TO: The Faculty of the College of Engineering
FROM: Faculty of the School of Aeronautics and Astronautics
RE: New Graduate Course, AAE 64800 Modeling Damage and Strengthening Mechanisms in Materials

The faculty of the School of Aeronautics and Astronautics have approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

Course no. **AAE 64800 Modeling Damage and Strengthening Mechanisms in Materials**
Terms offered Fall, Lecture 3, Lab 0, Cr. 3.

Description: The usage of materials is the backbone of engineering practice. Yet, advances in materials have stagnated due to overly conservative approaches, trial-and-error testing, and long qualification times. Material modeling offers tremendous opportunities to address these issues. This class offers advanced modeling strategies at the intersection of mechanics and materials science for both polycrystalline and composite materials. The course topics are defined as follows: First, advanced micromechanics analysis of modern engineering materials with emphasis on relating elastic microstructural phenomena to the mechanics of material behavior, via the Eshelby inclusion problem and its application to fiber reinforced composites. Second, classical plasticity is summarized via phenomenological and mathematical formulation of the constitutive laws, including yielding, yield surface; von Mises, Tresca yield criteria; Drucker's stability postulate; strain or work hardening, normality rule, perfect plasticity, and stress-strain law. Third, crystal plasticity is discussed, specifically physical and mathematical foundation for plasticity in crystalline materials, with a detailed description of the Bishop and Hill implementation of the Taylor model for deformation of polycrystals. Lastly, concepts of dislocations leading to strengthening mechanisms in metals are discussed: (i) by studying the anisotropy of material and elastoplastic properties at crystal level, microstructural basis for deformation in metals, polymers, and ceramics and (ii) failure mechanisms and toughening in metals, with primary emphasis on work/strain hardening, solid solution hardening, precipitate hardening, and grain boundaries. The course will be comprised of three projects, where the student chooses the topic of the third and final project.

Reason: The course is beneficial to a wide range of students interested in material modeling and to distinguish Purdue as a leader in the field of material modeling. In the previous two times this course was offered, it has been taken by students in the following schools: AAE, CE, IE, MSE, and ME. This course has limited overlap with other courses offered at Purdue (only ME 559 and CE 689 are remotely similar, yet the topics covered in this course are quite distinct, as the instructors have discussed course topics).

Tom Shih, J. William Uhrig and Anastasia Vournas Head and Professor of Aeronautics and Astronautics
School of Aeronautics and Astronautics

Office of the Registrar
FORM 40G REV. 8/16

PURDUE UNIVERSITY
REQUEST FOR ADDITION, EXPIRATION, OR REVISION OF A GRADUATE COURSE (50000-60000 LEVEL)

DEPARTMENT: AAE   EFFECTIVE SESSION: Fall 2017

INSTRUCTIONS: Please check the items below which describe the purpose of this request.

- [x] 1. New course with supporting documents (complete proposal form)
- [ ] 2. Add existing course offered at another campus
- [ ] 3. Expiration of a course
- [ ] 4. Change in course number
- [ ] 5. Change in course title
- [ ] 6. Change in course credit/type
- [ ] 7. Change in course attributes
- [ ] 8. Change in instructional hours
- [ ] 9. Change in course description
- [ ] 10. Change in course requisites
- [ ] 11. Change in semesters offered
- [ ] 12. Transfer from one department to another

PROPOSED:
Subject Abbreviation: AAE
Course Number: 64800
Long Title: Modeling Damage and Strengthening Mechanisms in Materials
Short Title: Mdlg Damage Strength Mech Mat
Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

EXISTING:
Subject Abbreviation: AAE
Course Number: 69000

TERMS OFFERED
Check All That Apply:
- [ ] Fall
- [x] Spring
- [ ] Summer

CAMPUS(ES) INVOLVED
- [ ] Calumet
- [ ] Cont Ed
- [ ] Ft. Wayne
- [ ] Indianapolis
- [ ] N. Central
- [ ] Tech Statewide
- [x] W. Lafayette

CREDIT TYPE
1. Fixed Credit: Cr. Hrs. 3
2. Variable Credit Range:
   Minimum Cr. Hrs ____
   (Check One) To [ ] Or [ ]
   Maximum Cr. Hrs ____
3. Equivalent Credit: Yes [ ] No [x]
4. Thesis Credit: Yes [ ] No [x]

COURSE ATTRIBUTES: Check All That Apply
1. Pass/Not Pass Only [ ]
2. Satisfactory/Unsatisfactory Only [ ]
3. Repeatable [ ]
   Maximum Repeatable Credit: [ ]
4. Credit by Examination [ ]
5. Fees [ ] Coop [ ] Lab [ ] Rate Request
   Include comment to explain fee
6. Registration Approval Type
   Department [ ] Instructor [ ]
7. Variable Title [ ]
8. Honors [ ]
9. Full Time Privilege [ ]
10. Off Campus Experience [ ]

Schedule Type	Minutes Per Mtg	Meetings Per Week	Weeks Offered	% of Credit Allocated
Lecture	75	2	15	100
Recitation				
Presentation				
Laboratory				
Lab Prep				
Studio				
Distance				
Clinic				
Experiential				
Research				
Ind. Study				
Pract/Observ				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS): (Note: If description will not fit in space provided, please create a separate document and attach it to this form.)

See attached

*COURSE LEARNING OUTCOMES: (Note: If course learning outcomes will not fit in space provided, please create a separate document and attach it to this form.)

See attached

Calumet Department Head	Date	Calumet School Dean	Date	Calumet Director of Graduate Studies	Date
Fort Wayne Department Head	Date	Fort Wayne School Dean	Date	Fort Wayne Director of Graduate Studies	Date
Indianapolis Department Head	Date	Indianapolis School Dean	Date	IUPUI Associate Dean for Graduate Education	Date
North Central Department Head	Date	North Central School Dean	Date	North Central Director of Graduate Studies	Date
[signature] West Lafayette Department Head	9/6/17 Date	West Lafayette College/School Dean	Date	Date Approved by Graduate Council	Date
Graduate Area Committee Convener	Date	Graduate Dean	Date	Graduate Council Secretary	Date
				West Lafayette Registrar	Date

OFFICE OF THE REGISTRAR

Grad Form 40G must include the Graduate Council's supporting document, which is available at http://www.purdue.edu/registrar/forms/form_40_Intro.html

Course Description

The usage of materials is the backbone of engineering practice. Yet, advances in materials have stagnated due to overly conservative approaches, trial-and-error testing, and long qualification times. Material modeling offers tremendous opportunities to address these issues. This class offers advanced modeling strategies at the intersection of mechanics and materials science for both polycrystalline and composite materials. The course topics are defined as follows: First, advanced micromechanics analysis of modern engineering materials with emphasis on relating elastic microstructural phenomena to the mechanics of material behavior, via the Eshelby inclusion problem and its application to fiber reinforced composites. Second, classical plasticity is summarized via phenomenological and mathematical formulation of the constitutive laws, including yielding, yield surface; von Mises, Tresca yield criteria; Drucker's stability postulate; strain or work hardening, normality rule, perfect plasticity, and stress-strain law. Third, crystal plasticity is discussed, specifically physical and mathematical foundation for plasticity in crystalline materials, with a detailed description of the Bishop and Hill implementation of the Taylor model for deformation of polycrystals. Lastly, concepts of dislocations leading to strengthening mechanisms in metals are discussed: (i) by studying the anisotropy of material and elastoplastic properties at crystal level, microstructural basis for deformation in metals, polymers, and ceramics and (ii) failure mechanisms and toughening in metals, with primary emphasis on work/strain hardening, solid solution hardening, precipitate hardening, and grain boundaries. The course will be comprised of three projects, where the student chooses the topic of the third and final project.

Student Learning Outcomes

Ability to express displacement field for an arbitrary elliptical inclusion via a Green's function.
Ability to prove the stress/strain fields within inclusion is uniform.
Ability to calculate Eshelby interaction tensor for arbitrary shape inclusion.
Ability to express the stress/strain fields external to the inclusion.
Ability to implement Eshelby problem via Mori-Tanaka approach and apply to stiffness of composites.
Ability to express interaction energy of inclusion.
Ability to understand physical basis of plasticity.
Ability to express yield surface and associated criteria via stress invariants and on the Pi-plane.
Ability to express flow rules for evolution of the yield surface and implement into principal of virtual velocities.
Ability to express convexity and normality constraints.
Ability to express crystal orientation as a series of rotations and express via a pole figure representation.
Ability to identify texture of materials
Ability to resolve shear stress on slip systems during deformation of single crystals and calculate the velocity gradient.
Ability to apply equilibrium and compatibility constraints to plastic flow of polycrystalline materials.
Ability to calculate the Taylor factor, geometric hardness of a polycrystalline material.
Ability to express grain orientation evolution, via an exponential mapping.

Ability to implement the Taylor model within a Bishop and Hill implementation to express texture evolution of polycrystalline materials.
Ability to understand and express kinetics (strain rate and temperature) into deformation via thermodynamic expressions.
Ability to model work hardening in crystalline materials.
Ability to understand the physical origins and model incompatibilities.
Ability to define grain boundary structure and their affect on mechanical behavior.
Ability to apply concepts learned from this class into a research project of the student's choice.

Detailed Graduate Course Proposal for Academic Review

Note: The detailed course proposal is intended for academic review by the appropriate area committee of the Graduate Council. It supplements the Form 40G that is intended for administrative review of the Graduate School and Registrar.

To: Purdue University Graduate Council

From: Faculty Member: Michael D. Sangid
Department: School of Aeronautics and Astronautics
Campus: West Lafayette

Date: January 30, 2017

Subject: Proposal for New Graduate Course

Contact for information if questions arise:
Name: Michael D. Sangid
Phone: 40146
Email: msangid@purdue.edu
Address: ARMS 3329

Course Number: AAE64800
Course Title: Modeling Damage and Strengthening Mechanisms in Materials
Short Title: Mdlg Damage Strength Mech Mat

Course Description:

This course is intended to be a graduate level course, which focuses on modeling at the microstructure level of primarily metals but also composites. The course topics and modules are defined as follows:

I. Eshelby inclusion problem (1/4 Class)
   - Advanced micromechanics analysis of modern engineering materials with emphasis on relating elastic microstructural phenomena to the mechanics of material behavior.

Project 1: Application to fiber reinforced composites – Mori-Tanaka implementation

II. Overview of classical plasticity (1/4 Class)
   - Phenomenological and mathematical formulation of the constitutive laws of plasticity.
   - Yielding, yield surface; von Mises, Tresca yield criteria; Drucker's stability postulate; strain or work hardening, normality rule, perfect plasticity, and stress-strain law

III. Crystal plasticity (1/4 Class)
   - Physical and mathematical foundation for plasticity in crystalline materials, with application to deformation processes.

Project 2: Bishop and Hill implementation in Taylor problem for deformation of polycrystals

IV. Concepts of dislocations leading to strengthening mechanisms in metals (1/4 class)

- Study of anisotropy of material and elastoplastic properties at crystal level, microstructural basis for deformation in metals, polymers, and ceramics.
- Failure mechanisms and toughening in metals, with primary emphasis on work/strain hardening, solid solution hardening, precipitate hardening, and grain boundaries.

Project 3: The topic of this project must be relevant to this class and discussed with the instructor. Students are required to give a class presentation (see note above concerning projects) and turn in a report. Although it is helpful to choose a topic relevant to your research, this work cannot be completed prior to this semester or used to satisfy another requirement.

CS&E Program: This class is listed as a Relevant Course to count towards the requirements of the CS&E Program.

A. Justification for the Course

Justification of the need for the course

The usage of materials is the backbone of engineering practice. Yet, advances in materials have stagnated due to overly conservative approaches, trial-and-error testing, and long qualification times. Material modeling offers tremendous opportunities to address these issues. This class offers advanced modeling strategies at the intersection of mechanics and materials science. The course is beneficial to a wide range of students interested in material modeling and to distinguish Purdue as a leader in the field of material modeling. In the previous two times this course was offered, it has been taken by students in the following schools: AAE, CE, IE, MSE, and ME. This course has limited overlap with other courses offered at Purdue (only ME 559 and CE 689 are remotely similar, yet the topics covered in this course are quite distinct, as the instructors have discussed course topics).

Justification that course will be taught at a graduate level

- The course is being offered at the 600-level. It has been offered two times, each time with enrollment of ~15 students.
- Advanced (graduate level) texts and relevant journal papers are used throughout this course.
- The codes developed through the project are high level that will be useful to a wide range of research projects.
- At the end of the course, the students will demonstrate learning outcomes that are indicative of graduate level concepts.

Justification of the demand for the course

- Anticipated enrollment
    - Graduate 20
    - Graduate (distance) 10

Justification for online delivery

In future years, this course will be offered online, due to demand by distance students. The first online delivery is expected Spring of 2020. The course is appropriate for online delivery and interactions with distance students.

B. Learning Outcomes and Methods of Assessment

Learning Outcomes	Assessment Methods
Ability to express displacement field for an arbitrary elliptical inclusion via a Green's function.	• Class discussion and HW#1.
Ability to prove the stress/strain fields within inclusion is uniform.	• Class discussion and HW#1.
Ability to calculate Eshelby interaction tensor for arbitrary shape inclusion.	• Class discussion and HW#1.
Ability to express the stress/strain fields external to the inclusion.	• Class discussion.
Ability to implement Eshelby problem via Mori-Tanaka approach and apply to stiffness of composites.	• Individual Project #1.
Ability to express interaction energy of inclusion.	• Class discussion.

Ability to understand physical basis of plasticity.	• Class discussion.
Ability to express yield surface and associated criteria via stress invariants and on the Pi-plane.	• Class discussion and HW#2.
Ability to express flow rules for evolution of the yield surface and implement into principal of virtual velocities.	• Class discussion and HW#2.
Ability to express convexity and normality constraints.	• Class discussion and HW#2.
Ability to express crystal orientation as a series of rotations and express via a pole figure representation.	• Class discussion and HW#3.
Ability to identify texture of materials	• Class discussion
Ability to resolve shear stress on slip systems during deformation of single crystals and calculate the velocity gradient.	• Class discussion and HW#4.
Ability to apply equilibrium and compatibility constraints to plastic flow of polycrystalline materials.	• Class discussion and HW#4.
Ability to calculate the Taylor factor, geometric hardness of a polycrystalline material.	• Class discussion and HW#4.
Ability to express grain orientation evolution, via an exponential mapping.	• Individual Project #2.
Ability to implement the Taylor model within a Bishop and Hill implementation to express texture evolution of polycrystalline materials.	• Individual Project #2.
Ability to understand and express kinetics (strain rate and temperature) into deformation via thermodynamic expressions.	• Class discussion and HW#5.
Ability to model work hardening in crystalline materials.	• Class discussion and HW#5.
Ability to understand the physical origins and model incompatibilities.	• Class discussion and HW#5.
Ability to define grain boundary structure and their affect on mechanical behavior.	• Class discussion and HW#5.
Ability to apply concepts learned from this class into a research project of the student's choice.	• Individual Project #3.

Final Grading Criteria

Assessment Methods (should match method types in the previous table)	Weight Toward Final Course Grade
Projects (three)	75%
Homework	25%

Methods of Instruction

Class Hrs/Week	Method of Instruction	Contribution to Outcomes
3	Lecture	Each class includes a lecture given by a combination of chalkboard and PowerPoint notes. This lecture is meant to be an open discussion as students can engage with questions.
2	Independent Study	Students are assigned reading each week either in the form of textbook or journal papers.
0.25	Seminar	Two or three times a semester, students are encouraged to go to seminars that are aligned with course subjects.

C. Prerequisite(s)

- An entry-level class in solid mechanics (such as elasticity or continuum mechanics) that covers indicial notation and basic equilibrium/ compatibility conditions.

D. Course Instructor(s)

Name	Rank	School, dept., or center	Graduate Faculty or expected date
Michael D. Sangid	Assistant Professor	AAE	Yes (C8403)

Michael D. Sangid received his B.S. (2002) and M.S. (2005) in Mechanical Engineering from the University of Illinois at Urbana-Champaign (UIUC). After his Master's degree, Dr. Sangid spent two years working in Indianapolis, IN for Rolls-Royce Corporation, specializing in material characterization, fatigue, fracture, and creep of high temperature aerospace materials before resuming his education in 2007. He received his PhD in Mechanical Engineering from UIUC in 2010 and continued as a post-doctoral associate. In the spring of 2012, Dr. Sangid started as an assistant professor at Purdue University in the School of Aeronautics and Astronautics with a courtesy appointment in Materials Engineering, where he continues his work on building computational materials models for failure of structural materials with experimental validation efforts focused at characterization of the stress/strain evolution at the microstructural scale during in situ loading. He is a recipient of the TMS Young Leaders Award, the ASME Orr Award, TMS Early Career Faculty Fellow, and the AFOSR, ONR, and DARPA Young Investigator/Faculty Awards. He is currently the Purdue lead in the Lightweight Innovations for Tomorrow (LIFT) Institute and the Advanced Analytics thrust of the Digital Manufacturing and Design Innovation Institute (DMDII).

E. Course Schedule or Outline

I.	Elasticity and Eshelby Inclusion Problem		
	A. Mechanics Preliminaries		
		1. Indicial notation (optional)	1 hour
		2. Elasticity basics	1.5 hours
	B. Eshelby inclusions		
		1. Description of Eshelby formulation	1.5 hours
		2. Interior stress/strain fields of inclusion	1.5 hours
		3. Example for spherical inclusion	1.5 hours
		4. Exterior stress/strain fields of inclusion	1.5 hours
		5. Mori-Tanaka implementation	1.5 hours
		6. Application to composites	1.5 hours
		7. Energy of inclusion	1.5 hours
II.	Plasticity		
	A. Classical Plasticity		
		1. Introduction to plasticity	1.5 hours
		2. Pi-plane and yield surface	1.5 hours
		3. Yield conditions	1.5 hours
		4. Flow rules	1.5 hours
		5. Normality and convexity	1.5 hours
	B. Crystal Plasticity		
		1. Texture introduction	2 hours
		2. Single crystal plasticity	1.5 hours
		3. Polycrystalline plasticity	3 hours
		4. Exponential mapping of grain rotation	1.5 hours
		5. Bishop-Hill deformation modeling	3 hours
III.	Strengthening Mechanisms		
		1. Kinetics	3 hours
		2. Work hardening	1.5 hours
		3. Strain incompatibility	3 hours
		4. Grain boundaries	1.5 hours
		5. Special topics (based on student interest)	3 hours
		6. Project III consultation/presentations	8 hours

F. Reading List (including course text)

Primary Reading List

- Micromechanics of Defects in Solids, by T. Mura, Springer, 2nd Edition, ISBN – 9024732565

Secondary Reading List

- The Mechanics of Crystals and Textured Polycrystals, William F. Hosford, Oxford
- Micromechanics: Overall Properties of Heterogeneous Materials, by S. Nemat-Nasser, M. Hori, Elsevier
- Crystals, Defects, and Microstructure, Rob Phillips, Cambridge
- The Mathematical Theory of Plasticity, R. Hill, Oxford
- Introduction to Texture Analysis, O. Engler, V Randle, CRC Press
- Strengthening Mechanisms in Crystal Plasticity, A.S. Argon, Oxford
- Mechanical Behaviour of Engineering Materials: Metals, Ceramics, Polymers, and Composite, Roesler, Joachim, Harders, Harald, Baeker, Martin; Springer, http://www.springer.com/materials/mechanics/book/978-3-540-73446-8
- Theory of Elasticity, S.P. Timoshenko, N. Goodier, McGraw

G. Library Resources

Name of journal, proceedings, book, video, or other acquisition	Already in Libraries?
Micromechanics of Defects in Solids, by T. Mura, Springer	Yes
The Mechanics of Crystals and Textured Polycrystals, William F. Hosford, Oxford	Yes
Micromechanics: Overall Properties of Heterogeneous Materials, by S. Nemat-Nasser,	Yes
Crystals, Defects, and Microstructure, Rob Phillips, Cambridge	Yes
The Mathematical Theory of Plasticity, R. Hill, Oxford	Yes
Introduction to Texture Analysis, O. Engler, V Randle, CRC Press	Yes
Strengthening Mechanisms in Crystal Plasticity, A.S. Argon, Oxford	Yes
Mechanical Behaviour of Engineering Materials: Metals, Ceramics, Polymers, and Composites, Joachim Roesler, Harald Harders, Martin Baeker, Springer.	Yes
Theory of Elasticity, S.P. Timoshenko, N. Goodier, McGraw	Yes

H. Course Syllabus (now required)

Example shown from Spring 2016.

AAE 690 Modeling Damage and Strengthening Mechanisms in Materials

Course Registration Numbers: 15939 (Mdlg Dmg&Strnth Mchsm In Mtrls)

Schedule: Tuesdays and Thursdays at 10:30 – 11:45 am in 3115 ARMS

Instructor: Michael D. Sangid; Email: msangid@purdue.edu
Office: 3329 ARMS; Telephone: 494-0146
Office Hours: Tuesdays and Thursdays, immediately after class and Wednesdays 3 – 4 pm in 3329 ARMS.

Please note: To ensure that everyone has the same access to questions/answers, please ask questions about the HW/projects during class or office hours. Emailing questions should be avoided. Also, please do not ask general/vague questions, such as 'how do I do #X (while showing up with no prior work)?', 'can you find the bug in my code', or 'is this right?'

Prerequisites: An entry-level class in solid mechanics (such as elasticity or continuum mechanics) that covers indicial notation and basic equilibrium/ compatibility conditions.

Required Text: None
Will supply journal papers / book chapters as hand-outs on webpage: https://engineering.purdue.edu/AAE/Academics/Courses/aae69000_Modeling_Damage_and_Strengthening_Mechanisms_in_Materials

Recommended Text: *Micromechanics of Defects in Solids*, by T. Mura, Springer, 2nd Edition, ISBN – 9024732565

Supplemental Texts:

The Mechanics of Crystals and Textured Polycrystals, William F. Hosford, Oxford
Micromechanics: Overall Properties of Heterogeneous Materials, by S. Nemat-Nasser, M. Hori, Elsevier
Crystals, Defects, and Microstructure, Rob Phillips, Cambridge
The Mathematical Theory of Plasticity, R. Hill, Oxford
Introduction to Texture Analysis, O. Engler, V Randle, CRC Press
Strengthening Mechanisms in Crystal Plasticity, A.S. Argon, Oxford
Mechanical Behaviour of Engineering Materials: Metals, Ceramics, Polymers, and Composite, Roesler, Joachim, Harders, Harald, Baeker, Martin; Springer, http://www.springer.com/materials/mechanics/book/978-3-540-73446-8
Theory of Elasticity, S.P. Timoshenko, N. Goodier, McGraw

Grading: 3 Credit Hours – HW (25%), Project 1 (25%), Project 2 (25%), and Project 3 (25%). In general, we will have a 90%|80%|70%|60% grade scale with +/- grades. Depending on how the class performs on its assignments and projects, the instructor reserves the right to curve the scale in the favor of the class, if necessary, based on his discretion. Grades will never be curved downward.

Exams: There will be no exam or finals, as part of this class.

Homework: There will be roughly 5 HW assignments given during the semester. You may work in teams of 1 to 3 on the HW. Please write each of your names on the HW assignment that you turn in.

The HW is for your own benefit and is necessary to properly learn the material. It is expect that each student put forward an honest effort in solving each problem. Working together is not a means to 'divide up' the work. If you turn in an assignment with more than one name on it; each person must have put forth their best effort on every problem and discussed this problem with the group. Any abuse of this policy and we will go back to individual assignments.

Project: Each student is expected to turn in his/her own project, containing a written report with figures, tables, equations, codes, references, etc. For Projects 1 and 2, the entire class will work toward the same project: (i) Mori-Tanaka implementation of the Eshelby inclusion model and (ii) Bishop and Hill implementation of a Taylor crystal plasticity model. For the third project, each student must choose his/her own topic, which must be relevant to this class and discussed with the instructor. Additionally, for the third project, students are required to give a class presentation (7 min – but this may be variable based on class size). Although it is helpful to choose a topic relevant to your research, this work cannot be completed prior to this semester or used to satisfy another requirement.

Course Description: This course is intended to be a graduate level course, which focuses on modeling at the microstructure level of primarily metals but also composites. The course topics and modules are defined as follows:

I. Eshelby inclusion problem (1/4 Class)
   - Advanced micromechanics analysis of modern engineering materials with emphasis on relating elastic microstructural phenomena to the mechanics of material behavior.

Project 1: Application to fiber reinforced composites – Mori-Tanaka implementation

II. Overview of classical plasticity (1/4 Class)
   - Phenomenological and mathematical formulation of the constitutive laws of plasticity.
   - Yielding, yield surface; von Mises, Tresca yield criteria; Drucker's stability postulate; strain or work hardening, normality rule, perfect plasticity, and stress-strain law

III. Crystal plasticity (1/4 Class)
   - Physical and mathematical foundation for plasticity in crystalline materials, with application to deformation processes.

Project 2: Bishop and Hill implementation in Taylor problem for deformation of polycrystals

IV. Concepts of dislocations leading to strengthening mechanisms in metals (1/4 class)
   - Study of anisotropy of material and elastoplastic properties at crystal level, microstructural basis for deformation in metals, polymers, and ceramics.
   - Failure mechanisms and toughening in metals, with primary emphasis on work/strain hardening, solid solution hardening, precipitate hardening, and grain boundaries.

Project 3: The topic of this project must be relevant to this class and discussed with the instructor. Students are required to give a class presentation (see note above concerning projects) and turn in a report. Although it is helpful to choose a topic relevant to your research, this work cannot be completed prior to this semester or used to satisfy another requirement.

CS&E Program: This class is listed as a Relevant Course to count towards the requirements of the CS&E Program.

Approach: Active learning – classes are a mixture of lecture and discussion
Students are expected to be present and prompt for class, to keep up with the materials and homework assignments, and to live up to the highest standards of honesty and integrity. Students are encouraged and expected to be lively and participate with the lectures. The class notes will be given on the blackboard with figures shown on the overhead (the figures will be made available through the class website). It is expected that the students come to class and take notes. If a student cannot make it to class, they should arrange to get the notes from one of their classmates.

In general, notes and handouts are "considered to be 'derivative works' of the instructor's presentations and materials, and they are thus subject to the instructor's copyright in such presentations and materials."

Definition of Academic Dishonesty: Purdue prohibits "dishonesty in connection with any University activity. Cheating, plagiarism, or knowingly furnishing false information to the University are examples of dishonesty" (*University Regulations*, Part 5, Section III, B, 2, a). Furthermore, the University Senate has stipulated that "the commitment of acts of cheating, lying, and deceit in any of their diverse forms is dishonest and must not be tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest" (University Senate Document 72-18, December 15, 1972).

Academic Integrity: "Purdue University values intellectual integrity and the highest standards of academic conduct. To be prepared to meet societal needs as leaders and role models, students must be educated in an ethical learning environment that promotes a high standard of honor in scholastic work. Academic dishonesty undermines institutional integrity and threatens the academic fabric of Purdue University. Dishonesty is not an acceptable avenue to success. It diminishes the quality of a Purdue education which is valued because of Purdue's high academic standards" (S. Akers, *Academic Integrity, A Guide for Students*, 1995, revised 1999). Also, see PURDUE UNIVERSITY CODE OF HONOR

Students with Disabilities: Students with disabilities requiring additional assistance should make themselves known to the instructor.

Campus Emergency: In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances beyond the instructor's control.

Additional Information: This class will uphold Purdue University's policies on 'Attendance and Grief Absence', 'Adverse Weather', 'Campus Emergency', etc. Please consult purdue.edu for more information.

			Topic	Handouts	Assignments	Due Dates
	Week	**1**				
1	Tues	12-Jan	Class Introductions			
2	Wed	13-Jan	Review: Indicial Notation		***2:30-3:30 in ARMS 3118***	
3	Thur	14-Jan	Elasticity Fundamentals			
	Week	**2**				
4	Tues	19-Jan	Eshelby Analysis	Eshelby / Han		
5	Thur	21-Jan	Interior of Inclusion	Ellipse Formulation		
	Week	**3**				
6	Tues	26-Jan	Spherical Inclusion Example		HW1	
7	Thur	28-Jan	External to Inclusion			
8	Fri	29-Jan	Mori-Tanaka Implementation	Tucker	***4 - 6 pm ARMS 1103***	
	Week	**4**				
9	Tues	2-Feb	Project I Description		P1	HW1
10	Thur	4-Feb	Inclusion Energy			
	Week	**5**				
11	Tues	9-Feb	Plasticity Introduction			
12	Thur	11-Feb	Pi-Plane	Hill		
	Week	**6**				
	Tues	16-Feb	*No Class - TMS*			
	Thur	18-Feb	*No Class - TMS*			
	Week	**7**				
13	Tues	23-Feb	Yield Condition		HW2	
14	Thur	25-Feb	Flow Rule			P1
	Week	**8**				
15	Tues	1-Mar	Normality / Convexity			
16	Thur	3-Mar	Texture Introduction	Hosford / Rollett	HW3	HW2
17	Fri	4-Mar	Single Crystal Deformation	Dawson	***4 - 6 pm ARMS 1103***	
	Week	**9**				
18	Tues	8-Mar	Polycrystalline Deformation I	Kocks		
19	Thur	10-Mar	Polycrystalline Deformation II			HW3
	Week	**10**				
	Tues	15-Mar	*No class - Spring Break*			
	Thur	17-Mar	*No class - Spring Break*			
	Week	**11**				
20	Tues	22-Mar	Exponetial Mapping	Crystal Rotation	HW4	
21	Thur	24-Mar	Bishop-Hill Algorithm	Bishop-Hill		
22	Fri	25-Mar	Project II & III Description	***4-6 pm in ARMS 3326***	P2 & P3	
	Week	**12**				
23	Tues	29-Mar	Kinetics I	McDowell		
24	Thur	31-Mar	Kinetics II			HW4
	Week	**13**				
25	Tues	5-Apr	Work Hardening	Mecking / Beaudoin		
26	Thur	7-Apr	Incompatibility I		HW5	P3 Abstracts
	Week	**14**				
27	Tues	12-Apr	Incompatibility II			
28	Thur	14-Apr	Grain Boundaries	Hirth / Sangid / Rittner		P2
	Week	**15**				
29	Tues	19-Apr	Self Consistent Approaches	Lebensohn & Tome		
30	Thur	21-Apr	X-Ray Diffraction			HW5
	Week	**16**				
31	Tues	26-Apr	Project III Consultation			
32	Thur	28-Apr	Project III Consultation			
	Week	**17**				
33	***TBD***		Project III Presenations			P3

EMERGENCY PREPAREDNESS LECTURE

1 *Prior to the first day of class, obtain a copy of the building emergency plan for each building in which you will be teaching. Note the evacuation route and assembly area, as well as the shelter in place locations. BEPs are located on the Emergency Preparedness website* http://www.purdue.edu/ehps/emergency_preparedness/

2 *On the first day of class, the following information is required to be presented to students:*

As we begin this semester I want to take a few minutes and discuss emergency preparedness. Purdue University is a very safe campus and there is a low probability that a serious incident will occur here at Purdue. However, just as we receive a "safety briefing" each time we get on an aircraft, we want to emphasize our emergency procedures for evacuation and shelter in place incidents. Our preparedness will be critical IF an unexpected event occurs!

Emergency preparedness is your personal responsibility. Purdue University is actively preparing for natural disasters or human-caused incidents with the ultimate goal of maintaining a safe and secure campus. Let's review the following procedures:

- For any emergency call 911.
- There are nearly 300 Emergency Telephone Systems throughout campus that connect directly to the Purdue Police Department (PUPD). If you feel threatened or need help, push the button and you will be connected to the PUPD.
- If we hear a fire alarm we will immediately evacuate the building
  - **Do not use the elevator.**
  - Go over evacuation route…see specific Building Emergency Plan.
- If we are notified of a Shelter in Place requirement for a tornado warning we will shelter in the lowest level of this building away from windows and doors. Our preferred location is near the elevators, outside of B119.
- If we are notified of a Shelter in Place requirement for a hazardous materials release we will shelter in our classroom shutting any open doors and windows.
- If we are notified of a Shelter in Place requirement for a civil disturbance such as a shooting we will shelter in a room that is securable preferably without windows.

(NOTE: Each building will have different evacuation & shelter locations. The specific Building Emergency Plan will provide specific locations and procedures)

Attached to the syllabus is an "Emergency Preparedness for Classrooms" sheet that provides additional preparedness information. Please review the sheet and the Emergency Preparedness website for additional emergency preparedness information.

EMERGENCIES CALL 911
PURDUE POLICE & FIRE

EMERGENCY PREPAREDNESS SYLLABUS ATTACHMENT

EMERGENCY NOTIFICATION PROCEDURES are based on a simple concept – if you hear a fire alarm inside, proceed outside. If you hear a siren outside, proceed inside.

- **Indoor Fire Alarms** mean to stop class or research and immediately **evacuate** the building.
- Proceed to your Emergency Assembly Area away from building doors. **Remain outside** until police, fire, or other emergency response personnel provide additional guidance or tell you it is safe to leave.
- **All Hazards Outdoor Emergency Warning Sirens** mean to immediately seek shelter (**Shelter in Place**) in a safe location within the closest building.
  - "Shelter in place" means seeking immediate shelter inside a building or University residence. This course of action may need to be taken during a tornado, a civil disturbance including a shooting or release of hazardous materials in the outside air. Once safely inside, find out more details about the emergency*. **Remain in place** until police, fire, or other emergency response personnel provide additional guidance or tell you it is safe to leave.

**In both cases, you should seek additional clarifying information by all means possible…Purdue Emergency Status page, text message, Twitter, Desktop Alert, Alertus Beacon, digital signs, email alert, TV, radio, etc…review the Purdue Emergency Warning Notification System multi-communication layers at http://www.purdue.edu/ehps/emergency_preparedness/warning-system.html*

EMERGENCY RESPONSE PROCEDURES:

- Review the **Emergency Procedures Guidelines** https://www.purdue.edu/emergency_preparedness/flipchart/index.html
- Review the **Building Emergency Plan** (available on the Emergency Preparedness website or from the building deputy) for:
  - evacuation routes, exit points, and emergency assembly area
  - when and how to evacuate the building.
  - shelter in place procedures and locations
- additional building specific procedures and requirements.

EMERGENCY PREPAREDNESS AWARENESS VIDEOS

"Shots Fired on Campus: When Lightning Strikes," is a 20-minute active shooter awareness video that illustrates what to look for and how to prepare and react to this type of incident. See: http://www.purdue.edu/securePurdue/news/2010/emergency-preparedness-shots-fired-on-campus-video.cfm (Link is also located on the EP website)

MORE INFORMATION

Reference the Emergency Preparedness web site for additional information: https://www.purdue.edu/ehps/emergency_preparedness/