

# Metallurgical and Materials Engineering

## Degrees Offered

- Master of Engineering (Metallurgical and Materials Engineering)
- Master of Science (Metallurgical and Materials Engineering)
- Doctor of Philosophy (Metallurgical and Materials Engineering)

## Program Description

The program of study for the Master or Doctor of Philosophy degrees in Metallurgical and Materials Engineering is selected by the student in consultation with her or his advisor, and with the approval of the Thesis Committee. The program can be tailored within the framework of the regulations of the Graduate School to match the student's interests while maintaining the main theme of materials engineering and processing.

There are three areas of specialization within the Department:

- Physical and Mechanical Metallurgy;
- Physicochemical Processing of Materials; and,
- Ceramic Engineering.

The Department is home to four research centers:

- Advanced Steel Processing and Products Research Center (ASPPRC);
- Center for Advanced Non Ferrous Structural Alloys (CANFSA)
- Center for Welding Joining, and Coatings Research (CWJCR); and,
- Colorado Center for Advanced Ceramics (CCAC).

The Kroll Institute for Extractive Metallurgy (KIEM) and Nuclear Science and Engineering Center (NuSEC) research centers also operate closely with the Department.

A Graduate Certificate is offered by each Department Center – the requirements for the Graduate Certificate are:

1. Be admitted to MME Graduate Certificate Program upon the recommendation of the MME Department.
2. Complete a total of 12 hours of course credits of which only 3 credit hours can be at the 400 level.

The specific courses to be taken are determined by the Graduate Advisor in the Department Center selected by the candidate. A cumulative grade point average of B or better must be maintained while completing these requirements.

## Degree Program Requirements

The program requirements for the three graduate degrees offered by the Department are listed below:

### Master of Engineering Degree

Requirements: A **minimum total of 30.0 credits** consisting of:

Coursework	Credits
Approved Coursework*	18.0 - 26.0
MTGN501	MME GRADUATE SEMINAR ** 1.0

MTGN700	GRADUATE RESEARCH CREDIT: MASTER OF ENGINEERING (or designated design course) ***
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\* 18 of the 26 credits must be taken from the Metallurgy or Materials Science courses. All other course credits can be taken in any department.

\*\* Students are expected to enroll in this seminar every semester, but a maximum of 1 credit may apply toward the degree.

\*\*\* Students can choose to fulfill the NT masters degree requirements by either taking 30 credits, including 3 hours of a "design" course, or with advisor approval, take 25 hours of course credits and have 5 hours devoted to a project; in that case, students will have to defend an engineering report to a 3 person committee.

### Designated Design courses include:

MTGN465	MECHANICAL PROPERTIES OF CERAMICS	3.0
MTGN549	CURRENT DEVELOPMENTS IN FERROUS ALLOYS	3.0
MTGN564	ADVANCED FORGING AND FORMING	3.0
MTGN560	ANALYSIS OF METALLURGICAL FAILURES	3.0

Alternative courses can be substituted with approval from the advisor and department head

### Restrictions:

1. Only three (3) credits of independent coursework, e.g. MTGN599, may be applied toward the degree.
2. Courses taken to remove deficiencies may not be applied toward the degree.

The Master of Engineering Degree can also be obtained as part of the combined undergraduate/graduate degree program.

### Master of Science Degree

Requirements: A **minimum total of 30.0 credits** consisting of:

Coursework	Credits
Approved Coursework*	18.0 - 23.0
MTGN501	MME GRADUATE SEMINAR ** 1.0
MTGN707	GRADUATE THESIS / DISSERTATION RESEARCH CREDIT *** 6.0-11.0

\* Minimum of 18 credits of approved coursework is required. 12 credits must be taken from the Metallurgy or Materials Science courses. All other course credits can be taken in any department.

\*\* Students are expected to enroll in this seminar every semester, but a maximum of 1 credit may apply toward the degree.

\*\*\* 6.0 to 11.0 research credits, to include MTGN707.

### Restrictions:

1. Only three (3) credits of independent coursework, e.g. MTGN599, may be applied toward the degree.
2. Courses taken to remove deficiencies may not be applied toward the degree.

### Additional Degree Requirements:

1. Approval of all courses by the Thesis Committee and the Department Head. (Thesis Committee: consisting of 3 or more members, including the advisor and at least 1 additional member from the Metallurgical and Materials Engineering Department.)
2. Submittal and successful oral defense of a thesis before a Thesis Committee. The thesis must present the results of original scientific research or development.

The Master of Science Degree can also be obtained as part of the combined undergraduate/graduate degree program.

## Doctor of Philosophy Degree

Requirements: A **minimum total of 72.0 credits** consisting of:

Coursework	Credits
Approved Coursework*	36.0 - 48.0
MTGN501	MME GRADUATE SEMINAR ** 1.0
MTGN707	GRADUATE THESIS / DISSERTATION RESEARCH CREDIT *** 24.0-36.0

\* A minimum of 36.0 credits of approved coursework, 24 of which must be in MTGN or MLGN. Credits previously earned for a Master's degree may be applied, subject to approval, toward the Doctoral degree provided that the Master's degree was in Metallurgical and Materials Engineering or a similar field. At least 21.0 credits of approved course work must be taken at the Colorado School of Mines.

All courses and any applicable Master's degree credits must be approved by the Thesis Committee and the Department Head (Thesis Committee consisting of: 4 or more members, including the advisor, at least 2 additional members from the Metallurgical and Materials Engineering Department, and at least 1 member from outside the Department.)

\*\* Students are expected to enroll in this seminar every semester, but a maximum of 1 credit hour may apply toward the degree.

\*\*\*A minimum of 24.0 research credit hours, to include MTGN707.

### Restrictions:

1. Only six (6) credits of independent coursework, e.g. MTGN599, may be applied toward the degree.
2. Courses taken to remove deficiencies may not be applied toward the degree.

### Additional Degree Requirements:

1. Presentation of a Proposal on the Thesis-Research Project to the Thesis Committee.
2. A passing grade on the written and oral Qualifying-Process (Q.P.) Examinations.
3. Presentation of a Progress Report on their Research Project to the Thesis Committee is strongly recommended; this presentation is usually 6 months after successfully completing the Q.P. Examinations and no fewer than 6 weeks before the Defense of Thesis.
4. Submittal and successful oral defense of a thesis before the Thesis Committee. The thesis must present the results of original scientific research or development.

## Prerequisites

The entering graduate student in the Department of Metallurgical and Materials Engineering must have completed an undergraduate program equivalent to that required for the BS degree in: Metallurgical and Materials Engineering, Materials Science or a related field. This undergraduate program should have included a background in science fundamentals and engineering principles. A student, who possesses this background but has not taken specific undergraduate courses in Metallurgical and Materials Engineering, will be allowed to rectify these course deficiencies at the beginning of their program of study.

## Mines' Combined Undergraduate / Graduate Degree Program for Non-Thesis MS and Thesis-Based MS and PhD

Students enrolled in Mines' combined undergraduate/graduate program may double count up to six credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with "B-" or better, not be substitutes for required coursework, and meet all other University, Department, and Program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

## Fields of Research

### Ceramic Research

- Ceramic processing
- Ceramic-metal composites
- Functional materials
- Ion implantation
- Modeling of ceramic processing
- Solid oxide fuel cell materials and membranes
- Transparent conducting oxides

### Coatings Research

- Chemical vapor deposition
- Coating materials, films and applications
- Epitaxial growth
- Interfacial science
- Physical vapor deposition
- Surface mechanics
- Surface physics
- Tribology of thin films and coatings

### Extractive and Mineral Processing Research

- Chemical and physical processing of materials
- Electrometallurgy
- Hydrometallurgy
- Mineral processing
- Pyrometallurgy
- Recycling and recovery of materials
- Thermal plasma processing

## Nonferrous Research

- Aluminum alloys
- High entropy alloys
- Magnesium alloys
- Nonferrous structural alloys
- Shape memory alloys
- Superalloys
- Titanium alloys

## Polymers and Biomaterials Research

- Advanced polymer membranes and thin films
- Biopolymers
- Bio-mimetic and bio-inspired materials engineering
- Calcium phosphate-based ceramics
- Drug delivery
- Failure of medical devices
- Interfaces between materials and tissue
- Living/controlled polymerization
- Organic-inorganic hybrid materials
- Porous structured materials
- Self- and directed-assembly
- Structural medical alloys
- Tissue as a composite material

## Steel Research

- Advanced high strength steels
- Advanced steel coatings
- Carburized steels
- Deformation behavior of steels
- Fatigue behavior of steels
- Microalloyed steels
- Nickel-based steels
- Quench and partitioned steels
- Plate steels
- Sheet steels

## Welding and Joining Research

- Brazing of ultra wide gaps
- Explosive processing of materials
- Laser welding and processing
- Levitation for kinetics and surface tension evaluation
- Materials joining processes
- Pyrochemical kinetics studies using levitation
- Underwater and under oil welding
- Welding and joining science
- Welding rod development
- Welding stress management
- Weld metallurgy
- Weld wire development

## Nuclear Materials Research

- Nuclear materials characterization
- Nuclear materials processing
- Nuclear materials properties

## Experimental Methods

- 3D atom probe tomography
- Atomic force microscopy
- Computer modeling and simulation
- Electron microscopy
- Mathematical modeling of material processes
- Nanoindentation
- Non-destructive evaluation
- X-ray diffraction

## Other Research Areas

- Combustion synthesis
- Corrosion science and engineering
- Failure analysis
- Mechanical metallurgy
- Phase transformation and mechanism of microstructural change
- Physical metallurgy
- Reactive metals properties
- Strengthening mechanisms
- Structure-property relationships

## Courses

### MTGN501. MME GRADUATE SEMINAR. 0.5 Semester Hrs.

(I, II) All full-time MME graduate students must attend the Metallurgical and Materials Engineering seminar. Students must take the Graduate Seminar course every semester that they are enrolled at CSM. At the end of each semester, students are assigned either a satisfactory or unsatisfactory progress grade, based on attendance, until the final semester of the student's degree program, when a letter grade is assigned based on all prior semesters' attendance grades. As a result, while these courses are taken each year, only a maximum of 1.0 hours total of course credit is conferred. Students who have official part-time status are not required to sign up for Graduate Seminar. Attendance of other seminars outside MME can substitute for seminar attendance in MME following course instructor approval. 1 hour lecture; 0.5 hours. Repeatable up to 1 hour.

### MTGN511. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS. 1-3 Semester Hr.

(I) Independent advanced work, not leading to a thesis. This may take the form of conferences, library, and laboratory work. Selection of assignment is arranged between student and a specific Department faculty-member. Prerequisite: Selection of topic. 1 to 3 semester hours. Repeatable for credit under different titles.

### MTGN512. SPECIAL METALLURGICAL AND MATERIALS ENGINEERING PROBLEMS. 1-3 Semester Hr.

(II) Continuation of MTGN511. Prerequisite: Selection of topic. 1 to 3 semester hours. Repeatable for credit under different titles.

**MTGN523. APPLIED SURFACE AND SOLUTION CHEMISTRY. 3.0 Semester Hrs.**

(II) Solution and surface chemistry of importance in mineral and metallurgical operations. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN526. GEL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**

An introduction to the science and technology of particulate and polymeric gels, emphasizing inorganic systems. Interparticle forces. Aggregation, network formation, percolation, and the gel transition. Gel structure, rheology, and mechanical properties. Application to solid-liquid separation operations (filtration, centrifugation, sedimentation) and to ceramics processing. Prerequisite: Graduate Status. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN527. SOLID WASTE MINIMIZATION AND RECYCLING. 3.0 Semester Hrs.**

(II) Industrial case-studies, on the application of engineering principles to minimize waste formation and to meet solid waste recycling challenges. Proven and emerging solutions to solid waste environmental problems, especially those associated with metals. Prerequisites: ESGN500 and ESGN504. 3 hours lecture; 3 semester hours.

**MTGN528. EXTRACTIVE METALLURGY OF COPPER, GOLD AND SILVER. 3.0 Semester Hrs.**

Practical applications of fundamentals of chemical-processing-of-materials to the extraction of gold, silver and copper. Topics covered include: History; Ore deposits and mineralogy; Process Selection; Hydrometallurgy and leaching; Oxidation pretreatment; Purification and recovery; Refinement; Waste treatment; and Industrial examples. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.

**MTGN529. METALLURGICAL ENVIRONMENT. 3.0 Semester Hrs.**

(I) Effluents, wastes, and their point sources associated with metallurgical processes, such as mineral concentration and values extraction? providing for an interface between metallurgical process engineering and the environmental engineering areas. Fundamentals of metallurgical unit operations and unit processes, applied to waste and effluents control, recycling, and waste disposal. Examples which incorporate engineering design and cost components are included. Prerequisites: MTGN334. 3 hours lecture; 3 semester hours.

**MTGN530. ADVANCED IRON AND STEELMAKING. 3.0 Semester Hrs.**

(I) Physicochemical principles of gas-slag-metal reactions applied to the reduction of iron ore concentrates and to the refining of liquid iron to steel. The role of these reactions in reactor design?blast furnace and direct iron smelting furnace, pneumatic steelmaking furnace, refining slags, deoxidation and degassing, ladle metallurgy, alloying, and continuous casting of steel. Prerequisite: DCGN209 or MTGN351. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN531. THERMODYNAMICS OF METALLURGICAL AND MATERIALS PROCESSING. 3.0 Semester Hrs.**

(I) Application of thermodynamics to the processing of metals and materials, with emphasis on the use of thermodynamics in the development and optimization of processing systems. Focus areas will include entropy and enthalpy, reaction equilibrium, solution thermodynamics, methods for analysis and correlation of thermodynamics data, thermodynamic analysis of phase diagrams, thermodynamics of surfaces, thermodynamics of defect structures, and irreversible thermodynamics. Attention will be given to experimental methods for the measurement of thermodynamic quantities. Prerequisite: MTGN351. 3 hours lecture; 3 semester hours.

**MTGN532. PARTICULATE MATERIAL PROCESSING I - COMMINUTION AND PHYSICAL SEPARATIONS. 3.0 Semester Hrs.**

An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in comminution and physical separation. Topics covered include: crushing (jaw, cone, gyratory), grinding (ball, pebble, rod, SAG, HPGR), screening, thickening, sedimentation, filtration and hydrocyclones. Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.

**MTGN533. PARTICULATE MATERIAL PROCESSING II - APPLIED SEPARATIONS. 3.0 Semester Hrs.**

An introduction to the fundamental principles and design criteria for the selection and use of standard mineral processing unit operations in applied separations. Topics covered include: photometric ore sorting, magnetic separation, dense media separation, gravity separation, electrostatic separation and flotation (surface chemistry, reagents selection, laboratory testing procedures, design and simulation). Two standard mineral processing plant-design simulation software (MinOCad and JK SimMet) are used in the course. Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours.

**MTGN535. PYROMETALLURGICAL PROCESSES. 3.0 Semester Hrs.**

(II) Detailed study of a selected few processes, illustrating the application of the principles of physical chemistry (both thermodynamics and kinetics) and chemical engineering (heat and mass transfer, fluid flow, plant design, fuel technology, etc.) to process development. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN536. OPTIMIZATION AND CONTROL OF METALLURGICAL SYSTEMS. 3.0 Semester Hrs.**

Application of modern optimization and control theory to the analysis of specific systems in extractive metallurgy and mineral processing. Mathematical modeling, linear control analysis, dynamic response, and indirect optimum seeking techniques applied to the process analysis of grinding, screening, filtration, leaching, precipitation of metals from solution, and blast furnace reduction of metals. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN537. ELECTROMETALLURGY. 3.0 Semester Hrs.**

(II) Electrochemical nature of metallurgical processes. Kinetics of electrode reactions. Electrochemical oxidation and reduction. Complex electrode reactions. Mixed potential systems. Cell design and optimization of electrometallurgical processes. Batteries and fuel cells. Some aspects of corrosion. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN538. HYDROMETALLURGY. 3.0 Semester Hrs.**

(II) Kinetics of liquid-solid reactions. Theory of uniformly accessible surfaces. Hydrometallurgy of sulfide and oxides. Cementation and hydrogen reduction. Ion exchange and solvent extraction. Physicochemical phenomena at high pressures. Microbiological metallurgy. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).



**MTGN539. PRINCIPLES OF MATERIALS PROCESSING REACTOR DESIGN. 3.0 Semester Hrs.**

(II) Review of reactor types and idealized design equations for isothermal conditions. Residence time functions for nonreacting and reacting species and its relevance to process control. Selection of reactor type for a given application. Reversible and irreversible reactions in CSTR's under nonisothermal conditions. Heat and mass transfer considerations and kinetics of gas-solid reactions applied to fluo-solids type reactors. Reactions in packed beds. Scale up and design of experiments. Brief introduction into drying, crystallization, and bacterial processes. Examples will be taken from current metallurgical practice. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN545. FATIGUE AND FRACTURE. 3.0 Semester Hrs.**

(I) Basic fracture mechanics as applied to engineering materials, S-N curves, the Goodman diagram, stress concentrations, residual stress effects, effect of material properties on mechanisms of crack propagation. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN548. TRANSFORMATIONS IN METALS. 3.0 Semester Hrs.**

(I) Surface and interfacial phenomena, order of transformation, grain growth, recovery, recrystallization, solidification, phase transformation in solids, precipitation hardening, spinoidal decomposition, martensitic transformation, gas metal reactions. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN549. CURRENT DEVELOPMENTS IN FERROUS ALLOYS. 3.0 Semester Hrs.**

(I) Development and review of solid state transformations and strengthening mechanisms in ferrous alloys. Application of these principles to the development of new alloys and processes such as high strength low alloy steels, high temperature alloys, maraging steels, and case hardening processes. Prerequisite: MTGN348. 3 hours lecture; 3 semester hours.

**MTGN551. ADVANCED CORROSION ENGINEERING. 3.0 Semester Hrs.**

(I) Advanced topics in corrosion engineering. Case studies and industrial application. Special forms of corrosion. Advanced measurement techniques. Prerequisite: MTGN451. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN553. STRENGTHENING MECHANISMS. 3.0 Semester Hrs.**

(II) Strain hardening in polycrystalline materials, dislocation interactions, effect of grain boundaries on strength, solid solution hardening, martensitic transformations, precipitation hardening, point defects. Prerequisite: MTGN543 or concurrent enrollment. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN555. SOLID STATE THERMODYNAMICS. 3.0 Semester Hrs.**

(I) Thermodynamics applied to solid state reactions, binary and ternary phase diagrams, point, line and planar defects, interfaces, and electrochemical concepts. Prerequisite: none. 3 hours lecture; 3 semester hours.

**MTGN556. TRANSPORT IN SOLIDS. 3.0 Semester Hrs.**

(I) Thermal and electrical conductivity. Solid state diffusion in metals and metal systems. Kinetics of metallurgical reactions in the solid state. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of even years only.).

**MTGN557. SOLIDIFICATION. 3.0 Semester Hrs.**

(I) Heat flow and fluid flow in solidification, thermodynamics of solidification, nucleation and interface kinetics, grain refining, crystal and grain growth, constitutional supercooling, eutectic growth, solidification of castings and ingots, segregation, and porosity. Prerequisite: none. 3 hours lecture; 3 semester hours. (Fall of odd years only.).

**MTGN560. ANALYSIS OF METALLURGICAL FAILURES. 3.0 Semester Hrs.**

(II) Applications of the principles of physical and mechanical metallurgy to the analysis of metallurgical failures. Nondestructive testing. Fractography. Case study analysis. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.).

**MTGN564. ADVANCED FORGING AND FORMING. 3.0 Semester Hrs.**

(II) Overview of plasticity. Examination and Analysis of working operations of forging, extrusion, rolling, wire drawing and sheet metal forming. Metallurgical structure evolution during working. Laboratory experiments involving metal forming processes. Prerequisites: MTGN445/MLGN505, 2 hours lecture; 3 hours lab, 3 semester hours.

**MTGN565. MECHANICAL PROPERTIES OF CERAMICS AND COMPOSITES. 3.0 Semester Hrs.**

(I) 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. Prerequisites: MTGN445 or MLGN505. 3 hours lecture; 3 semester hours. (Fall of even years only.).

**MTGN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.**

Equivalent with CBEN569,MEGN569,MLGN569,

(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials- science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

**MTGN570. BIOCOMPATIBILITY OF MATERIALS. 3.0 Semester Hrs.**

Introduction to the diversity of biomaterials and applications through examination of the physiologic environment in conjunction with compositional and structural requirements of tissues and organs. Appropriate domains and applications of metals, ceramics and polymers, including implants, sensors, drug delivery, laboratory automation, and tissue engineering are presented. Prerequisites: BIOL110 or equivalent. 3 hours lecture; 3 semester hours.

**MTGN572. BIOMATERIALS. 3.0 Semester Hrs.**

Equivalent with MLGN572,

(I) A broad overview on materials science and engineering principles for biomedical applications with three main topics: 1) The fundamental properties of biomaterials; 2) The fundamental concepts in biology; 3) The interactions between biological systems with exogenous materials. Examples including surface energy and surface modification; protein adsorption; cell adhesion, spreading and migration; biomaterials implantation and acute inflammation; blood-materials interactions and thrombosis; biofilm and biomaterials-related pathological reactions. Basic principles of bio-mimetic materials synthesis and assembly will also be introduced. 3 hours lecture; 3 semester hours.

**MTGN573. COMPUTATIONAL MATERIALS. 3.0 Semester Hrs.**

(II) Computational Materials is a course designed as an introduction to computational approaches and codes used in modern materials science and engineering, and to provide the hands-on experience in using massively parallel supercomputers and 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. Graduate students are expected to successfully complete 4 projects while the undergraduate students are required to finish 3 out of 4 projects. 3 hours lecture; 3 semester hours.

**MTGN580. ADVANCED WELDING METALLURGY. 3.0 Semester Hrs.**

(II) Weldability of high strength steels, high alloys, and light metals; Welding defects; Phase transformations in weldments; Thermal experience in weldments; Pre- and Post-weld heat treatment; Heat affected zone formation, microstructure, and properties; Consumables development. Prerequisite: none. 3 hours lecture; 3 semester hours. (Spring of odd years only.)

**MTGN593. NUCLEAR MATERIALS SCIENCE AND ENGINEERING. 3.0 Semester Hrs.**

(I) Introduction to the physical metallurgy of nuclear materials, including the nuclear, physical, thermal, and mechanical properties for nuclear materials, the physical and mechanical processing of nuclear alloys, the effect of nuclear and thermal environments on structural reactor materials and the selection of nuclear and reactor structural materials are described. Selected topics include ceramic science of ceramic nuclear material, ceramic processing of ceramic fuel, nuclear reaction with structural materials, radiation interactions with materials, the aging of nuclear materials, cladding, corrosion and the manufacturing of fuels elements. Relevant issues in the modern fuel cycle will also be introduced including nuclear safety, reactor decommissioning, and environmental impacts. Prerequisites: Graduate or Senior in good-standing. 3 hours lecture, 3 semester hours. (Fall of even years only.)

**MTGN598. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MTGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MTGN605. ADVANCED TRANSMISSION ELECTRON MICROSCOPY. 2.0 Semester Hrs.**

Introduction to transmission electron microscopy techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: MTGN 505. Co-requisite: MTGN 605L. 2 hours lecture, 2 semester hours.

**MTGN605L. ADVANCED TRANSMISSION ELECTRON MICROSCOPY LABORATORY. 1.0 Semester Hr.**

Specimen preparation techniques and their application to materials characterization. Topics include electron optics, electron-specimen interactions, imaging, diffraction, contrast mechanisms, defect analyses, compositional measurements using energy dispersive x-ray spectroscopy and energy loss spectroscopy, scanning transmission electron microscopy, high angle annular dark field imaging, energy filtered TEM and high resolution phase contrast imaging. Prerequisite: Concurrent enrollment in MTGN 605. 3 hours lab, 1 semester hour.

**MTGN631. TRANSPORT PHENOMENA IN METALLURGICAL AND MATERIALS SYSTEMS. 3.0 Semester Hrs.**

Physical principles of mass, momentum, and energy transport. Application to the analysis of extraction metallurgy and other physicochemical processes. Prerequisite: MATH225 and MTGN461 or equivalent. 3 hours lecture; 3 semester hours.

**MTGN656. ADVANCED ELECTRON MICROSCOPY. 2.0 Semester Hrs.**

Advanced 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. Co-requisite: MTGN656L.

**MTGN656L. ADVANCED ELECTRON MICROSCOPY LABORATORY. 1.0 Semester Hr.**

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. Co-requisite: MTGN656.

**MTGN698. SPECIAL TOPICS IN METALLURGICAL AND MATERIALS ENGINEERING. 6.0 Semester Hrs.**

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

**MTGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.**

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

**MTGN700. GRADUATE RESEARCH CREDIT: MASTER OF ENGINEERING. 1-6 Semester Hr.**

(I, II, S) Research credit hours required for completion of the degree Master of Engineering. Research under the direct supervision of a faculty advisor. Credit is not transferable to any 400, 500, or 600 level courses. However, MTGN 705 credit hours may be transferred, in accordance with the requirements for this (M.E.) degree, by a Master of Science graduate-student who previously accumulated these credit-hours and subsequently opted to change their degree program to a Master of Engineering. Repeatable for credit. Variable: 1 to 6 semester hours.

**MTGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.**

(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

**Professors**

Amy Clarke, Co-Director of the Center for Advanced Non-Ferrous Structural Alloys (CANFSA), John Henry Moore Distinguished Professor

Kip O. Findley

Brian P. Gorman

Michael J. Kaufman, Co-Director of the Center for Advanced Non-Ferrous Structural Alloys (CANFSA)

Jeffrey C. King

Suveen N. Mathaudhu

Ryan O'Hayre

Ivar E. Reimanis, Department Head, George S. Ansell Distinguished Chair

Angus A. Rockett

John G. Speer, Director of the Advanced Steel Processing and Products Research Center (ASPPRC), American Bureau of Shipping Endowed Chair in Metallurgical and Materials Engineering

**Associate Professors**

Geoff L. Brenneka, Director of the Colorado Center for Advanced Ceramics (CCAC) and Co-Director of the Alliance for the Development of Additive Processing Technologies (ADAPT), Herman F. Coors Distinguished Professor of Ceramic Engineering

Kester Clarke, Forging Industry Educational and Research Foundation Professor

Emmanuel De Moor

Jeffrey C. King

Corinne E. Packard

Vladan Stevanovic

Zhenzhen Yu, Director of the Center for Welding, Joining and Coatings Research (CWJCR)

**Assistant Professors**

Megan Holtz

Jihye Kim

Jonah Klemm-Toole

Eve Mozur

Anna Staerz

**Teaching Professors**

Gerald Bourne, Associate Department Head, Charles F. Fogarty Limited Professorship

Kimberly Scott

**Research Faculty**

Corby G. Anderson

Lawrence Cho

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