MSE 4002 Syllabus
Ceramic Materials, Properties, Processing, and Applications

Fall Semester 2026
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Course Description

Properties, processing, and applications of the industrially and technically important ceramic materials. Traditional and oxide ceramics are explored in addition to glass and nonoxide ceramics.

Course Learning Objectives

Upon successful completion of this course, you should be able to:

- Categorize ceramics based on their ionic structure or silica backbone. Describe the structure, processing and properties of triaxial porcelains, concretes, and refractories.
- Use random network theory to describe the glass forming tendency of various oxide components and predict properties such as coefficient of thermal expansion and index of refraction. Understand the operation of industrial glass forming operations, from raw materials, furnace design, and forming methods (e.g. bottle and sheet glass). Be able to describe the optical properties of glass and the principles of fiber optics.
- The characterization tools to evaluate ceramic powders, open and closed porosity, and deflocculation of ceramic aqueous suspensions will be understood. Comprehension will be demonstrated for green body formation methods such as pressing, extrusion, injection molding, and 3D printing. From this methods to optimize thermolysis and sintering to form net-shape bodies of optimum will be mastered.
- A sampling of the structure, processing, and properties of high-performance ceramics, e.g. alumina, stabilized zirconia, silicon nitride, silicon carbide, and boron carbide, for applications in refractories, bearings, turbine engines, and armor, will be understood.

Required Course Materials

Printed and bound notes will be provided. This is the only required resource for the class.

Policies and Etiquette

- All lectures will be live during the class hour, and not recorded. Students are encouraged to email the professor with questions; video conferencing or in-person meetings with individuals and study groups are encouraged and may be set up by appointment. Missed classes or exams may be excused (at the Professor's discretion) for reasons of health, professional or sports travel, so long as requested by email in advance.
- It is hoped that the classroom environment is one of learning and interaction. There will be certain pause points during the lecture in which questions are invited, which include requests to repeat portions of the lecture. All students should feel welcome to raise questions during the lecture, preferably with no students remaining silent for the entirety of the semester and no students who overwhelmingly dominate the discourse.

Grading Policy

Grading will be based on attendance (15%) and exams (85%). All grades will be based on a 90 and above is an A, 80-89 is a B,... scale, after a curve is applied.

Description of Graded Components

Attendance: The lecture hour will consist of presentation of the content to be covered that day, answers to student questions, and students answering the Professor's questions to review and refine understanding of the lecture. To be marked as present, students are expected to be attentive (no distractions such as texting), sit in designated seating, actively participate, and make a good-faith effort to answer questions. All electronic devices need to be put away; however, students may audio record the lectures using their phones or other audio devices. Students who are more than five minutes late to class will be counted as absent. Grading: 0-2 missed classes = 100, 3 missed class = 90, 4 missed classes = 80, $\cdots$.

Exams: Six exams will be given during the class hour and a seventh exam will be given during the final exam period; see the Course Schedule (Table 1) for dates. Students are responsible for information in the hand-written notes, figures and figure captions, and what is said in the lectures that supplements the notes. Exams are closed-notes; answers are hand-written into blue books; these, along with the question sheets are to be handed in at the end of the exam. All exams are equally weighted. After a curve is applied, exams are on a 90-100% = A, 80-89% = B, $\cdots$, basis.

Students may appeal the grading of exams if it is believed a mistake in grading has occurred, or more explanation is requested as to why more credit was not given. The student should email Professor Speyer, who will forward it to the graders for evaluation. They will respond with either corrected grading or a further explanation for why the requested credit was not awarded. Students should not interact directly with the graders.

Course Topics

1. CLASSICAL CERAMICS
   (a) Crystal Structures of Largely Ionic Compounds (Speyer Ch1-2): A. Radius Ratios; B. Ionic Structures; C. Multiple Cation Ionic Structures.
   (b) Mineralogy and Crystal Structures of Largely Covalent Structures (Speyer Ch1-2, Frye Ch7, Klein Ch14-15, Meyers, Considine): A. Minerology; B. Igneous Rock; C. Pegmagtites and Gemstones; D. Sedimentary Minerals and Rocks.
   (c) Triaxial Porcelains (Norton2 Ch3-5, Worrall, Norton1 Ch4-5, ASM 943-952, Meyers): A. Clay Deposits; B. Transformations During Heat-treatment of Clays; C. The Three Components of Porcelain; D. Workability of a Triaxial Porcelain Mixture; F. Forming Methods; G. Firing of Triaxial Porcelains; H. Other Whitewares.
   (d) Glazes and Porcelain Enamels (Norton1 Ch19-28, Norton2 Ch7-10,15,16,18, CeramFabProc Ch4): A. Glazes; B. Porcelain Enamels.
   (e) Plaster, Cement, and Concretes (Yanagita 3.4.5, CeramFabProc Ch3, ASM p918-924, Gani, Young Ch11,12): A. Plaster; B. Cement; C. Mortars; D. Concrete; E. Asphalt Concrete.
   (f) Refractories (Norton1 Ch29, Norton3, ASM p894-917, Lee-Rainforth Ch8, Schacht, Pye p545-61): A. Silica Refractories; B. Aluinosilicate Refractories; C. MgO-based Refractories; D. Carbon-containing Refractories; E. Fusion Cast Refractories; F. Refractory Applications.
2. GLASS (Speyer Ch6)
   (a) Fused Silica
   (b) Glass-Forming Compositions: A. Sodium-silicate Random Network; B. CaO-SiO_2 Glass; C. Na_2O-CaO-SiO_2 Glass; D. Zachariasen's Rules; E. Network Formers; Intermediates, and Modifiers; F. Exceptions to Zachariasen's Rules.
   (c) Composition-Property Relations: A. Sodium-silicate Glass; B. Effect of Choice of the Alkali Element; C. Durability and Conductivity; D. The Mixed Alkali Effect; E. The Borate Anomaly; F. Soda-lime Glass; G. Borosilicate Glass; H. Alkali-lead Glass; I. Solder Glass; J. Fiberglass; K. Summary.
   (d) Temperature-Related Behavior: A. Viscosity; B. The Glass Transition Temperature; C. Stresses in Glass.

Table 1: Course Schedule

Date	Event	Sections	Note Pages
August 24	Lecture 1	1(a)A-C, 1(b)A	**1**. 1-14
August 26	Lecture 2	1(b)B-D	**1**. 14-40
August 28	Lecture 3	1(b)D, 1(c)A-C	**1**. 40-46
August 31	Lecture 4	1(c)D-H	**1**. 46-57
September 2	Review Session	-	-
September 4	Exam 1	-	-
September 9	Lecture 5	1(d)A-B	**1**. 58-67
September 11	Lecture 6	1(e)A-D	**1**. 67-83
September 14	Lecture 7	1(e)D-E, 1(f)A-B	**1**. 83-90
September 16	Lecture 8	1(f)C-F	**1**. 91-111
September 18	Review Session	-	-
September 21	Exam2	-	-
September 23	Lecture 9	2(a), 2(b)A-F	**2**. 1-10
September 25	Lecture 10	2(c)A-I	**2**. 11-19
September 28	Lecture 11	2(c)J-K, 2(d)A-C, 2(e)A-C	**2**. 20-30
September 30	Lecture 12	2(f), 2(g), 2(h)A-C	**2**. 30-41
October 2	Review Session	-	-
October 7	Exam3	-	-
October 9	Lecture 13	2(h)D-H, 2(i)A-B	**2**. 41-53
October 12	Lecture 14	2(j)A-D	**2**. 53-58
October 14	Lecture 15	2(j)E-G	**2**. 58-68
October 16	Lecture 16	3(a)A-F	**3**. 1-9
October 19	Review Session	-	-
October 21	Exam 4	-	-
October 23	Lecture 17	3(a)G-I	**3**. 9-18
October 26	Lecture 18	3(a)I-J, 3(b)A-B	**3**. 19-26
October 28	Lecture 19	3(c)A-C	**3**. 26-32
October 30	Lecture 20	3(c)D-F, 3(d)A-B	**3**. 32-41
November 2	Review Session	-	-
November 4	Exam 5	-	-
November 6	Lecture 21	3(d)B-C	**3**. 42-50
November 9	Lecture 22	3(d)D, 3(e)A	**3**. 51-58
November 11	Lecture 23	3(e)B	**3**. 88-65
November 13	Lecture 24	3(e)C-D, 4(a)A-C	**3**. 66-70, **4**. 1-5
November 16	Review Session	-	-
November 18	Exam 6	-	-
November 20	Lecture 25	4(a)D 4(b)A-C	**4**. 6-13
November 23	Lecture 26	4(b)D-G	**4**. 13-20
November 30	Lecture 27	4(c)A-D	**4**. 20-33
December 2	Lecture 28	4(d)A-D, 4(e)A-D	**4**. 33-46
December 4	Lecture 29	4(f)A-D, 4(g)A-H	**4**. 47-56
TBD	Final Exam	-	-

(e) Strengthening of Glass: A. Primer on Brittle and Ductile Fracture; B. Fracture of Glass; C. Strengthening Processes.

(f) Phase-Separated Glass

(g) Glass-Ceramics

(h) Commercial Glass Melting (Pye p237-327, ASM p386-393): A. Glass Melting Tanks; B. Melter Characteristics; C. Raw Materials; D. Melting; E. Batch Particle Size; F. Accelerating Melting; G. Refining; H. Homogenization.

(i) Glass Forming: A. Shaped Glass; B. Sheet Glass.

(j) Optical Properties of Glass: A. Absorption; B. Refraction and Dispersion; C. Total Internal Reflection; D. Anti-reflective Coating; E. Optical Fibers (ASM 409-17); F. Colored Glasses; G. Photochromic Glasses.

3. CERAMIC PROCESSING

(a) Powder Characterization (Reed Ch 17-20, Onada Ch 11, ASM p75-82): A. Screens; B. Microscopy; C. Sedimentation; D. Coulter Counters; E. Laser Diffraction; F. X-ray Line Broadening; G. Log-normal Particle Size Distribution; H. Surface Area; I. Density; J. Porosity–Mercury Intrusion Porosimetry.

(b) Particle Packing and Communition (Reed Ch13, Onada Ch26): A. Particle Packing; B. Communition.

(c) Ceramic Suspensions (Atkins p 122, Rahaman Ch4, ASM p153-160): A. Purifying Water; B. Acids Bases, and pH in Aqueous Solutions; C. Suspensions of Colloidal Particles in Water; D. Steric Stabilization; E. Electrosteric Stabilization; F. Consolidated Colloids.

(d) Ceramic Forming (Reed Ch9-12,21-25, Rahaman Ch6, German-Bose): A. Slip Casting; B. Pressing; C. Extrusion; D. Injection Molding.

(e) Thermal Processing (Reed Ch27,29, Kingery Ch10, German2, Lee-Rainforth p33-54, ASM p186-192, p194-201): A. Binder Extraction; B. Solid-state Sintering; C. Liquid-phase Sintering; D. Pressure-assisted Sintering.

4. HIGH-PERFORMANCE CERAMICS

(a) Alumina (Lee-Rainforth Ch5): A. Alumina Powder Production; B. Liquid-phase Sintered Alumina; C. Solid-state Sintered Alumina; D. Single Crystal Growth–Sapphire and Ruby.

(b) Zirconia (Lee-Rainforth Ch6, ASM p775): A. Synthesis; B. Polymorphs; C. Fully-stabilized Zirconia; D. Partially-stabilized Zirconia; E. Tetragonal Zirconia Polycrystals; F. Compressive Surface Layers; G. Zirconia-toughened Alumina.

(c) Silicon Nitride (Lee-Rainforth Ch7, ASM p812-20): A. Structure; B. Powder Synthesis; C. Fabrication; D. Applications.

(d) Silicon Carbide (Lee-Rainforth Ch7): A. Structure; B. Synthesis; C. Fabrication; D. Applications.

(e) Ceramic Matrix Composites (Madsen): A. Turbine Engines; B. Silicon Carbide Fibers; C. Melt-infiltrated Ceramic Matrix Composites; D. Mechanical Behavior of CMC's.

(f) Boron Carbide: A. Powder Synthesis; B. Phase Equilibria, Structure, and Properties; C. Densification; D. Application—Control Rods for Nuclear Reactors.

(g) Ceramic Armor (Hazell1, Hazell2, Crouch): A. Bullets; B. Personal Armor; C. History of Ceramic Armor; D. Purpose of Ceramic and Backing; E. Dwell, F. Shatter Gap; G. Backing, F. Confinement; H. Choice of Ceramic.

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Any student suspected of cheating or plagiarism on a quiz, exam, or assignment will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations.

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If you are a student with learning needs that require special accommodation, contact the Office of Disability Services (404-894-2563) as soon as possible to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail me as soon as possible in order to set up a time to discuss your learning needs.

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At Georgia Tech, we believe that it is important to strive for an atmosphere of mutual respect, acknowledgment, and responsibility between faculty members and the student body. The Student-Faculty Expectations articulate some basic expectations that you can have of me and that I have of you. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, I encourage you to remain committed to the ideals of Georgia Tech while in this class.