Bachelor of Science in Metallurgical and Materials Engineering

Program Description

Metallurgical and Materials Engineering play a major role in the development, utilization, and advancement of technology in every engineering discipline and on a broader scale – society's way of life. The department of Metallurgical & Materials Engineering offers two programs united in core beliefs to provide undergraduates with the fundamental knowledge associated with materials processing and manufacturing in the context of sustainability, material properties, and materials selection and application. Graduates of either program will have the necessary background and skills for successful careers in a wide variety of engineering industries that include mining, aerospace, automotive, electronic, biomedical, and many more; or for pursuit of graduate education in materials research and technology development and related fields.

The Metallurgical & Materials Engineering program instills fundamental knowledge pertaining to materials processes including extraction and refining of materials, alloy development, casting, mechanical working, joining and forming, high-temperature reactions, and of engineered materials. The relationship of materials' properties and performance with the microchemistries, microstructures, and controlled defect structures or their elimination is emphasized for all types of applications.

The program emphasizes hands-on experimental work in addition to classroom learning to provide a well-integrated undergraduate education. Engineers from these programs will acquire knowledge in materials' structure, properties, processing, and performance which can be applied to their desired area of focus.

Program Educational Objectives

The programs have shared department educational objectives such that students graduating:

1. Obtain a range of positions in industry or government facilities or pursue graduate education in engineering, science, or other fields.
2. Demonstrate advancement in their chosen careers.
3. Engage in appropriate professional societies and continuing education activities.

Student Learning Outcomes

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

ABET Accreditation

The Bachelor of Science in Metallurgical and Materials Engineering is accredited by the Engineering Accreditation Commission of ABET, https://www.abet.org, under the commission's General Criteria and Program Criteria for Materials (1), Metallurgical (2), Ceramics (3), and Similarly Named Engineering Programs.

The accreditation status for the MME program can be found on the Mines accreditation page.

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Curriculum

The Metallurgical and Materials Engineering (MME) curriculum is organized to educate students in the fundamentals of materials (MME Basics) and their applications (MME Applications).

A. MME Basics: The basic curriculum in the Metallurgical and Materials Engineering program will provide a background in the following topic areas:

1. Crystal Structures and Structural Analysis: crystal systems; symmetry elements and Miller indices; atomic bonding; metallic, ceramic and polymeric structures; x-ray and electron diffraction; stereographic projection and crystal orientation; long range order; defects in materials.
2. Thermodynamics of Materials: heat and mass balances; thermodynamic laws; chemical potential and chemical equilibrium; solution thermodynamics and solution models; partial molar and excess quantities; solid state thermodynamics; thermodynamics of surfaces; electrochemistry.
3. Transport Phenomena and Kinetics: Heat, mass and momentum transport; transport properties of fluids; diffusion mechanisms; reaction kinetics; nucleation and growth kinetics.
4. Phase Equilibria: phase rule; binary and ternary systems; microstructural evolution; defects in crystals; surface phenomena; phase transformations: eutectic, eutectoid, martensitic, nucleation and growth, recovery; microstructural evolution; strengthening mechanisms; quantitative stereology; heat treatment.
5. Properties of Materials: mechanical properties; chemical properties (oxidation and corrosion); electrical, magnetic and optical properties: failure analysis.

B. MME Applications: The course content in the Metallurgical and Materials Engineering program emphasizes the following applications:

1. Materials Processing: particulate processing; thermo- and electro-chemical materials processing; hydrometallurgical processing; synthesis of materials; deformation processing; solidification and casting; welding and joining.
2. Design and Application of Materials: materials selection; ferrous and nonferrous metals; ceramics; polymers; composites; electronic materials.
3. Statistical Process Control and Design of Experiments: statistical process control; process capability analysis; design of experiments.

C. MME Curriculum Requirements: The Metallurgical and Materials Engineering course sequence is designed to fulfill the program goals and to satisfy the curriculum requirements. The time sequence of courses organized by degree program, year, and semester is listed below.

Degree Requirements (Bachelor of Science in Metallurgical and Materials Engineering)

First Year

		lec	lab	sem.hrs
CHGN121	PRINCIPLES OF CHEMISTRY I			4.0
CSM101	FRESHMAN SUCCESS SEMINAR			1.0
MATH111	CALCULUS FOR SCIENTISTS AND ENGINEERS I			4.0
HASS100	NATURE AND HUMAN VALUES			3.0
CSCI128	COMPUTER SCIENCE FOR STEM			3.0
S&W	SUCCESS AND WELLNESS			1.0
CHGN125	MOLECULAR ENGINEERING & MATERIALS CHEMISTRY			4.0
PHGN100	PHYSICS I - MECHANICS			4.0
MATH112	CALCULUS FOR SCIENTISTS AND ENGINEERS II			4.0
EDNS151	CORNERSTONE - DESIGN I			3.0
CSM202	INTRODUCTION TO STUDENT WELL-BEING AT MINES			1.0
				32.0

Freshman

Summer		lec	lab	sem.hrs
MTGN272	MME FIELD SESSION			3.0
				3.0

Sophomore

Fall		lec	lab	sem.hrs
MATH213	CALCULUS FOR SCIENTISTS AND ENGINEERS III			4.0
PHGN200	PHYSICS II-ELECTROMAGNETISM AND OPTICS			4.0
MTGN202	ENGINEERED MATERIALS			3.0
MTGN251	METALLURGICAL AND MATERIALS THERMODYNAMICS			3.0
HASS215	FUTURES			3.0
				17.0

Spring		lec	lab	sem.hrs
MATH225	DIFFERENTIAL EQUATIONS			3.0
CEEN241	STATICS			3.0
MTGN211	STRUCTURE OF MATERIALS			3.0
MTGN281	INTRODUCTION TO PHASE EQUILIBRIA IN MATERIALS SYSTEMS			2.0
EBGN321	ENGINEERING ECONOMICS*For the 2023 Catalog EBGN321 replaced EBGN201 as a Core requirement. EBGN321 was added to the core, but has a prerequisite of 60 credit hours. Students whose programs that required EBGN201 the sophomore year may need to wait to take EBGN321 until their junior year. For complete details, please visit: https://www.mines.edu/registrar/core-curriculum/			3.0
				14.0

Junior

Fall		lec	lab	sem.hrs
CEEN311	MECHANICS OF MATERIALS or MEGN 212			3.0
MTGN352	METALLURGICAL AND MATERIALS KINETICS			3.0
MTGN350	STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS			3.0
MTGN310	POWDER PROCESSING AND FORMING			2.0
ELECTIVE	CULTURE AND SOCIETY (CAS) Mid-Level Restricted Elective			3.0
MTGN310L	POWDER PROCESSING AND FORMING LABORATORY			1.0
				15.0

Spring		lec	lab	sem.hrs
MTGN334	CHEMICAL PROCESSING OF MATERIALS			3.0
MTGN334L	CHEMICAL PROCESSING OF MATERIALS LABORATORY			1.0
MTGN348	MICROSTRUCTURAL DEVELOPMENT			3.0
MTGN348L	MICROSTRUCTURAL DEVELOPMENT LABORATORY			1.0
FREE	Free Elective			3.0
MTGN315	ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS			3.0
				14.0

Senior

Fall		lec	lab	sem.hrs
MTGN445	MECHANICAL PROPERTIES OF MATERIALS			3.0

MTGN445L	MECHANICAL PROPERTIES OF MATERIALS LABORATORY			1.0
MTGN	MTGN Elective			3.0
MTGN461	TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL AND MATERIALS ENGINEERS			3.0
ELECTIVE	CULTURE AND SOCIETY (CAS) Mid-Level Restricted Elective			3.0
MTGN467	MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION			2.0
				15.0
Spring		**lec**	**lab**	**sem.hrs**
MTGN	MTGN Elective			3.0
MTGN	MTGN Elective			3.0
MTGN	MTGN Elective			3.0
FREE	Free Elective			3.0
MTGN468	MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION			2.0
ELECTIVE	CULTURE AND SOCIETY (CAS) 400-Level Restricted Elective			3.0
				17.0

Total Semester Hrs: 127.0

Major GPA

During the 2016-2017 academic year, the Undergraduate Council considered the policy concerning required major GPAs and which courses are included in each degree's GPA. While the GPA policy has not been officially updated, in order to provide transparency, council members agreed that publishing the courses included in each degree's GPA is beneficial to students.

The following list details the courses that are included in the GPA for this degree:

- MTGN100 through MTGN599 inclusive

Five-Year Combined Metallurgical and Materials Engineering Baccalaureate and Master of Engineering in Metallurgical and Materials Engineering with an Electronic-Materials Emphasis.*

The departments of Metallurgical and Materials Engineering and Physics collaborate to offer a five-year program designed to meet the needs of the electronics and similar high-tech industries. Students who satisfy the requirements of the program obtain an undergraduate degree in Engineering Physics, Metallurgical and Materials Engineering, or Ceramic Engineering in four years and a Master of Engineering degree in Metallurgical and Materials Engineering at the end of the fifth year. The program is designed to provide a strong background in science fundamentals as well as specialized training in the materials-science and processing needs of these industries. Thus, the educational objective of the program is to provide students with the specific educational requirements to begin a career in microelectronics and, at the same time, a broad and flexible background necessary to remain competitive in this exciting and rapidly-changing industry. The undergraduate electives which satisfy the requirements of the program and an overall curriculum need to be discussed with the student's advisor and approved by the Physics or Metallurgical and Materials Engineering departments. A program mentor in each department can also provide counseling on the program.

Application for admission to this program should be made during the first semester of the sophomore year (in special cases, later entry may be approved upon review by one of the program mentors). Undergraduate students admitted to the program must maintain a 3.0 grade-point average or better. The graduate segment of the program requires a case study report, submitted to the student's graduate advisor. Additional details on the Master of Engineering can be found in the Graduate Degree and Requirements section of the graduate bulletin. The case study is started during the student's senior design project and completed during the year of graduate study. A student admitted to the program is expected to select a graduate advisor in advance of the graduate-studies final year and prior to the start of their senior year. The case-study topic is then identified and selected in consultation with the graduate advisor. A formal application during the senior year for admission to the graduate program in Metallurgical and Materials Engineering must be submitted to the Graduate School. Students who have maintained all the standards of the program requirements leading up to this step can expect to be admitted.

COURSES

MTGN198. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 1-3 Semester Hr.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN199. INDEPENDENT STUDY. 1-3 Semester Hr.
(I, II, S) Independent work leading to a comprehensive report. This work may take the form of conferences, library, and laboratory work. Choice of problem is arranged between student and a specific department faculty-member. Prerequisite: Selection of topic; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit.

MTGN199. INDEPENDENT STUDY. 0.5-6 Semester Hr.

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MTGN202. ENGINEERED MATERIALS. 3.0 Semester Hrs.
Equivalent with SYGN202,
Introduction to the Metallurgical and Materials Engineering paradigm: processing, structure, and properties. The course will relate technologically significant processing procedures to resultant structures. The material structure will be examined to determine its effect upon material properties. Students will study materials engineering methodologies and learn terminology. 3 hours lecture; 3 semester hours. Prerequisite: CHGN121, MATH112, and PHGN100.
Course Learning Outcomes

- No change

MTGN211. STRUCTURE OF MATERIALS. 3.0 Semester Hrs.
Principles of atomic bonding, crystallography, and amorphous structures. ii) Symmetry relationships to material properties. iii) Atomic structure determination through diffraction techniques. 3 hours lecture; 3 semester hours. Prerequisite: MTGN202. Co-requisite: PHGN200.
Course Learning Outcomes

- ABET 1, 5

MTGN219. ART AND SCIENCE OF GLASSBLOWING. 0-2 Semester Hr.
Explore the science of glass by learning artistic glassblowing. Lectures will cover basic glass network structure, melt processing and viscosity, forming and cold working, as well as optical and mechanical properties. Over the course of the semester, laboratory exercises will train students in basic glassblowing and safe use of a hot glass shop. Students who pass the course with a B or better will be certified to use the Hill Hall hot glass shop during open shop hours. Due to the limited capacity of this course, registration opportunities are determined each semester by a random lottery. Details are announced via the Daily Blast a couple of weeks prior to registration begins. This course is not counted towards MME major completion as an MTGN elective.
Course Learning Outcomes

- ABET #4

MTGN251. METALLURGICAL AND MATERIALS THERMODYNAMICS. 3.0 Semester Hrs.
Applications of thermodynamics in extractive and physical metallurgy and materials science. Thermodynamics of solutions including solution models and thermodynamic properties of alloys and slags. Reaction equilibria with examples in alloy systems and slags. Phase stability analysis. Thermodynamic properties of binary alloys in the solid state, defect equilibrium, and interactions. 3 hours lecture; 3 semester hours. Prerequisites: MATH112 and PHGN100. Corequisites: CHGN122 or CHGN125.
Course Learning Outcomes

- ABET1

MTGN272. MME FIELD SESSION. 3.0 Semester Hrs.
Introduction to the field of Metallurgical and Materials Engineering. Overview of opportunities, expectations, and practices within the MME department and the broader materials community. Introduction to bonding, crystal and grain structure, application space, and Structure-Property-Processing relationships. Laboratory projects and plant visits. Prerequisites: MATH112, PHGN100. 9 hours lab; 3 semester hours.
Course Learning Outcomes

- No change

MTGN281. INTRODUCTION TO PHASE EQUILIBRIA IN MATERIALS SYSTEMS. 2.0 Semester Hrs.
Review of the concepts of chemical equilibrium and derivation of the Gibbs phase rule. Use of thermodynamic principles for constructing and interpreting one, two and three component phase equilibrium diagrams. Application to alloy and ceramic materials systems. Emphasis on the evolution of phases and their amounts and the resulting microstructural development. Prerequisite: MTGN202, MTGN251.
Course Learning Outcomes

- ABET 1

MTGN298. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 0-3 Semester Hr.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN298. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 0-3 Semester Hr.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN299. INDEPENDENT STUDY. 1-3 Semester Hr.
(I, II, S) Independent work leading to a comprehensive report. This work may take the form of conferences, library, and laboratory work. Choice of problem is arranged between student and a specific department faculty-member. Prerequisite: Selection of topic; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit.

MTGN299. INDEPENDENT STUDY. 1-3 Semester Hr.

MTGN300. FOUNDRY METALLURGY. 2.0 Semester Hrs.
Design and metallurgical aspects of casting, patterns, molding materials and processes, solidification processes, risers and gating concepts, casting defects and inspection, melting practice, cast alloy selection. 2 hours lecture; 2 semester hours. Co-requisite: MTGN300L.
Course Learning Outcomes

- ABET 3

MTGN300L. FOUNDRY METALLURGY LABORATORY. 1.0 Semester Hr.
Equivalent with MTGN302,
Experiments in the foundry designed to supplement the lectures of MTGN300. 3 hours lab; 1 semester hour. Co-requisite: MTGN300.
Course Learning Outcomes

- ABET 3

MTGN310. POWDER PROCESSING AND FORMING. 2.0 Semester Hrs.
Fabrication of components from powder-based feedstocks is central to both ceramic and metallurgical engineering, and the concepts of powder processing apply to industries as diverse as mining, food products, paints, and many more. This course covers the handling, measurement, and application of powdered feedstocks to the formation of green bodies (i.e., powder compacts) using both wet and dry methods. Particular attention is paid to the importance of powder characteristics, green density, impurities and other defects in these initial stages to the final density, microstructure and overall properties of the subsequent part, whether the parts are sintered or consolidated in another way such as laser powder bed fusion (LPBF). Prerequisite: MTGN202, MTGN251. Co-requisite: MTGN310L.
Course Learning Outcomes

- 1. exhibit basic competence in wet and dry handling of fine powders
- 2. apply both optical and mechanical approaches to the measurement of particle size and distribution and apply both mechanical and fluid-based approaches to particle size sorting

- 3. exhibit basic competence in wet processing of powders and control of rheology through colloidal dispersion and stabilization techniques
- 4. demonstrate powder based forming of a macroscopic component

MTGN310L. POWDER PROCESSING AND FORMING LABORATORY. 1.0 Semester Hr.

Fabrication of components from powder-based feedstocks is central to both ceramic and metallurgical engineering, and the concepts of powder processing apply to industries as diverse as mining, food products, paints, and many more. This course covers the handling, measurement, and application of powdered feedstocks to the formation of green bodies (i.e., powder compacts) using both wet and dry methods. Particular attention is paid to the importance of powder characteristics, green density, impurities and other defects in these initial stages to the final density, microstructure and overall properties of the subsequent part, whether the parts are sintered or consolidated in another way such as laser powder bed fusion (LPBF). Prerequisite: MTGN202, MTGN251. Co-requisite: MTGN310.

Course Learning Outcomes

- 1. exhibit basic competence in wet and dry handling of fine powders
- 2. apply both optical and mechanical approaches to the measurement of particle size and distribution and apply both mechanical and fluid-based approaches to particle size sorting
- 3. exhibit basic competence in wet processing of powders and control of rheology through colloidal dispersion and stabilization techniques
- 4. demonstrate powder based forming of a macroscopic component

MTGN315. ELECTRICAL PROPERTIES AND APPLICATIONS OF MATERIALS. 3.0 Semester Hrs.

Survey of aspects of modern physics needed to understand selected properties of materials including conductivity (electrical, thermal, etc.), electronic states of materials, density of states, the nature of bands and bonding and how they arise, total and cohesive energy of solids based on filling of states, the nature of metals, semiconductors, and dielectrics and how these arise from electronic states, and the application of these concepts to understand dielectrics, magnetism, and semiconductor devices. Prerequisite: PHGN200, MATH225. Corequisite: MTGN211.

Course Learning Outcomes

- ABET 1, 2, 5

MTGN319. INTRODUCTION TO GLASS SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.

Introduction to the principles of glass science and engineering and non-crystalline materials. Glass formation, structure, crystallization and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes and applications. Prerequisite: MTGN202. Co-requisite: MTGN319L.

Course Learning Outcomes

- 1. Understand atomic origins and structure of amorphous solids
- 2. Understand the principles of glass formation from melts
- 3. Understand and engineer the mechanical, optical, transport, and electrical properties of glasses
- 4. Engineer glass materials for biological, optical, and thermal applications

MTGN319L. INTRODUCTION TO GLASS SCIENCE AND TECHNOLOGY LABORATORY. 1.0 Semester Hr.

Introduction to the principles of glass science and engineering and non-crystalline materials. Glass formation, structure, crystallization and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes and applications. Prerequisite: MTGN202. Co-requisite: MTGN319.

Course Learning Outcomes

- 1. Understand atomic origins and structure of amorphous solids
- 2. Understand the principles of glass formation from melts
- 3. Understand and engineer the mechanical, optical, transport, and electrical properties of glasses
- 4. Engineer glass materials for biological, optical, and thermal applications

MTGN333. INTRODUCTION TO BLADESMITHING. 3.0 Semester Hrs.

An introduction to the metallurgy and art of bladesmithing. The course covers ferrous metallurgy with a focus on tools steels used for creating edged tools. Students will learn and execute techniques for alloy selection, shaping, profiling, beveling, heat treating, and sharpening knives. Students will complete at least two knives, one specified by the instructor, and one of the students own design. Co-requisite: MTGN348 or instructor consent.

Course Learning Outcomes

- ABET a, b, c

MTGN334. CHEMICAL PROCESSING OF MATERIALS. 3.0 Semester Hrs.

Development and application of fundamental principles related to the processing of metals and materials by thermochemical, aqueous, and fused salt electrochemical/chemical routes. The course material is presented within the framework of a formalism that examines the physical chemistry, thermodynamics, reaction mechanisms and kinetics inherent to a wide selection of chemical processing systems. The general formalism provides for a transferable knowledge-base to other systems not specifically covered in the course. Prerequisite: MTGN251. Co-requisite: MTGN334L.

Course Learning Outcomes

- no change

MTGN334L. CHEMICAL PROCESSING OF MATERIALS LABORATORY. 1.0 Semester Hr.

Experiments in chemical processing of materials to supplement the lectures of MTGN334. 3 hours lab; 1 semester hour. Co-requisite: MTGN334.

Course Learning Outcomes

- ABET 1, 2

MTGN340. COOPERATIVE EDUCATION. 1-3 Semester Hr.

(I, II, S) Supervised, full-time, engineering-related employment for a continuous six-month period (or its equivalent) in which specific educational objectives are achieved. 1 to 3 semester hours. Cooperative education credit does not count toward graduation except under special conditions. Repeatable.

Course Learning Outcomes

- depends

MTGN345. SINTERING OF CERAMICS. 3.0 Semester Hrs.

This course covers the fundamentals and applications of sintering based processes in ceramic engineering. It includes solid-state, liquid phase, reactive and vapor phase sintering and covers densifying and non-densifying mechanisms as well as microstructure development for

bulk, coatings, and additively manufactured parts. The course covers technologies used in the processing of ceramics. Prerequisite: MTGN310, MTGN352, MTGN281. Co-requisite: MTGN345L.
Course Learning Outcomes

- 1. Exhibit a basic understanding of sintering mechanisms in ceramics
- 2. Engineer microstructure development of powder-based specimens from green body to dense polycrystalline ceramics
- 3. Design a thermal profile to produce a desired microstructure for a given material for different processing techniques
- 4. Characterize abnormal grain growth, solute drag, pore drag, and Zener pinning

MTGN345L. SINTERING OF CERAMICS LABORATORY. 1.0 Semester Hr.
This is the laboratory course for MTGN345. This course covers the fundamentals and applications of sintering based processes in ceramic engineering. It includes solid-state, liquid phase, reactive and vapor phase sintering and covers densifying and non-densifying mechanisms as well as microstructure development for bulk, coatings, and additively manufactured parts. The course covers technologies used in the processing of ceramics. Prerequisite: MTGN310, MTGN352, MTGN281. Co-requisite: MTGN345.
Course Learning Outcomes

- 1. exhibit a basic understanding of sintering mechanisms in ceramics
- 2. engineer microstructure development of powder-based specimens from green body to dense polycrystalline ceramics
- 3. design a thermal profile to produce a desired microstructure for a given material for different processing techniques
- 4. to characterize abnormal grain growth, solute drag, pore drag, and Zener pinning

MTGN348. MICROSTRUCTURAL DEVELOPMENT. 3.0 Semester Hrs.
An introduction to the relationships between microstructure and properties of materials, with emphasis on metallic and ceramic systems; Fundamentals of imperfections in crystalline materials on material behavior; recrystallization and grain growth; strengthening mechanisms: microstructural refinement, solid solution strengthening, precipitation strengthening, cold work; and phase transformations. Prerequisite: MTGN211, MTGN251. Co-requisite: MTGN281, MTGN348L.
Course Learning Outcomes

- ABET 1, 3

MTGN348L. MICROSTRUCTURAL DEVELOPMENT LABORATORY. 1.0 Semester Hr.
Experiments in microstructural development of materials to supplement the lectures of MTGN348. 3 hours lab; 1 semester hour. Co-requisite: MTGN348.
Course Learning Outcomes

- ABET 1, 3

MTGN350. STATISTICAL PROCESS CONTROL AND DESIGN OF EXPERIMENTS. 3.0 Semester Hrs.
Introduction to statistical process control, process capability analysis and experimental design techniques. Statistical process control theory and techniques developed and applied to control charts for variables and attributes involved in process control and evaluation. Process capability concepts developed and applied to the evaluation of manufacturing processes. Theory of designed experiments developed and applied to full factorial experiments, fractional factorial experiments, and multilevel experiments. Analysis of designed experiments by graphical and statistical techniques. Introduction to computer software for statistical process control and for the design and analysis of experiments.
Course Learning Outcomes

- ABET 1, 3

MTGN352. METALLURGICAL AND MATERIALS KINETICS. 3.0 Semester Hrs.
Introduction to reaction kinetics: chemical kinetics, atomic and molecular diffusion, surface thermodynamics and kinetics of interfaces and nucleation-and-growth. Applications to materials processing and performance aspects associated with gas/solid reactions, precipitation and dissolution behavior, oxidation and corrosion, purification of semiconductors, carburizing of steel, formation of p-n junctions and other important materials systems. Prerequisite: MTGN272. Co-requisite: MTGN251.
Course Learning Outcomes

- ABET 1, 2

MTGN398. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 0-3 Semester Hr.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN398. SPECIAL TOPICS. 1-3 Semester Hr.

MTGN399. INDEPENDENT STUDY. 1-3 Semester Hr.
(I, II, S) Independent work leading to a comprehensive report. This work may take the form of conferences, library, and laboratory work. Choice of problem is arranged between student and a specific department faculty-member. Prerequisite: Selection of topic; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit.

MTGN399. INDEPENDENT STUDY. 1-3 Semester Hr.

MTGN399. INDEPENDENT STUDY. 1-3 Semester Hr.

MTGN399. INDEPENDENT STUDY. 1-6 Semester Hr.

MTGN399. INDEPENDENT STUDY. 0.5-6 Semester Hr.

MTGN399. INDEPENDENT STUDY. 0.5-6 Semester Hr.

MTGN399. INDEPENDENT STUDY. 0.5-6 Semester Hr.

MTGN399. INDEPENDENT STUDY. 0.5-6 Semester Hr.

MTGN399. INDEPENDENT STUDY. 0.5-6 Semester Hr.

MTGN403. SENIOR THESIS. 3.0 Semester Hrs.
(I, II,S) Two-semester individual research under the direction of members of the MME faculty. Work may include library and laboratory research on topics of relevance. Oral presentation will be given at the end of the second semester and written thesis submitted to committee of evaluation. 3 hours research; 3 semester hours.
Course Learning Outcomes

- depends

MTGN410. THERMAL PROPERTIES OF CERAMICS. 3.0 Semester Hrs.
This course covers the fundamentals and applications of ceramic materials' responses to thermal energy. Thermal responses are fundamentally borne from atomic scale processes which will be covered

in detail. Particular attention is paid to thermal conduction, melting, thermally induced strain, thermomechanical stresses, and engineering microstructures to obtain specific thermal performances. Prerequisite: MTGN315, MTGN310.

Course Learning Outcomes

- 1. Understand atomic and thermodynamic material responses to thermal energy
- 2. Understand and engineer thermal conduction processes in materials and devices
- 3. Engineer thermomechanical responses to thermal energy including expansion and thermal shock
- 4. Engineer ceramic materials for thermal insulation applications

MTGN414. ADVANCED PROCESSING AND SINTERING OF CERAMICS. 3.0 Semester Hrs.

Principles of ceramics processing and the relationship between processing and microstructure, with a focus on advanced microstructural control using thermal and athermal energy input in single and multiphase systems. Principles will be illustrated using case studies on specific ceramic materials. A project to design a ceramic fabrication process is required. 3 hours lecture; 3 semester hours.

Course Learning Outcomes

- ABET 1, 2, 3

MTGN419. NON-CRYSTALLINE MATERIALS. 3.0 Semester Hrs.

Introduction to the principles of glass science and engineering and non-crystalline materials in general. Glass formation, structure, crystallization and properties will be covered, along with a survey of commercial glass compositions, manufacturing processes and applications. Prerequisite: MTGN211.

Course Learning Outcomes

- ABET 1, 2

MTGN429. METALLURGICAL ENVIRONMENT. 3.0 Semester Hrs.

(I) Examination of the interface between metallurgical process engineering and environmental engineering. Wastes, effluents and their point sources in metallurgical processes such as mineral concentration, value extraction and process metallurgy are studied in context. Fundamentals of metallurgical unit operations and unit processes with those applicable to waste and effluent control, disposal and materials recycling are covered. Engineering design and engineering cost components are also included for selected examples. Fundamentals and applications receive equal coverage. Prerequisites: MTGN334. 3 hours lecture; 3 semester hours.

MTGN430. PHYSICAL CHEMISTRY OF IRON AND STEELMAKING. 3.0 Semester Hrs.

Physical chemistry principles of blast furnace and direct reduction production of iron and refining of iron to steel. Discussion of raw materials, productivity, impurity removal, deoxidation, alloy additions, and ladle metallurgy. Prerequisite: MTGN334, MTGN251.

Course Learning Outcomes

- ABET 1, 2

MTGN431. HYDRO- AND ELECTRO-METALLURGY. 3.0 Semester Hrs.

Physicochemical principles associated with the extraction and refining of metals by hydro- and electrometallurgical techniques. Discussion of unit processes in hydrometallurgy, electrowinning, and electrorefining. Analysis of integrated flowsheets for the recovery of nonferrous metals. Offered every other year. 3 hours lecture; 3 semester hours. Prerequisite: MTGN334, MTGN352, and MTGN251. Co-requisite: MTGN461.

Course Learning Outcomes

- ABET 1

MTGN432. PYROMETALLURGY. 3.0 Semester Hrs.

Extraction and refining of metals including emerging practices. Modifications
driven by environmental regulations and by energy minimization. Analysis and design of processes and the impact of economic constraints. Prerequisite: MTGN334. 3 hours lecture; 3 semester hours.

MTGN435. PYROMETALLURGICAL PROCESSES. 0-3 Semester Hr.

MTGN440. MAGNETIC MATERIALS AND MODERN TECHNOLOGIES. 3.0 Semester Hrs.

Every material is magnetic – although only some of them have useful magnetism. This course is designed to provide a practical view of magnetism in materials science, starting with the fundamentals of magnetism and classification of magnetic materials. We will discuss the fundamentals of magnetism, atomistic origins of magnetism and materials, and applications of magnetism in modern technologies. Throughout the course, we will interrogate how magnetism affects a materials bonding, structure, and functionality. Prerequisites: MTGN211, MTGN315.

Course Learning Outcomes

- Explain the fundamentals of magnetism as they relate to materials using classical physics and quantum mechanics
- Classify materials according to their field- and temperature-dependent magnetic behavior
- Describe the underlying physics of uncorrelated and correlated systems using empirical theories
- Predict the magnetic response of simple systems
- Describe how magnetism can be exploited for technological applications
- Plot and analyze magnetic data in Python

MTGN441. SUSTAINABLE METALLURGY AND WASTE RECYCLING. 3.0 Semester Hrs.

Student learning outcomes are assessed through assignments, quizzes, and a summative final project. Regular assignments and quizzes measure students' ability to analyze metallurgical processes using thermodynamics, diffusion, and kinetics; compare production and recycling routes; and apply sustainability frameworks and tools such as life cycle assessment and material flow analysis. These assessments also gauge students' understanding of system-level considerations, including energy use, water demands, waste generation, and process design. The summative project serves as an integrative assessment in which students formulate and analyze a material and/or energy balance problem related to metal production or recycling. In addition to performing technical analysis, students evaluate environmental, economic, and social implications and propose strategies to improve current industrial practices. This project also supports the development of teamwork, communication, and critical thinking skills. Group discussions and team-based problem solving are also used throughout the course to encourage peer learning and create a collaborative learning environment.

Course Learning Outcomes

- Analyze the fundamental principles underlying metallurgical processes in the context of metal production and recycling, using concepts of thermodynamics, diffusion, and kinetics.
- Apply sustainability frameworks to at least two distinct industrial contexts.
- Compare and contrast various metal production and recycling processes using tools such as life cycle assessment and material flow analysis.
- Evaluate the environmental, economic, and social implications associated with metal production and recovery, and propose potential solutions to address these issues.
- Understand the various factors affecting system design, including energy consumption, the role of water, waste management, and reactor design.
- Develop teamwork, communication, and critical thinking skills to effectively achieve engineering objectives.

MTGN442. ENGINEERING ALLOYS. 3.0 Semester Hrs.
This course is intended to be an important component of the physical metallurgy sequence, to reinforce and integrate principles from earlier courses, and enhance the breadth and depth of understanding of concepts in a wide variety of alloy systems. Metallic systems considered include iron and steels, copper, aluminum, titanium, superalloys, etc. Phase stability, microstructural evolution and structure/property relationships are emphasized. Offered every year. Prerequisite: MTGN348.
Course Learning Outcomes

- ABET 2, 6

MTGN445. MECHANICAL PROPERTIES OF MATERIALS. 3.0 Semester Hrs.
Mechanical properties and relationships. Plastic deformation of crystalline materials. Relationships of microstructures to mechanical strength. Fracture, creep, and fatigue. 3 hours lecture, 3 semester hours. Prerequisite: MTGN348, CEEN241, and CEEN311 or MEGN212. Co-requisite: MTGN445L.
Course Learning Outcomes

- ABET 4, 5,7

MTGN445L. MECHANICAL PROPERTIES OF MATERIALS LABORATORY. 1.0 Semester Hr.
Laboratory sessions devoted to advanced mechanical-testing techniques to illustrate the application of the fundamentals presented in the lectures of MTGN445. Corequisite: MTGN445. 3 hours lab; 1 semester hour.
Course Learning Outcomes

- ABET 4,5 7

MTGN451. CORROSION ENGINEERING. 3.0 Semester Hrs.
Principles of electrochemistry. Corrosion mechanisms. Methods of corrosion control including cathodic and anodic protection and coatings. Examples of corrosion problems and solutions from various industries. Prerequisite: MTGN251.
Course Learning Outcomes

- No change

MTGN456. ELECTRON MICROSCOPY. 2.0 Semester Hrs.
Introduction to electron optics and the design and application of transmission and scanning electron microscopes. Interpretation of images produced by various contrast mechanisms. Electron diffraction analysis and the indexing of electron diffraction patterns. 2 hours lecture; 2 semester hours. Prerequisite: MTGN211. Co-requisite: MTGN456L.
Course Learning Outcomes

- ABET 1, 3

MTGN456L. ELECTRON MICROSCOPY LABORATORY. 1.0 Semester Hr.
Equivalent with MTGN458,
Laboratory exercises to illustrate specimen preparation techniques, microscope operation, and the interpretation of images produced from a variety of specimens, and to supplement the lectures in MTGN456. 3 hours lab; 1 semester hour. Co-requisite: MTGN456.
Course Learning Outcomes

- ABET 1, 3

MTGN457. SOLIDIFICATION. 3.0 Semester Hrs.
This course is intended to provide students with a working understanding of solidification processing of metals relevant to crystal growth, casting, welding, and additive manufacturing. Topics in the course are: 1) thermodynamics, 2) nucleation, 3) heat transfer, 4) interface stability and solidification morphology, 5) dendritic growth, 6) microsegregation, and 7) columnar vs equiaxed dendritic growth. Prerequisite: MTGN348.
Course Learning Outcomes

MTGN461. TRANSPORT PHENOMENA AND REACTOR DESIGN FOR METALLURGICAL AND MATERIALS ENGINEERS. 3.0 Semester Hrs.
Introduction to the conserved-quantities: momentum, heat, and mass transfer, and application of chemical kinetics to elementary reactor-design. Examples from materials processing and process metallurgy. Molecular transport properties: viscosity, thermal conductivity, and mass diffusivity of materials encountered during processing operations. Uni-directional transport: problem formulation based on the required balance of the conserved- quantity applied to a control-volume. Prediction of velocity, temperature and concentration profiles. Equations of change: continuity, motion, and energy. Transport with two independent variables (unsteady-state behavior). Interphase transport: dimensionless correlations friction factor, heat, and mass transfer coefficients. Elementary concepts of radiation heat-transfer. Flow behavior in packed beds. Design equations for: continuous- flow/batch reactors with uniform dispersion and plug flow reactors. Digital computer methods for the design of metallurgical systems. Prerequisite: MATH225, MTGN334, and MTGN352. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- ABET 1,3

MTGN462. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.
This course will examine, using case studies, how industry applies engineering principles to minimize waste formation and to meet solid waste recycling challenges. Both proven and emerging solutions to solid waste environmental problems, especially those associated with metals, will be discussed. Prerequisites: CEEN301, CEEN302, and CHGN403. 3 hours lecture; 3 semester hours.

MTGN464. FORGING AND FORMING. 3.0 Semester Hrs.
Introduction to plasticity, survey and analysis of working operations including forging, extrusion, rolling, wire drawing and sheet-metal forming. Metallurgical structure evolution during working. Prerequisite: MTGN281 and, CEEN311 or MEGN212, MTGN348. Co-requisite: MTGN464L.

Course Learning Outcomes

- ABET 1

MTGN464L. FORGING AND FORMING LABORATORY. 1.0 Semester Hr.

Experiments in forging and forming to supplement the lectures of MTGN464. 3 hours lab; 1 semester hour. Co-requisite: MTGN464.

Course Learning Outcomes

- ABET 1

MTGN465. MECHANICAL PROPERTIES OF CERAMICS. 3.0 Semester Hrs.

Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high-temperature mechanical behavior, including fracture and creep deformation. Offered every year. Prerequisite: MTGN310, CEEN241, CEEN311 or MEGN212. Co-requisite: MTGN465L.

Course Learning Outcomes

- ABET 1

MTGN465L. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES LABORATORY. 1.0 Semester Hr.

Mechanical properties of ceramics and ceramic-based composites; brittle fracture of solids; toughening mechanisms in composites; fatigue, high temperature mechanical behavior, including fracture, creep deformation. Co-requisite: MTGN465.

Course Learning Outcomes

- 1) Reduce, interpret and analyze experimental data from a variety of mechanical property tests.
- 2) Prepare and submit concise and coherent technical laboratory reports.
- 3) apply mechanical property models such as fracture mechanics to ceramic and composite behavior.
- 4) Describe ceramic and composite mechanical properties and behavior in terms of mechanisms.
- 5) Identify and classify different types of ceramic and composite mechanical constitutive responses.

MTGN467. MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION. 2.0 Semester Hrs.

Application of fundamental materials engineering principles to the design of systems, processes, and/or components for extraction, synthesis, operation and/or selection of materials in open-ended projects with realistic constraints. Project topics range from processes used for metallurgical processing and extraction to design and development of emergent materials to process/component analysis and (re)design. Chemical and microstructural characterization and property measurements provide the basis for linking synthesis to application and/or process to product. Selection criteria tied to specific requirements drive design under realistic constraints that include an appropriate mix of technical, economic, safety, and other considerations. Activities are carried out in teams in collaboration with project sponsors/clients. 1 hour lecture, 3 hours lab; 2 semester hours. Prerequisite: MTGN350, MTGN352, and MTGN348 or MTGN345.

Course Learning Outcomes

- ABET 1-7

MTGN468. MATERIALS DESIGN: SYNTHESIS, CHARACTERIZATION AND SELECTION. 2.0 Semester Hrs.

Application of fundamental materials engineering principles to the design of systems, processes, and/or components for extraction, synthesis, operation and/or selection of materials in open-ended projects with realistic constraints. Project topics range from processes used for metallurgical processing and extraction to design and development of emergent materials to process/component analysis and (re)design. Chemical and microstructural characterization and property measurements provide the basis for linking synthesis to application and/or process to product. Selection criteria tied to specific requirements drive design under realistic constraints that include an appropriate mix of technical, economic, safety, and other considerations. Activities are carried out in teams in collaboration with project sponsors/clients. Prerequisite: MTGN467. 1 hour lecture, 3 hours lab; 2 semester hours.

Course Learning Outcomes

- ABET 1-7

MTGN469. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.

Fuel cells provide one of the most efficient means for converting the chemical energy stored in a fuel to electrical energy. Fuel cells offer improved energy efficiency and reduced pollution compared to heat engines. While composed of no (or very few) moving parts, a complete fuel cell system amounts to a small chemical plant for the production of power. This course introduces students to the fundamental aspects of fuel cell systems, with emphasis placed on proton exchange membrane (PEM) and solid oxide fuel cells (SOFC). Students will learn the basic principles of electrochemical energy conversion while being exposed to relevant topics in materials science, thermodynamics, and fluid mechanics. Offered every other year. Prerequisite: PHGN200, MATH225, MTGN251 or CHGN209 or CHGN210 or MEGN261.

Course Learning Outcomes

- ABET 1, 2, 6

MTGN472. BIOMATERIALS I. 3.0 Semester Hrs.

This course introduces biomaterials by combining materials engineering principles with understanding of aspects of molecular and cellular biology so that students learn how materials interact with biological systems, particularly for medical use. The course is organized around four main topics: 1) fundamental properties of biomaterials; 2) fundamental concepts in biology relevant to biomaterials; 3) interactions of physiological systems with biomaterials, and 4) processing of biopolymers, bioceramics and glasses, biometals and composites. Key topics covered include processing of materials to achieve specific biological responses, surface energy and surface modification; protein adsorption; cell adhesion, spreading and migration; biomaterials implantation and acute inflammation; blood-materials interactions; biofilms and biomaterials degradation; and clinical applications of biomaterials. Offered every other year. Prerequisite: MTGN202. 3 hours lecture; 3 semester hours.

Course Learning Outcomes

- ABET 1, 5, 6

MTGN473. COMPUTATIONAL MATERIALS. 3.0 Semester Hrs.

(II) Computational Materials is a course designed as an introduction to computational approaches used in modern materials science and engineering, and to provide the hands-on experience in using massively parallel supercomputers and executing popular materials software packages. The main goal is to provide exposure to students to the

growing and highly interdisciplinary field of computational materials science and engineering, through a combination of lectures, hands-on exercises and a series of specifically designed projects. The course is organized to cover different length scales including: atomistic (electronic structure) calculations, molecular dynamics, and phase equilibria modeling. The emerging trends in data driven materials discovery and design are also covered. Particular emphasis is placed on the validation of computational results and recent trends in integrating theory, computations and experiment. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- Module 1: 1. Introduction to computational materials science and engineering
- Module 2: Electronic structure calculations
- Module 3: Molecular dynamics calculations
- Module 4: Materials thermodynamics and phase equilibria modeling

MTGN475. METALLURGY OF WELDING. 2.0 Semester Hrs.
Introduction to welding processes; thermal aspects; selection of filler metals; stresses; stress relief and annealing; pre- and postweld heat treating; weld defects; welding ferrous and nonferrous alloys; weld metal phase transformations; metallurgical evaluation of resulting weld microstructures and properties; and welding tests. Offered every year. Prerequisite: MTGN348. Co-requisite: MTGN475L.
Course Learning Outcomes

- ABET 1, 3, 4

MTGN475L. METALLURGY OF WELDING LABORATORY. 1.0 Semester Hr.
Equivalent with MTGN477,
Experiments designed to supplement the lectures in MTGN475. Offered every year. Co-requisite: MTGN475.
Course Learning Outcomes

- ABET 1,3, 4

MTGN480. ADVANCED WELDING METALLURGY. 3.0 Semester Hrs.
This course will explore microstructural development that occurs during welding. Solidification in the fusion zone as well as solid-state microstructural changes in the heat affected zone will be discussed. We will use the understanding of microstructural changes during welding to interpret cracking mechanisms and unique behaviors of specific alloy systems. The interrelationship between modeling/simulation and experiments will be emphasized. Throughout the course, we will think about how the people to who actually weld (welders) can provide critical insight to solve welding metallurgy problems. Prerequisite: MTGN348. Co-requisite: none.
Course Learning Outcomes

- At the completion of the course, the student will be able to: 1) Describe welding related phenomena with correct terminology 2) Understand how composition affects welding behavior 3) Apply models to predict aspects of microstructure, properties, and performance 4) Evaluate model predictions against experimental results

MTGN497. SUMMER PROGRAMS. 0.0 Semester Hrs.
(S) Summer registration. Repeatable.
Course Learning Outcomes

- n/a

MTGN498. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 0-3 Semester Hr.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). The course topic is generally offered only once. Prerequisite: none. 1 to 3 semester hours. Repeatable for credit under different titles.

MTGN498. SPECIAL TOPICS. 0-3 Semester Hr.

MTGN498. SPECIAL TOPICS. 1-3 Semester Hr.

MTGN498. SPECIAL TOPICS. 1-3 Semester Hr.

MTGN498LA. SPECIAL TOPICS LAB. 1-3 Semester Hr.

MTGN498LB. SPECIAL TOPICS LAB. 1-3 Semester Hr.

MTGN498LC. SPECIAL TOPICS LAB. 1-3 Semester Hr.

MTGN499. INDEPENDENT STUDY. 1-6 Semester Hr.
(I, II, S) Independent advanced-work leading to a comprehensive report. This work may take the form of conferences, library, and laboratory work. Selection of problem is arranged between student and a specific Department faculty-member. Prerequisite: Selection of topic; Independent Study Form must be completed and submitted to Registrar. 1 to 3 semester hours. Repeatable for credit to a maximum of 6 hours.

MTGN499. INDEPENDENT STUDY. 1-6 Semester Hr.

MTGN499. INDEPENDENT STUDY. 1-3 Semester Hr.

MTGN499. INDEPENDENT STUDY. 1-4 Semester Hr.

MTGN499. INDEPENDENT STUDY. 1-3 Semester Hr.

MTGN499. INDEPENDENT STUDY. 1-3 Semester Hr.

MTGN499. INDEPENDENT STUDY. 1-3 Semester Hr.

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Professors

Geoff Brennecka, Department Head, George S. Ansell Distinguished Chair

Kip O. Findley, Director of the Advanced Steel Processing and Products Research Center (ASPPRC), John Henry Moore Chair

Brian P. Gorman

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Suveen N. Mathaudhu, Director of the Center for Advanced Non-Ferrous Structural Alloys (CANFSA)

Emmanuel De Moor

Ryan P. O'Hayre, University Distinguished Professor

Ivar E. Reimanis, Director of the Colorado Center for Advanced Ceramics (CCAC), Herman F. Coors Distinguished Professor of Ceramic Engineering

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