

# FAILURE ANALYSIS & PREVENTION

## course syllabus

enr 3820

### INSTRUCTOR INFORMATION

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### COURSE INFORMATION

**Meeting Times** MR 1:30 - 3:10 pm. **Location** AC 413. **Web Site** <http://faculty.olin.edu/~jstolk/failure2008>. **Course Credit** 4 engineering credits. **Prerequisites** SCI 1410 Materials Science and Solid State Chemistry.

### COURSE DESCRIPTION

(Catalog version) Students will complete projects and case studies to gain practical experience in the analysis of fractured and failed engineering materials and components. The course focus will be on material microstructure and the micromechanisms of fracture, and topics will include failure analysis methodology, mechanisms of failure, fracture classifications, corrosion and environmental factors, fractography, and design for failure prevention. Students will learn advanced materials characterization techniques including scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and compositional dot mapping, x-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), optical microscopy, and fracture surface sample preparation.

(Version for real people) *Failure Analysis and Prevention* is a project-based course in which student development is focused on professional-level competencies and application of self-directed learning skills. By organizing and carrying out failure investigations of real-world components and systems, and through analysis of published case studies, students in the course “learn failure analysis by doing failure analysis.” Throughout the semester, student teams gain practical experience in the analysis of fractured and failed

engineering materials and components. The student-directed projects emphasize the interdisciplinary nature of failure investigations, and the various contextual factors that contribute to engineering decision-making. Course discussions address failure analysis methodology, mechanisms of failure, fracture classifications, design and human factors, material attributes that affect failure, corrosion and environmental factors, and re-design for failure prevention. Students develop skills in advanced materials characterization techniques, and analytical techniques such as stress analysis, failure life estimation, and finite element analysis. Student autonomy in the course is high. Project teams set their own goals and timelines, regulate their time and effort, manage their teaming interactions, identify and evaluate resources, and select readings and facilitate class discussions. Students communicate their failure analysis findings through case-study reports, posters, and presentations.

### INFORMATION RESOURCES

There is one required book for this course:

- *Inviting Disaster: Lessons From the Edge of Technology* by James R. Chiles (Harper, 2002). This book is about \$11 on amazon.com. Pick up a copy as soon as you can.

We won't use a single **textbook** for this course, but rather a wealth of resources, including case studies, journal articles, engineering handbooks and textbooks, and web-based articles. Links to loads of potentially useful information will be provided on the web site, and you and your classmates will identify additional resources as you progress through the projects. Use these resources.

### LEARNING OBJECTIVES

This course will assist you in achieving the following goals. Competency areas are shown in parentheses.

- Explain the significance of failure and failure analysis in engineering design (Understanding of Context, Design).
- Identify how design, materials selection, processing and manufacturing, and service environment affect the life (and death) of engineering components (Qualitative and Quantitative Analysis, Design).
- Design and implement failure analysis strategies that make use of research and experimentation to diagnose failure symptoms, identify failure mechanisms, and determine causes of failure in components (Diagnosis, Qualitative and Quantitative Analysis).
- Interact and work effectively as a member of a project team (Teamwork).
- Use written, oral, visual, and graphical communication to convey experimental methods, results, and analyses (Communication).
- Demonstrate a capacity for self-directed learning, including goal setting, selection of learning strategies, time and effort regulation, motivation management, resource discovery, and self-reflection and self-assessment (Lifelong Learning).
- Other student-defined learning objectives appropriate to your individual educational goals and interests.

## GRADING

You will likely develop your knowledge, skills, and attitudes in many of the Olin competencies in this course, including design and contextual analysis, but we may not be able to effectively evaluate all competencies in a single semester. So, your evaluations for the course will be based on the following six competencies and expected levels of achievement:

Competency	Level of Achievement
Qualitative Analysis	Advanced
Communication	Advanced
Diagnosis	Intermediate
Teamwork	Advanced
Lifelong Learning	Intermediate
Quantitative Analysis	Intermediate
[Student-specified]	[To be determined]

Each of the competencies will be evaluated through the assignments described in the table shown below. These assignments and their corresponding competency areas are described in horrifying detail in the assignment handouts.

Assignments and Competencies	Instructor-Assessed?	Student-Assessed?
<b>Projects</b>		
Qualitative Analysis	Yes	Yes
Communication	Yes	Yes
Diagnosis	Yes	Yes
Quantitative Analysis	Yes	Yes
<b>Teaming Evaluations</b>	No	Yes
<b>Lifelong Learning Assessments</b>	Yes	Yes
<b>Student-specified competency</b>	No	Yes

Throughout the course, you will complete self-assessments or peer-assessments of your learning. Yes, indeed. Self-assessment of performance can be challenging, so to help you with the self-assessments, I'll provide some structure in the form of detailed grading rubrics.

As shown in the table, a portion of your overall evaluation will be in a competency area to be determined by you. The basic idea is that I wanted to provide you with the freedom to develop in areas that are aligned with your personal goals, but that may not be addressed by the formal course assignments. Depending on your goals, you may decide to add extra emphasis to a competency area that is already measured in this course, or you may identify a different competency area (e.g., contextual understanding or design) and incorporate appropriate activities to address your goals in these other areas. For example, if improving the design of a failed component is in line with your learning goals, you may identify a strategy for including significant design activity in one of your projects, and then evaluate your competency development in Design. Additional information on this student-specified portion of the overall course evaluation will be provided in class, and you may work with me to develop your self-specified competency plan.

For the major project deliverables (reports and posters), I will provide detailed feedback in the relevant competency areas. In addition, you will provide a self-evaluation of your work in each project. These self-assessments will include ratings and comments that describe the ways in which you have met or failed to meet the criteria and goals for the project. I'll provide a grading rubric for both reports and posters, and plenty of help throughout the self-assessment process. We'll do our best to discuss any significant variance in the instructor and student evaluations, so that we clearly understand our differences in perspective. Additional detail on competency assessment in the projects and individual assignment will be provided in the assignment handouts.

You and your peers will evaluate your teaming competency. I'll provide information on expected teaming behavior and survey tools designed to enable teaming assessment and highlight team strengths and problem areas. You will evaluate your own lifelong learning skill development through a self-rating scale and self-reflective essays, and I'll provide my take on your development as a lifelong learner in the final narrative evaluation.

The competency feedback you receive or assign yourself throughout the semester should give you a good idea of how you are doing in the course, but you are welcome to discuss your assessments with me at any time during the semester.

**Experimental Grading (EG).** Now, here comes the really fun part! This course is part of an effort at Olin aimed at exploring non-traditional evaluation approaches. That's right, I'm talking Experimental Grading (EG). Rather than assigning a final letter grade in this course, I'll provide each of you with detailed, narrative evaluations based on the competency areas described above. This means that instead of an A, A-, B+, etc., your transcript will read "EG" for this course, and you'll get a two-page narrative evaluation

from me at the end of the term. I'll provide additional details on how Experimental Grading will work in this course, so stay tuned, and please feel free to ask me lots of detailed questions about the new EG effort at Olin.

#### TIME EXPECTATIONS

A student with good self-regulated learning skills and plenty of caffeine and empty carbohydrates should expect to spend about 12 hours per week doing everything associated with attainment of the learning goals in this course. Bump up the caffeine, and you may be able to shave six to eight minutes off that total.

#### SUPPLIES

Use a lab notebook to record your project work and ideas. If you're into the authentic, real laboratory notebooks are bound and include numbered pages, and they are usually available in black and a variety of ugly colors. Lab notebooks for kids do not have numbered pages and typically come in pretty colors such as chartreuse and orchid, and in fancy designs that evoke carefree feelings. We will have none of that here.

#### ATTENDANCE

Our class time will include a combination of class discussions, presentations, and open project time. For the open project time, you are responsible for deciding how you want to spend your time. This is a team-based, project-based course, so you need to consider the effects your absence may have on your teammates and your project work. You have responsibilities to your team, and you should communicate with them regarding absences. If you are sick, do not come to class. But let me know about your illness via email as soon as possible, and I'll help you catch up on things you missed. If you have a different reason for missing class, contact me as early as possible.

#### HOMEWORK POLICIES

You're going to do a lot of reading in this course. Readings will be included in all of the homework assignments (actually, most of the homework assignments are readings, with very few problem sets). The readings are important, as they form the basis for our class discussions. Based on your particular projects or topics that come up in our class discussions, I'll assign supplemental readings on occasion. Problems and relevant activities will be distributed as necessary, but these will be kept to a minimum to save more time for your project work. In general, I will not be collecting the smaller assignments, and my assessments will focus on the larger projects. But if you're having trouble with the readings or smaller assignments, please report these difficulties to me. I want to help you work through the trouble spots, but I need to hear from you what they are.

#### FEEDBACK

I use in-class discussions and short surveys as my primary mechanisms for feedback. You don't have to wait for the formal feedback sessions to provide course feedback to me.

If something is on your mind, please let me know. Stop by my office, catch me after or during class, or send me an email message. I'm always happy to listen to your comments and consider your suggestions for improvement or modification of the course.

#### COLLABORATION & HONOR CODE

The Honor Code is our friend. Your conduct and work in this course should adhere to the standards of the Olin College Honor Code. I encourage collaboration on all homework and project assignments – it's a critical part of this course, and you won't be happy without it. I may require you to work individually on a few assignments. When individual work is required (this rarely, if ever, is the case), I will let you know.

Citing sources. Be sure to always cite the sources you use to support your work. This is an important aspect of professional level engineering work, so try to develop good habits in this area as you put together your project reports, posters, and presentations. If you are at all uncertain about how to cite a source, or whether a particular kind of collaboration is acceptable, please ask me about it.

#### LAPTOPS IN CLASS

Please bring your laptops to class. You will likely need them for data collection, research, note taking, information access, or killing time while you're collecting x-rays. Please use your laptops appropriately, e.g., don't queue up the "I'm on a boat" video while your peers are trying to facilitate a case study discussion.

#### SCHEDULE

I'll post the semester schedule on the web site. The schedule takes the form of a beautiful calendar, with hyperlinks to your homework assignments, etc. This schedule is designed to be somewhat flexible to allow us to make adjustments according to your needs. As the need arises, I will post revisions to due dates on the web-based calendar.

#### COURSE APPROACHES

Since this course may be a bit different than what you're used to seeing, please allow me to provide a better idea of the "feel" of the course through a description of my methodologies and classroom approaches. I think of this course as a collaborative endeavor of students and an instructor (that's me) who are, for a variety of reasons, moved to explore the world of failure analysis and prevention in an unconventional educational environment. Like other Olin courses, *Failure Analysis* comprises many things – knowledge, activities, lab time, assessments, teams, PowerPoint, due dates, hunger, technical challenges, heavy workload at times, amazing successes, and blow-your-mind micrographs – but the most important element of this course are the individuals involved. Your educational goals, personal ambitions and interests, needs, knowledge, experiences, thoughts and ideas, emotions, and feelings will

help shape your time in the *Failure Analysis* course, and you should always feel free to express your thoughts and feelings in this environment. Please be yourself in this course.

You'll quickly realize that the way we interact with each other is critical to the success of this course. There are about 15 students and one instructor in this course, each having his or her own genuine ideas, interests, and feelings. As a result, there will be certainly be times in this course when you feel that the course direction or focus has shifted away from your personal goals, and there will be occasional conflicts of interests or goals, misunderstandings, and miscommunications with other course participants. In these times, my hope is that we all strive to maintain the health of the learning environment by confronting the problem while maintaining trust in our colleagues, respect and acceptance of others' ideas and feelings, and empathy for situations that are different from our own. Let's strive for open dialogue. Let's make this a collaborative, open, respectful, growth-oriented, and fun learning community.

In the spirit of recognizing you as an individual and in an attempt to initiate productive interactions, I invite you to sign up for a meeting with me to discuss, well, you and your goals. I'll make a sign-up sheet available during the first few class sessions. This meeting is, of course, optional.

The *Failure Analysis* course emphasizes student autonomy and the building of self-directed learning skills, but some aspects of the course require either collaborative student-instructor decision-making, or direct faculty control. To aid the development of a shared and realistic understanding of this learning environment, and to hopefully foster the greatest creativity, productivity, and attainment of your learning goals, I have outlined what I believe are the responsibilities of the student and instructor in this setting:

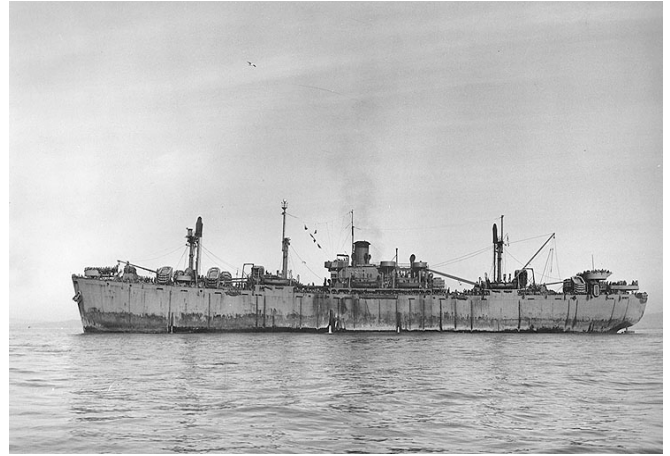
**Student Responsibilities.** You are in control of a large portion of this course. You will self-direct your learning in many ways, and depending on the project, you will make decisions related to the motivating context of your learning, the knowledge or skill areas to be learned, the processes by which you learn, and the assessment of your development. The high levels of autonomy in *Failure Analysis* suggest that you hold an important responsibility for making this course interesting, stimulating, and motivating. Indeed, this is certainly the case. Without your input, energy, and insights, this course would be dreadful.

You are responsible for unleashing your own sense of inquiry and curiosity – I can't do this for you. You should engage in course-related activities that spark your motivation and resonate with your intrinsic interests in failure analysis topics. But I also hope that you will explore new concepts and challenges that lie outside your current intrinsic interest, in an effort to grow and expand your thinking. You are responsible for interpreting and applying the failure analysis course objectives in a manner that is guided by your learning goals. You are responsible for identifying and clarifying your own learning goals, and for engaging in processes that helps you attain these goals. Since you will

be setting many of your own due dates and developing your own project strategies, and since I do not apply too many project constraints, you have the enormous responsibility of managing your time and effort in this course. You are responsible for expressing open and honest opinions in the self- and peer-assessment activities, and in providing honest feedback to me. You share the responsibility with me for maintaining constructive and encouraging interactions with others, and for fostering a sense of mutual respect in the environment.

**Instructor Responsibilities.** As your instructor, I view myself as a facilitator of your learning. I am responsible for the establishment and maintenance of a learning environment conducive to student development and attainment of course-related goals. I am responsible for clearly identifying aspects of the course that lie under student control, collaborative control, and instructor control. I am responsible for defining or helping you define the project and subject matter constraints; for making learning resources available or helping you find learning resources; and for identifying laboratory and budget resources and limitations. I am responsible for building supportive relationships with students, for facilitating communication among students, for valuing and trusting individuals, and for fostering feelings of mutual respect among all course participants. I am responsible for communicating an honest evaluation of your work, for helping you develop a capacity for self-assessment, and for reporting the final evaluations of your learning as required by the institution. I will try to refrain from applying pressures that unnecessarily stifle your creativity or productivity, or that steer you away from relevant learning goals. Finally, I am responsible for maintaining my own interests in materials science topics and in educational research in this course, which means that I get to share my experiences with you and help steer our class discussions in directions that I think are important, interesting, or valuable.

In summary, this course will provide an opportunity for you to explore failure analysis-related concepts and methodologies, develop your understandings and abilities in many areas, and progress toward your own learning goals in an environment that emphasizes student freedom, curiosity, and personal interests, as well as student responsibility. We're going to have an amazingly fun and productive semester of learning failure analysis by doing failure analysis, and I look forward to reflecting on our learning and growth.



# FAILURE ANALYSIS & PREVENTION

## søsemester overview

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This course has three required components that are described in the sections below. The Part 1 project will be completed on a relatively tight schedule that is defined by the instructor. Part 2 is quite a bit different, as it is a seven-week period during which you and your team will decide how to approach the failure analysis projects. Some of the Part 2 teams may decide to undertake several small-scale investigations, while other teams may use the entire seven weeks to complete one massive project. The time required to complete the projects during Part 2 will depend quite heavily on the component(s) or system(s) under investigation and your failure analysis team's goals and interests in studying the failed product. Because of this expected variability in project timelines, we will not restrict ourselves to a particular due date for the Part 2 projects. Rather, teams will complete their reports and present their findings as necessary throughout the seven-week period. But once the seven-week mark arrives, Part 2 will end and we will all move on to the final phase of the course. Additional details on this rolling project completion schedule will be discussed in class. The Part 3 Special Topics component of the course is designed to enable the meeting of individual learning goals through imaginative, inventive, creative discovery and problem solving in failure analysis.

### I THE WHAT, HOW, AND WHY OF FAILURE ANALYSIS

Part 1 will provide an introduction to and overview of failure and failure analysis processes. We'll take a broad look at the symptoms, causes, and consequences of failure in engineered components and systems. You will gain some familiarity with the terms used in failure investigations (e.g., failure mode, failure mechanism), the common categories of failure, and the analytical tools and techniques of failure analysis. You will get the opportunity to organize and complete a brief failure-related investigation, which will also serve as a laboratory refresher for those of you who haven't

used the wonderful materials science lab in a while. The assignments in Part 1 will include the following:

- Readings that provide some background to failure analysis and planning failure investigations, and that introduce you to real-world failure analysis case studies and a variety of analytical techniques
- In-class discussions of the readings
- Preparation of a brief written project report
- Presentation and class discussion of project findings

Additional details on the Part 1 project will be provided in supplementary documents.

### 2 UNDU E STRESS AND SEVER E ENVIRONMENTS

In Part 2, we will spend approximately seven weeks exploring a variety of topics in component failure. We'll focus on mechanical failures (undue stress) and environmentally influenced failures (severe environments), but you may find that your projects necessitate exploration of other topics.

**Undue stress.** Things tend to bend and break, especially when dairy farmers, dancing, giant tortoises, and plunge routers are involved. In Part 2, you will spend some time studying factors that lead to geometrical changes (distortion) or material separation (fracture) in engineered components. You will learn about the microscopic mechanisms of deformation and fracture, and you will examine macroscopic and microscopic evidence of different mechanical stress-related fracture modes. By building your knowledge of crack growth, brittle and ductile fracture, mechanical fatigue, thermomechanical fatigue, friction and wear, and creep, you will be better equipped to predict possible failure modes in engineering components, and you will gain insight into methods of failure prevention.

**Severe environments.** Humans and nature have created some pretty nasty service environments for our designs. I mean, just look at the giant holes in my house caused by a

wicked combination of trapped moisture and carpenter ants. For portions of Part 2, we'll turn our attention to the important role that environment plays in determining the behavior and service life of materials, components, and systems. You will study the different forms of chemical, electrochemical, and radiative attack, and you will examine the deleterious effects these environmental factors have on the properties and performance of engineering polymers, metals, or ceramics. Some students may choose to focus on corrosion mechanisms in structural metallic components, while others may decide to learn more about the degradation in structural polymers, composites, electronic materials, biomaterials, films, or other areas.

For the project component of Part 2, you and your team will spend about seven weeks investigating components or systems that failed in a stress- or environment-related manner. Each team may decide to tackle one larger project, or two or three smaller projects. Once you select a failed component or system, you will organize and complete a laboratory analysis of the failure, and produce a detailed case study report. Assignments in Part 2 will include the following:

- Readings: fracture mechanisms and fracture surface features, fracture-related case studies, background on corrosion and degradation in metals and polymers, environment-related case studies
- A few problems on fracture, fatigue, corrosion, and degradation
- Failure analysis project(s) and case study report(s)
- Presentation(s)
- In-class discussions of the readings (instructor- and student-facilitated)

Additional details on the Part 2 project will be provided in supplementary documents.

### 3 SPECIAL PROJECTS & TOPICS

Here's where things could get really interesting. After your failure analysis team completes your Part 2 investigation(s), you will use the remaining time in the semester to explore topics of team or personal interest. The Special Topics assignments are student-defined and may include but are not limited to the following:

- *Failure Analysis Project – Team or Individual.* Keep things rolling with another failure analysis investigation of a component of your choosing.
- *Deep Topical Exploration.* Design a hands-on project or literature study that involves deep exploration of an issue or topic that arose during one of the previous projects.
- *Product Re-design.* Conduct a detailed re-design of one of the components or systems you analyzed in the Part 2 project, and rationalize your design decisions through appropriate analyses. Show us that you can make it better in some way!
- *Try to publish your work.* Use your Part 2 project report as the basis of a journal article, and submit the manuscript to Engineering Failure Analysis journal for review and publication. Several teams have started this in the past,

but we have yet to submit a manuscript for consideration for publication. Will you be the first?

- *Individual or team experiments.* Propose and test a hypothesis, and report their results in an appropriate manner.
- *Review of journal articles.* Read, synthesize, and summarize recent, failure analysis-related research in an area of interest.
- *Library research.* Investigate an established failure analysis topic or historical engineering failure using books or case studies, and report your learning in an appropriate manner.
- *Field trips.* Make arrangements and take a trip to a large corporation, a smaller company, or an analytical laboratory, and visit with engineers or scientists engaged in failure analysis work. Nobody ever does this, but I'm not sure why not.
- *Interviews with experts.* Identify an interesting person engaged in failure analysis, get to know the person through interviews or other means, and create a narrative of the individual's work.
- *Textbook reading and problem solving.* Identify a textbook on failure analysis, and self-direct your reading and solving of problems. Seems boring, right? Maybe this works for some folks.
- *Demonstrations or classroom teaching.* Plan and demonstrate a failure analysis-related principle to the class.
- *Cost analysis.* Analyze the costs (economic, human, environmental) of failure in one of your Part 2 project components.
- *Posters.* Create a visually stunning and educational graphical representation of your project findings, or of a failure analysis concept or theme. Posters will be displayed in the academic center.

For the special projects and topics, you will be responsible for finding appropriate information and tools to support your work, and you will define your learning goals, learning plan, and deliverables. You may, of course, ask your instructor for assistance in all of these things. Your final project will be assessed in collaboration with your instructor and with respect to your stated learning goals.