ME 726 Fracture Mechanics (3 credits)
Spring 2024

Instructor: Dr. Xiangfa Wu; 206 Dolve Hall (231-8836); E-mail: xiangfa.wu@ndsu.edu
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Lecture Hours: **8:00-9:15 AM (T & Th)** Dolve Hall 118 (Jan. 8 – May 10)
(Dead Week: April 29 - May 3)
Holidays: Martin Luther King, Jr. Day: Jan. 15 (Monday); President's Day: Feb. 19 (Monday); Spring Break: Mar. 4-8; Spring Recess: Mar. 29 - Apr. 1

Special Days: Jan. 18 (Thursday): Withdraw to zero credits at 100% refund
Feb. 19 (Monday): Withdraw to zero credits at 75% refund
Mar. 21 (Thursday): Withdraw to zero credits at 50% refund (no refunds for withdraw to zero credits after this date)
Apr. 5 (Friday): Last day to drop class with "W" record

Office Hours: **Tuesday & Thursday: 3:30 - 4:30 PM**, other hours by appointment
Course Website: https://bb.ndsu.nodak.edu
Prerequisites: Graduate standing. Students taking this course are assumed to have attended courses in engineering mechanics to the level of Machine Design I (ME 442) and Finite Element Analysis (ME 477)

Textbook: *Fracture Mechanics: Fundamentals and Applications* (3th Ed.) by T. L. Anderson, Taylor & Francis, 2005.

References:
1. Fracture Mechanics-Fundamentals and Applications (3rd Ed.), T. L. Anderson, CRC Press, 2005.
2. Deformation and Fracture Mechanics of Engineering Materials (4th Ed.), Richard W. Hertzberg, John Wiley, 1995.
3. Fracture Mechanics (2nd Ed.), Michael Janssen, Jan Zuidema & Russel Wanhill, Spon Press, 2004.
4. Advanced Fracture Mechanics, M. F. Kanninen & C. H. Popelar, Oxford University Press, 1985.
5. Elementary Engineering Fracture Mechanics (3rd Ed.), David Broek, Martinus Nijhoff Publishers, 1984.
6. Advanced Mechanics of Materials (6th Ed), A. P. Boresi & R. J. Schmidt, John Wiley, 2003.

Course Description:

Fracture mechanics is a branch of classical engineering mechanics that deals with the stress field and crack growth criteria of cracked solids under external loading. The course covers the fundamental concepts of fracture mechanics and failure criteria, linear elastic fracture mechanics (LEFM), elastoplastic fracture, fracture in metals, polymers, ceramics and composites, and the mechanisms, such as J-Integral and COD, to measure the severity of the crack. Fatigue crack growth mechanisms, microcracks, and how cracks are developed and controlled are part of the course. The computational schemes describing how to evaluate fracture parameters using finite elements, multiscale fracture mechanics, and fracture at different scales will be covered.

Course Catalog: Linearly elastic fracture mechanics (LEFM), energy release rate, stress intensity factor, nonlinear fracture mechanics, J-integral, elastoplastic fracture, crack tip plasticity, crack propagation, fracture fatigue crack growth, fracture tests, fracture in polymers and composites, delamination and toughening of composite materials.

Course Aims:

- To provide a comprehensive understanding of the stress analysis and fracture mechanics concepts required for describing failure in engineering materials and structures containing cracks under brittle, ductile and creep conditions.

- To explain how these concepts are applied in a safety assessment analysis.
- To provide exercises in solving practical problems.
- To become familiar with analytic and numerical modeling (e.g., finite element methods, etc.) and evaluation of fracture of solids and multiscale fracture mechanics.

Course Objectives:

1. Students will have the knowledge of 2D and 3D field equations of elasticity, stress concentrations and Airy stress functions.
2. Students will have a fundamental understanding of linear-elastic fracture mechanics (LEFM), energy release rate; stress intensity factors (SIFs) and will be able to solve elementary LEFM-related problems.
3. Students will understand the crack-tip plasticity and elastic fracture and will be able to solve practical elastic-plastic fracture problems using J-Integral and COD methods.
4. Students will become familiar with finite elements modeling of fracture problems, crack tip singularity elements, and evaluation of stress and strain at crack tips.
5. Students will be able to analyze stationary cracks and perform crack propagation in 2D linear-elastic mechanical components of arbitrary geometry, and determine SIF using SIF tables and commercially available finite element software.
6. Students will have an elementary knowledge of fatigue crack growth and will be able to conduct fatigue life prediction of simple mechanical components under constant-amplitude loading.
7. Students will have the knowledge of fracture mechanisms in metals, polymers, ceramics and composites.

Course Outcomes:
At the completion of this course, students will be able to

(1) To understand the fundamentals of linear elastic fracture mechanics
(2) To evaluate the stress intensity factors for cracked solids
(3) To measure the crack-tip plasticity in metals
(4) To understand the fatigue-fracture interaction and the mechanisms of crack growth
(5) To determine the different means of experimental fracture mechanics
(6) To practice FEM analysis of fractured components and the efficiency of crack tip elements; and
(8) To know the mechanisms of fracture in metals, polymers and composites

Course Grading:
Students are expected to:

a) Take tests: midterm and final exam;
b) Complete homework assignments on time;
c) Solve projects using analytic and/or numerical methods; and
d) Complete term paper and presentation.

Homework	40%
Term paper	15%
Mid-term exam (2)	30%
Final Exam/Project Presentation	15%
Total	100%

Final course grades will be assigned according to the following scale.

A 90% or greater

B 80% to less than 90%
C 70% to less than 80%
D 60% to less than 70%
F less than 60%

No scaling will be applied in this course

Homework: Classical homework problems will be assigned during lectures and posted on the course website. It is essential for the students to do homework problems to learn how to apply the fundamental concepts and principles learned in this class.

Term Paper (Course Project): Each student is required to write a research paper relevant to this course content. General requirements of the paper include:

1. The paper should include a concise, informative title, author's name, and contact information;

2. Content of the paper consists of Introduction, Problem Statement/Formulation, Solutions (either analytic, numerical, or experimental), Discussions (if needed), Conclusions, Acknowledgement (if needed), and References (10-25);

3. The research problem should be closely related to the class content (at least with a ***Crack*** model plus sufficient derivation, simulation, experimentation, etc.) and should be ***new*** or ***from your recent or ongoing research***. If the problem is from literature, it should be an extension or further discussion of a specific problem researched in the literature. Trivial review of field literature, problems copied from the literature, routine collection/reduction of experimental data, routine FEM simulation using commercial software packages (e.g., ANSYS, ABAQUS, Dyna-3D, etc.), or problems below the level of this class will lead to **ZERO** grade in this project. Student is encouraged to discuss his/her research paper/project topic with the instructor before starting to write;

4. Format of the paper should follow those used in *ASME Journal of Applied Mechanics* (http://asmedl.aip.org/AppliedMechanics/), *International Journal of Solids and Structures* (http://www.journals.elsevier.com/international-journal-of-solids-and-structures/) or *Journal of Applied Physics* (http://jap.aip.org/). The following requirements are mandatory: Single column and single spaced; Font type: times new roman; Font size: 10-12 (Size 11 is preferred); Page size: letter 8.5×11 inches; Page margins: top & bottom: 1 inch, inside & outside: 1 inch; Page number: located at the right bottom; Header & Footer: No; Figures: with sufficient resolution. The paper should not be longer than 10 pages (including formulas; diagrams, and references);

5. Typed hardcopy of the paper should be turned in before the **exam day**. An electronic copy of the paper in the format of MS-Word should be sent by email attachment to the instructor at the time when the hardcopy is turned in. The instructor will grade and correct the paper based on the electronic file or the hardcopy.

Academic Honesty Statement: All work in this course must be completed in a manner consistent with NDSU University Senate Policy, Section 335. Code of Academic Responsibility and Conduct (available on the Web at http://www.dsu.nodak.edu/policy/335.htm). Violation of this code will result in a penalty or penalties to be determined by the instructor to fit the gravity of the offense and the circumstances of the particular case. The instructor may: (1) fail the student for the particular assignment or test, (2) give the student a failing grade in the course, or (3) recommend that the student drop the course.

Attendance: Students should realize that there are materials covered in class which are not discussed in the textbook. The student is responsible for **ALL** material presented in class whether or not s/he is present in class. If a student misses a class, it is the student's responsibility to obtain notes from a classmate. Full credit can be received for work turned in late due to an excused absence. It is the student's responsibility to contact the instructor in such a case. If the student is going to miss a test for a good reason, s/he should provide the instructor a written **DOCUMENT** with authority's (or administrative) signature and contact information BEFORE the test in order to arrange for a make-up exam.

Veterans and student soldiers with special circumstances or who are activated are encouraged to notify the instructor in advance

Disabilities: Any student with disability who needs accommodations is encouraged to talk to the instructor as soon as possible to make appropriate arrangements for these accommodations.

Tentative Course Outline (Subject to change):

Weeks	Sections	Topics	Note
1-2	Ch. 1	**Introduction to Fracture Mechanics** Historical review & prospective, fundamental concepts of fracture mechanics	
2-4	Ch. 2, 4	**Linear Elastic Fracture Mechanics** Stress analysis of cracked solids, LEFM singularity field, stress intensity factor, crack modes, energy release rate, SIF solutions for various specimens, effect of finite size, fracture toughness (K_{Ic}), SIF based failure criterion, mixed-mode fracture. Concepts of interfacial fracture and fracture dynamics	
5-6	Ch. 3	**Elastoplastic (Nonlinear Elastic) Fracture Mechanics** Crack-front process zone, crack –tip plasticity, estimation of plastic zone size, elastoplastic fracture analysis, J-Integral and COD	
		Midterm Exam	
7-8	Ch. 12	**Computational Fracture Mechanics** Singular finite elements, quarter points, method of computing SIF by FEM, displacement correlation, J-integral and virtual crack extension methods. Advanced topics of multiscale and molecular simulations of cracking	
9-11	Ch. 7, 8	**Experimental Fracture Mechanics** ASTM specimen standards and fracture tests, sustained load fracture, mixed mode fracture tests and measurements	
12-13	Ch. 10	**Fatigue Crack Growth and Life Prediction** Fatigue crack propagation, empirical crack-growth models, fatigue life prediction, crack closure, damage tolerance analysis	
14	Ch. 5	**Fracture Mechanisms in Metals** Ductile fracture, void nucleation, cleavage, fractography, ductile-brittle transition.	
15-16	Ch. 6	**Fracture Mechanisms in Nonmetals** Fracture in polymers and composites, mechanisms of fiber failures, delamination, microcracks in ceramics and composites.	
		Selective Advanced Topics Interfacial fracture, fracture dynamics, fracture of Li ion rechargeable batteries, fracture of electronic devices, environmentally assisted cracking, damage mechanics, etc.	