experiments introducing the fabrication of technical materials and the measurement of their properties. Designed to reinforce principles discussed in Mate 235.

MATE 301, Introduction to Ceramic Engineering, 3 cr, 3 cl hrs
Prerequisites: MATE 202, 235; or consent of instructor

Ceramic processing and benefication techniques, from raw materials to finished products. Chemistry and structure of ceramic raw materials. Microstructures of traditional (porcelain and glass) and advanced (modern structural and electrical) ceramics. Properties of ceramics, and their dependence on processing and microstructure.

MATE 310 Processing and Microstructure Methods and Analysis 3 cr, 2 cl hrs, 3 lab hrs
Prerequisites: MATE 202, MATE 235; or consent of instructor

Emphasis on the relationship between processing and microstructure. Processing techniques used to form metals, ceramics, polymers, and composites will be studied such as extrusion, pressing, forging, rolling, casting, and joining. Elementary analysis techniques such as optical and electron microscopy will be used to illustrate the effect of processing on microstructure.

MATE 311 Thermal and Mechanical Methods and Analysis 3 cr, 2 cl hrs, 3 lab hrs
Prerequisites: MATE 202, MATE 235; or consent of instructor

Emphasis on the use of thermal and mechanical techniques to both influence and measure the properties of metals, polymers, ceramics, and composites. Thermal techniques such as DSC, DTA, TGA, TMA, and dilatometry will be described. Thermal processing and temperature measurement techniques will also be covered. Mechanical techniques such as viscometry, rheometry, strength/toughness testing, hardness testing, and fatigue will be covered. These thermal and mechanical techniques will be used to elucidate the relationship between properties and microstructure, relaxation mechanisms, lifetime predictions, phase transformations, chemical reactions, and synthesis.

MATE 314, Transport Processes, 3 cr, 3 cl hrs
Prerequisites: MATH 131; PHYS 121

Introduction to the concepts of fluid dynamics and mass and heat transfer.

MATE 350, Materials Thermodynamics, 3 cr, 3 cl hrs
Prerequisite: MATH 231

The mathematical structure of thermodynamics is developed and elucidated from a transport-process-based perspective. Basic quantities such as heat and temperature are carefully defined. The conserved nature of the First-Law and the non-conserved nature of the Second Law are emphasized. The consequences of the ensuing stability-conditions are explored in the area of phase equilibrium in multicomponent mixtures. (Same as ChE 349)

MATE 351, Introduction to Polymeric Materials, 3 cr, 3 cl hrs
Prerequisites: MATH 231

Basic concepts of polymer science; polymerization reactions and mechanisms, as well as kinetics involved; polymer solutions, molecular-weight determinations, analysis and testing of polymers; structural properties of polymers; properties of commercial polymers; processing of polymers.

MATE 402, Physical Ceramics, 3 cr, 3 cl hrs
Prerequisite: MATE 301

Review of ceramic microstructures. Atomistic, microstructural, and thermodynamic origins of ceramic properties, with emphasis on the effects of atomic and structural defects and interpretation of phase diagrams.

MATE 410 Microstructural Characterization Methods and Analysis 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: Phys122, MATE 202, MATE 235 or consent of instructor

Crystalline and non-crystalline materials are characterized using various types of scattering, diffraction, absorption and microscopy techniques. Methodologies such as x-ray diffraction, electron diffraction and microscopy are introduced for analyzing crystallographic and other structural properties of metals, ceramics, polymers and composites.

MATE 430, Design and Analysis of Experiments, 3 cr, 3 cl hrs
Prerequisite: Senior standing

Methods of statistics and modeling important to many problems in materials science and engineering including Six Sigma. Examples are chosen from a number of actual experiences. Safety considerations and experiment design including analysis of risk, how risks may be integrated, and how formal procedures should be established. The use of information sources, such as materials safety data sheets (MSDS). (Same as ChE 463)

MATE 431, Fundamentals in Manufacturing Processes of Materials I, 3 cr, 3 cl hrs
Prerequisites: MATE 202; ES 302; and senior standing or consent of instructor

Introduction to materials design; flow theories and work of deformation; microstructure-property relationships for different materials; fracture; casting and heat-flow/mass-transfer issues; bulk deformation processing with applications to rolling and extrusion; powder metallurgy and sintering of metal and ceramic powders.

MATE 434, Introduction to Solidification and Phase Transformations, 3 cr, 3 cl hrs
Prerequisites: MATE 350; METE 327
Corequisite: MATE 442

Thermodynamic considerations and phase diagrams (review); influence of interfaces on equilibrium; influence of interfaces and of strain energy on microstructure and kinetics; solidification of single-component and multicomponent systems; ingots, castings, and weldings; sol-gel processing; diffusional transformations in solids: precipitation, eutectoid transformations, massive transformations, and ordering; diffusionless transformations in solids: martensitic transformations.

MATE 435, Mechanical Behavior of Materials, 3 cr, 3 cl hrs
Prerequisite: MATE 202 or consent of instructor

Elasticity and plasticity; flow criteria. Strengthening mechanisms. Deformation processes. Mechanical testing of materials: tensile, hardness, fatigue, fracture, formability.

MATE 441, 441L, X-Ray Diffraction, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: PHYS 122

Properties and generation of X-rays, X-ray diffraction phenomena. Single-crystal and powder techniques for study of structure of metals and alloys, imperfections, stress, and strain.

MATE 442, Solid State Diffusion, 3 cr, 3 cl hrs
Prerequisite: MATE 314

Development of the diffusion equations in solids and their solutions by analytical and numerical methods. Diffusion theory and mechanisms. Diffusion phenomena in semiconductors, metals, alloys, ionic crystals, and oxides. Thermodynamic, point-defect and defect reactions, and impurity effects. High-diffusivity paths; Electromigration (EM) in metallic films and EM measurement. Review of experimental techniques.

MATE 443, Magnetic Materials, 3 cr, 3 cl hrs
Prerequisite: MATE 235 *or consent of instructor*

The origin of magnetism, theory of magnetism, comparison of diamagnetic, paramagnetic, ferromagnetic, and ferromagnetic solids. Magnetic measurements, magnetic characterization techniques, domain theory and hysteresis. Structure-processing-property relationships in magnetic materials. Applications of "hard" and "soft" magnetic materials.

MATE 445, Introduction to Composite Materials, 3 cr, 3 cl hrs
Prerequisites: ES 302 or consent of instructor

Reinforcement materials, glass, Kevlar, polyethylene, carbon, boron, silicon carbide, alumina, metallic fibers. Interface between the matrix and fiber. Polymer matrix, metal matrix, and ceramic matrix composites. Mechanism of fiber strengthening. Micromechanics and macromechanics of composite materials, their strength and fracture behavior.

MATE 446, Computer Simulation in Materials Science, 3 cr, 3 cl hrs
Prerequisite: MATH 231

Computer simulation techniques are introduced and applied to systems of interest to Materials Science. Monte Carlo and Molecular Dynamics methods are used to explore properties at the atomic level.

MATE 447, Optical Materials, 3 cr, 3 cl hrs
Prerequisite: MATE 235 *or consent of instructor*

Review of optical phenomena: reflection, transmission, absorption, color, polarization, refraction and birefringence, and their origin in materials. Structure-processing-property relationships in optical materials including crystals, glasses, and thin films. Applications including mirrors, filters, lenses, lasers, electro-optics, detectors and fiber optics.

MATE 452, Physics of Metals and Ceramics, 3 cr, 3 cl hrs
Prerequisite: Senior standing *or consent of instructor*

Discussion of physical properties of metals, semiconductors, and dielectrics from the viewpoint of solid-state theories. Electron dynamics, electronic transport, electromagnetic wave interactions with solids, wave mechanics, quantum mechanics, free electron theory, band theory of solids. Application of semiconductor and quantum physics to modern electronic and opto-electronic devices.

MATE 452L, Electronic Materials Laboratory, 1 cr, 3 lab hrs
Prerequisites: MATE 235, 235L*, or consent of instructor*

Use of electronic measurement equipment to characterize the behavior of common circuit components: resistors, capacitors, inductors, temperature- and voltage-dependent resistors, diodes. Interpretation of electronic properties of materials.

MATE 460, Failure Analysis, 3 cr, 3 cl hrs
Prerequisite: ES 302

Failure analysis is the science of unraveling why a product failed unexpectedly. The results of the failure analysis may be used to design a better product, or as evidence in litigation. This course will cover the proper methodology for investigating a failure, the common failure modes of structures and machines, fractography, the procedure for writing a failure analysis report, and the legal implications.

MATE 466, Interfacial Phenomena, 3 cr, 3 cl hrs
Prerequisite: MATE 350 *or equivalent or consent of instructor*

Thermodynamics of interfaces (liquid/liquid, liquid/vapor, liquid/solid, solid/solid, solid/vapor) interfacial equilibria; interfacial free energy (surface tension measurements in liquids; specific surface free energy in solid systems); structure of solid surfaces and interfaces; properties of interfaces; case studies in

ethical decision making. Shares lectures with MATE 566, but is graded separately and additional work is required at the graduate level.

MATE 467, Materials Seminar, 2 cr, 2 cl hrs
Prerequisite: Senior standing
Students, faculty, and distinguished visitors discuss subjects of current and/or long-range interest in various fields of materials.

MATE 470, Corrosion Phenomena, 3 cr, 3 cl hrs
Prerequisite: CHEM 122
Theory of aqueous corrosion (thermodynamics and kinetics); forms of corrosion; corrosion testing and evaluation; designing to minimize corrosion; methods of corrosion prevention; corrosion of specific systems; case studies.

MATE 474, Polymer Processing and Characterization, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: MATE 202 or consent of instructor
A practical and "hands-on" course covering the essentials of polymer processing and polymer materials characterization. A survey of polymer processing techniques with emphasis on the fundamentals of extrusion. Lab topics include: extruder operation, compounding, scanning calorimetry, rheometry, and mechanical testing. Field trips to manufacturing facilities. (Same as ChE 474)

MATE 479, Transmission Electron Microscopy, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: MATE 441 or consent of instructor
Electron optics, design and operation of TEM; specimen preparation; electron diffraction and interpretation of diffraction patterns; imaging, dynamical theory; image interpretation for perfect crystals, crystal defects, interfaces and precipitates. Use of a TEM.

MATE 480, Advanced Dislocation Theory, 3 cr, 3 cl hrs
Prerequisite: METE 327 or consent of instructor
Dislocations in isotropic continua; effects of dislocations on crystal structure; point defects and physical properties; point defects and mechanical properties; dislocation-point-defect interactions and groups of dislocations; dislocation interactions. Shares lectures with MATE 580, but is graded separately and additional work is required at the graduate level.

MATE 481, 481L, Engineering Design I, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: Senior Standing, MATE 382
Student design teams begin a year-long capstone design project. The teams will identify project needs, establish goals, determine design requirements, produce alternate solutions, and perform detailed planning. Project initiation, periodic design reports and design reviews. Students, faculty, and distinguished visitors discuss subjects of current and/or long-range interest in various fields of materials. Undergraduate students majoring in Materials Engineering are required to take MATE 481 and MATE 481L concurrently. (Same as METE 481)

MATE 482, 482L, Engineering Design II, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: MATE 481
Continuation of the design projects initiated in MATE 481. The student design teams bring the projects to a successful conclusion. Economic analysis and detailed cost evaluation, use of engineering statistics in data analysis and design of experiments, preparation and presentation of final project report. Undergraduate students majoring in Materials Engineering are required to take MATE 482 and MATE 482L concurrently. (Same as METE 482)

MATE 483, 483L, Scanning Electron Microscopy, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: PHYS 122 *or consent of instructor*
Fundamental theory and experimental techniques in scanning electron microscopy. Electron optics, electron beam interactions with solids, signal detection and processing. Chemical X-ray microanalysis. Undergraduate students majoring in Materials Engineering are required to take MATE 483 and MATE 483L concurrently.

MATE 491, Directed Study/Senior Thesis, 3 cr
Prerequisite: Senior standing *or consent of instructor*

MATE 500, Directed Research, cr to be arranged
Prerequisite: Graduate standing
This course may not be used to fulfill graduate degree requirements.

MATE 501, Foundations of Materials, 3cr
Prerequisite: Graduate standing
This course is designed for the Materials graduate students with undergraduate degrees from other disciplines. Fundamental elements of metals, ceramics, polymers and composites will be covered.

MATE 502, Physical Ceramics, 3 cr, 3 cl hrs
Prerequisite: MATE 301
Review of ceramic microstructures. Atomistic, microstructural, and thermodynamic origins of ceramic properties, with emphasis on the effects of atomic and structural defects and interpretation of phase diagrams. Shares lectures with MATE 402, but is graded separately, and additional work is required at the graduate level.

MATE 503, Crystal Chemistry and Crystal Physics, 3 cr, 3 cl hrs
Prerequisite: Graduate standing or consent of instructor
Classification of elements and ions. Bonding and rules for building of structures in solids. Systematic review of the basic crystal structures of inorganic solids and their relationship with observed macroscopic properties. Introduction to crystal physics, relating measurable quantities to crystal symmetry.

MATE 504, Non-linear Dielectric Ceramics, 3 cr, 3 cl hrs
Prerequisite: MATE 235 and graduate standing; or consent of instructor
Review of polarization mechanisms and relaxation phenomena in non-linear dielectrics. New capacitor formulations (high permittivity) and "relaxor" ferroelectrics. Ferroelectric phase transitions and phenomenology. Piezoelectricity, pyroelectricity, and applications.

MATE 505, Electronic Materials, 3 cr, 3 cl hrs
Prerequisite: MATE 235 and graduate standing; or consent of instructor
Review of electronic, atomic, and defect structures which govern electrical behavior of ceramics and metals. Bulk and printed (thick film) electronic sensors and components. Superionic conductors used in solid

electrolyte batteries, and developments in new high-temperature superconducting ceramics. Polarization mechanisms and relaxation phenomena in dielectrics, with discussion of low-permittivity and microwave dielectrics.

MATE 509, Statistical Mechanics of Simple Materials, 3 cr, 3 cl hrs
Prerequisite: Graduate Standing or consent of instructor
Materials that can be "fooled" into looking like ideal gases are used to introduce the concepts and methods of statistical mechanics. Topics covered include: gas adsorption, blackbody radiation, superfluidity and superconductivity, blackhole formation, electrical conductivity, the Curie temperature, and the calculation of pi.

MATE 510, Mechanical Properties of Ordered Intermetallic Alloys, 3 cr, 3 cl hrs
Prerequisite: Graduate standing or consent of instructor
Development of understanding of the mechanical behavior of ordered alloys and of the process of alloy development. Crystal structures, ordering phenomena, lattice defects in ordered alloys, tensile and compressive behavior, anomalous yielding, enhanced work hardening, fracture, creep and fatigue, environmental effects, alloy development strategies.

MATE 512, Electronic Thin Films: Science and Technology, 3 cr, 3 cl hrs
Prerequisite: Graduate standing *or consent of instructor*
Discussion of thin-film deposition techniques (evaporation, sputtering, molecular beam epitaxy, liquid- phase epitaxy, and chemical vapor deposition), and their applications and limitations. Thin-film growth mechanism. Stress and interdiffusion in thin films. Electrical and optical properties of thin films, heterostructures, quantum wells, and superlattices.

MATE 514, Liquid State Theory, 3 cr, 3 cl hrs
Prerequisite: Graduate Standing or consent of instructor
An introduction to the study of many-particle systems and to the techniques of computer simulation. The statistical mechanics of simple liquids and their mixtures, with particular emphasis on the atomic origin of the structure factor and the relationships between atomic-level structure and macroscopic, thermodynamic properties.

MATE 516, Biomimetic Materials, 3 cr, 3 cl hrs
Prerequisite: Graduate standing or consent of instructor
An overview of the field of biomimetics: the achievement of unusual materials properties or processes by mimicry of various aspects of biological systems. Mimicry of natural structural design; biomimetic materials processing; "artificial photosynthesis"; biomolecular electronics; and biomimetic catalysis. Interdisciplinary studies.

MATE 530, Design and Analysis of Experiments, 3 cr, 3 cl hrs
Methods of statistics and modeling important to many problems in materials science and engineering including Six Sigma. Examples are chosen from a number of actual experiences. Safety considerations and experiment design including analysis of risk, how risks may be integrated, and how formal procedures should be established. The use of information sources, such as materials safety data sheets (MSDS). Shares lectures with MATE 430, but is graded separately, and additional work is required at the graduate level.

MATE 531, Fundamentals in Manufacturing Processes of Materials I, 3 cr, 3 cl hrs
Prerequisite: MATE 202 or equivalent; ES 302 or equivalent
Introduction to materials design; flow theories and work of deformation, microstructure-property relationships for different materials; fracture; casting and heat-flow/mass-transfer issues; bulk deformation processing with applications to rolling and extrusion; powder metallurgy and sintering of metal and ceramic powders. Shares lectures with MATE 431, but is graded separately, and additional work to include learning manufacturing software, as well as a detailed research paper, is required at the graduate level.

MATE 534, Introduction to Solidification and Phase Transformations, 3 cr, 3 cl hrs
Prerequisites: MATE 350; METE 327
Corequisite: MATE 442
Thermodynamic considerations and phase diagrams (review); influence of interfaces on equilibrium; influence of interfaces and of strain energy on microstructure and kinetics; solidification of single-component and multicomponent systems; ingots, castings, and weldings; sol-gel processing; diffusional transformations in solids: precipitation, eutectoid transformations, massive transformations, and ordering; diffusionless transformations in solids: martensitic transformations. Shares lectures with MATE 434 (formerly 444), but is graded separately, and additional work is required at the graduate level.

MATE 541, Advanced Physical Metallurgy, 3 cr, 3 cl hrs
Prerequisites: MATH 335 or equivalent; METE 327 or equivalent; MATE 235 or equivalent; or consent of the instructor
Application of thermodynamic principles to formation and stability of alloy systems. Recrystallization. Precipitation hardening. Physical metallurgy of steels, aluminum, rapidly solidified alloys, and quasi-crystals.

MATE 543, Advanced Mechanical Metallurgy, 3 cr, 3 cl hrs
Prerequisites: MATH 335 or equivalent; METE 327 or equivalent; MATE 235 or equivalent; or consent of instructor
Theory of elasticity/plasticity; dislocation theory; strengthening mechanisms; tensile testing; fracture and related failure phenomena; principal features of fatigue and creep; metalworking; related strain state- strain rate phenomena, including shock deformation and high energy rate forming.

MATE 544, Strengthening Mechanisms, 3 cr, 3 cl hrs
Prerequisite: METE 434 or consent of instructor
Application of dislocation theory to precipitation, dispersion and solution hardening; yielding; strain aging; Hall-Petch phenomena and strengthening by grain refinement; strengthening by dislocation substructures; work hardening; strength of martensite; fiber- reinforced composites; production of strong microstructures.

MATE 545, Micromechanics of Fracture, 3 cr, 3 cl hrs
Prerequisite: MATE 541 or 543 or equivalent or consent of instructor
Analysis of criteria for crack initiation and propagation leading to structural failure; study of fracture mechanics starting with Griffith theory for ideally brittle materials through plane strain and

ultimately elastic- plastic toughness phenomena. Effects of geometry, rate, environment, and microstructure will be considered as related to micromechanisms of fracture (cleavage, ductile fracture, fatigue, stress corrosion cracking).

MATE 548, Advanced Composite Materials, 3 cr, 3 cl hrs
Prerequisite: MATE 445 or consent of instructor
Reinforcements, their fabrication and properties. Matrix materials and their characteristics. Interfaces in various types of composites. Micromechanics of composites; macromechanics of composites. Failure processes in composites. Designing with composites. Specific important composite systems, their fabrication, properties, and applications.

MATE 554, Scattering Techniques, 3 cr, 3 cl hrs
Prerequisite: MATE 351 or consent of instructor
Application of scattering techniques to the characterization of polymeric materials, ranging from polymer solutions to melts or composites. Molecular motion of polymers in solutions and melts, Flory-Huggin theory, phase separation. Fundamentals and applications of scattering techniques to polymeric materials. Dynamic light scattering, laser light scattering neutron scattering, X- ray scattering.

MATE 560, Failure Analysis, 3 cr, 3 cl hrs
Prerequisite: ES 302
Failure analysis is the science of unraveling why a product failed unexpectedly. The results of the failure analysis may be used to design a better product, or as evidence in litigation. This course will cover the proper methodology for investigating a failure, the common failure modes of structures and machines, fractography, the procedure for writing a failure analysis report, and the legal implications. Shares lecture with MATE 460, but is graded separately, and additional graduate-level work is required.

MATE 563, Radiation Effects in Materials, 3 cr, 3 cl hrs
Fundamentals of radiation damage (energetic particles and energy dissipation, atomic displacements and cascades, evolution of damage); material-dependent radiation-damage phenomena (at atomic, microstructural, and macrostructural levels); applications (swift-ion irradiation effects, ion-beam modification of materials, nanostructure design via irradiation, nuclear fuels and waste forms, radiation detectors and dosimeters, solar and galactic cosmic particles).

MATE 566, Interfacial Phenomena, 3 cr, 3 cl hrs
Prerequisite: MATE 350 or equivalent or consent of instructor
Thermodynamics of interfaces (liquid/liquid, liquid/vapor, liquid/solid, solid/solid, solid/vapor); interfacial equilibria; interfacial free energy (surface tension measurements in liquids; specific surface free energy in solid systems); structure of solid surfaces and interfaces; properties of interfaces.

MATE 567, Dynamic Deformation of Solids, 3 cr, 3 cl hrs
Prerequisite: Graduate standing
Elastic waves. Plastic waves. Shock waves (Rankine-Hugoniot equations and more advanced treatments incorporating materials strength). Wave interactions and attenuation (including spalling). Spherical and cylindrical waves. Impact; Gurney equation. Principles of detonation.

MATE 568, Material Behavior at High Strain Rates, 3 cr, 3 cl hrs
Prerequisite: MATE 567
Mechanical properties of materials as a function of strain rate. Dislocation dynamics at high velocities. Structural changes introduced by shock waves: phase transformations, point defects, line defects, interfacial defects. Dislocation models for shock front. Materials aspects of adiabatic shear localization, spalling, dynamic deformation. Shock modification of ceramics.

MATE 570, Corrosion Phenomena, 3 cr, 3 cl hrs
Prerequisite: CHEM 122 and graduate standing
Theory of aqueous corrosion (thermodynamics and kinetics); forms of corrosion; corrosion testing and evaluation; designing to minimize corrosion; methods of corrosion prevention; corrosion in specific systems; case studies. Shares lecture with MATE 470, but is graded separately and additional graduate-level work is required.

MATE 575, Introduction to Nano Materials, 3 cr, 3 cl hrs
Prerequisite: Graduate standing or consent of instructor
An introduction to physical basics of nanosystems, physics and chemistry of nanostructure synthesis and fabrication. Other topics include: semiconductor nanostructures, magnetic nanostructures and spintronics, molecular nanostructures, electron transport in nanosystems, optical effects in nanosystems, nanomachines, nanoscale biological assemblies, nanocomposite materials.

MATE 579, Advanced Electron Microscopy, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: MATE 479
Advanced topics in transmission electron microscopy. In-situ studies of deformation and fracture processes, environmental effects, and radiation damage. High-resolution electron microscopy, weak-beam techniques, scanning transmission electron microscopy, electron microdiffraction. Analytical electron microscopy; electron energy loss spectroscopy and energy- dispersive analysis of X-rays; instrumentation, techniques, quantitation, applications.

MATE 580, Advanced Dislocation Theory, 3 cr, 3 cl hrs
Prerequisite: MATH 335; METE 327 or consent of instructor
Dislocations in isotropic continua; effects of dislocations on crystal structure; point defects and physical properties; point defects and mechanical properties; dislocation-point-defect interactions and groups of dislocations; dislocation interactions. Shares lectures with MATE 480, but is graded separately, and additional work is required at the graduate level.

MATE 581, Directed Study, cr to be arranged
Study under the guidance of a member of the department. In general, subject matter will supplement that available in the other graduate course offerings in metallurgy or materials engineering.

MATE 590, Independent Study, cr to be arranged
The student must clearly demonstrate the ability to

organize and pursue research. A written final report and public oral presentation is required.

MATE 591, Thesis (master's program), cr to be arranged

MATE 592, Materials Engineering Graduate Seminar, 1 cr, 1 cl hrs
Prerequisite: Graduate standing or consent of instructor
Seminar presentations by students, faculty and outside speakers. Discussion of topics of technical interest, and of global, societal, and ethical issues related to materials engineering.

MATE 595, Dissertation (doctoral degree program), cr to be arranged

MATE 599, Special Topics, cr to be arranged
Lectures in new or advanced areas of materials.

Metallurgical Engineering Courses:
METE 326, Introduction to Process Metallurgy, 3 cr, 3 cl hrs
Prerequisites: ES 111; MATH 132
Introduction to stoichiometric computations. Calculations of energy and material balance. Elementary process analysis and reactor design. Single-phase and multi-phase systems. (Same as ChE 326)

METE 327 Introduction to Physical Metallurgy, 3 cr, 3 cl hrs
Prerequisite: MATE 202
Mechanisms of deformation and fracture in metals. Binary phase diagrams. Phase transformations, age hardening, heat treatment of steels, TTT diagrams, CT diagrams, martensitic transformation, shape-memory effects. Common ferrous and non-ferrous alloys.
Undergraduate students majoring in Materials Engineering are required to take METE 327 and METE 327L concurrently.

METE 434, Introduction to Dislocation Theory, 3 cr, 3 cl hrs
Prerequisite: METE 327 *or consent of instructor*
An introduction to elasticity and the theory of plastic flow in materials. Geometrical and crystallographic features of dislocations, elastic equations of dislocations in crystals. Partial dislocations and stacking faults. Dislocation interactions and multiplication.

METE 481, 481L, Engineering Design I, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: Senior Standing
Student design teams begin a year-long capstone design project. The teams will identify project needs, establish goals, determine design requirements, produce alternate solutions, and perform detailed planning. Project initiation, periodic design reports and design reviews. Students, faculty, and distinguished visitors discuss subjects of current and/or long-range interest in various fields of materials.
Undergraduate students majoring in Materials Engineering are required to take METE 481 and METE 481L concurrently. (Same as MATE 481)

METE 482, 482L, Engineering Design II, 3 cr, 2 cl hrs, 3 lab hrs
Prerequisite: METE 481
Continuation of the design projects initiated in METE 481. The student design teams bring the projects to a successful conclusion. Economic analysis and detailed cost evaluation, use of engineering statistics in data analysis, preparation and presentation of final project report. Undergraduate students majoring in Materials Engineering are required to take METE 482 and METE 482L concurrently. (Same as MATE 482)

METE 491, Directed Study/Senior Thesis, 3 cr
Prerequisite: Senior standing or consent of instructor

Staff Research Interests
G. Bond—Electron Microscopy, Hydrogen Effects, Metal Hydrides, Radiation Damage, Biomimetic Materials and Processing, Carbon Dioxide Sequestration, Controlled Crystallization
Browning — Metal hydrides, Ion scattering techniques
Burleigh—Corrosion Mechanisms, Alloy Design, Coatings for Corrosion Prevention
Curro—Polymer Theory and Simulation
Doughty—Chemical Routes to Ceramic Materials, Chemical Sensors, Catalysis, Mechanisms of Chemical Reactions
Fuierer—Electronic Ceramics, Chemical Routes to Ceramic Materials and Thin Films, Atomic Force Microscopy
Hirschfeld—Properties and Processing of Structural Ceramics, Glass Ceramics, and Advanced Composites; Porous Ceramics; Ceramic Coatings for Corrosion Resistance, Thermal Spray
Hockensmith—Chemistry of Energetic Materials, Phytoremediation, Chemical Synthesis and Characterization
Inal—Radiation Damage, Shock-induced and Laser-exposure-induced Defects, Explosive Ceramic and Metal Working, Laser or Plasma Surface Modification of Metallic Materials, Enhancement of Low-temperature Ductility in Ordered Intermetallics
Jacobson — Alloys, Beryllian metallurgy and fracture testing
Kalugin — Optoelectronics and nonlinear optics, nanostructures and nanotechnology, TeraHz lasers and photodetectors, solid state physics of nanostructures, semiconductor materials and devices
Majumdar—Mechanics of Materials and Interfaces, Composites, Fracture
McCoy—Statistical Theory, Atomistic Simulation, Rheology, Glass Transition, Thin Films
Ravi—Processing of Composites, Coatings
Romig—Electron Optics, Phase Transformations, Solid-State Diffusion
M. Smith—Thermal Spraying