EXPERIMENTAL METHODS IN MECHANICS

Course contents:

Experimental solid mechanics is the study of materials to determine their physical properties. This study might include performing a stress analysis or measuring the extent of displacement, shape, strain and stress which a material suffers under controlled conditions. In the last few years there have been remarkable developments in experimental techniques that measure shape, displacement and strains and these sorts of experiments are increasingly conducted using computational techniques.
Present-day experimental methods for analyzing the stress–strain state (SSS) based on interference optical techniques for recording strain or displacement fields are given in the course including coherent optical methods (holographic interferometry, speckle photography, electronic digital speckle interferometry, digital holography), photoelastic techniques, and also the shadow optical method of caustics. The theoretical framework of the methods and fields of their effective application in modern practice are stated, and also problematics of their future development are characterized. Definite attention is given to new advanced developments fulfilled in recent years in the field of experimental and computational methods for studying residual stresses, determining parameters of material damage as well as the methods for obtaining characteristics of material deformation. Experimental methods that facilitate characterization of material properties with respect to fracture and analysis of crack tip stress and deformation fields are also summarized.

Subjects covered by the lectures are

- Interference-Optical Methods of Solid Mechanics
- Photoelasticity
- Moire Interferometry
- Holography
- Speckle Methods
- X-Ray Stress Analysis

Learning outcomes of the course :

Through a deep understanding of the theory and the realization of a project, the student will be able to apply theoretical tools to understand the experimental methods of Solid Mechanics. In particular:

- He will have a deep understanding of experimental method in mechanics and will be able to summary, compare and explain them.
- He will have a deep understanding of the experimental methods based on optics, and will be able to summary, compare and explain them. He will also know their application range.
- He will be able to apply the resolution methods to classical experimental techniques.
- He will be able to analyze and to evaluate (justify and criticise) these methods.
- He will be able to analyze new problems.

Prerequisites and co-requisites/ Recommended optional programme components :

Basic knowledge in

- Tensor analysis
- Vector calculus
- Elasticity Theory
- Plasticity Theory
- Elasticity Theory

- Fracture Mechanics
- Damage Mechanics
- Finite Element Method

Planned learning activities and teaching methods :

Exercises with professor assistance and personal project.

Mode of delivery (face-to-face ; distance-learning) :

Face-to-Face

Required readings :

- Handbook of Experimental Stress Analysis. New York: Springer, 2008. 1083 p.
- Kobayshi A.S. Handbook Experimental Mechanics. Prentice Hall, 1987.
- Doyle J.F. Modern Experimental Stress Analysis Completing the solution of partially specific problems. Chichester: Willey, 2004. 435 p.
- Razumovsky I.A. Interference-Optical Methods of Solid Mechanics. Berlin Heidelberg: Springer, 2011. 180 p.
- Thomas, K.: Handbook of Holographic Interferometry: Optical and Digital Methods, pp. 269–273. Wiley-VCH GmbH & Co. KGaA, Weinheim (2005).
- Schnars, U., Jüptner, W.: Digital Holography. 164 pp. Springer, Berlin (2005).
- Frocht, M.M.: Photoelasticity. John Wiley and Sons, New York (1941).
- Springer Handbook of Lasers and Optics. F. Träger (Ed.). Berlin, Heidelberg: Springer, 2007.
- W. Steinchen, L. X. Yang: *Digital Shearography – Theory and Application of the Digital Speckle Pattern Shearing Interferometry* (SPIE, Washington 2003)

Assessment methods and criteria :

Evaluation is based on the realization of a project related to the use / development of experimental methods and on an examination.
The examination is based on the whole content of the class. Problems similar to the ones studied during the classes, and new problems will be part of the questions. Justification using the theoretical content is also asked.
Participation to the examination and achievement of the project are mandatory.

Teaching Method: Class participation is mandatory. Everyone is expected to participate in discussions relating to reading materials, homework, exams and lectures.

Guaranteed Recipe for Success:
1) Take notes during lecture and sections.
2) After each lecture but before the next lecture review your notes. Identify the parts you do not understand.
3) Come to each lecture and discussion section with specific questions.
4) Keep up with the reading so that you have some familiarity with each topic prior to hearing about it in the lecture.
5) Find at least one "partner" in the class with whom you can meet at least once or twice a week to discuss materials from the lectures, the reading assignments and the homework.

6) Take the homework assignment seriously. Do not try to do the whole assignment the night before it is due. Some version of the homework questions will appear on the exams.

Course Contents

EXPERIMENTAL MECHANICS
Solid Mechanics Topics
1 **Analytical Mechanics of Solids**
1.1 Elementary Theories of Material Responses
1.2 Boundary Value Problems in Elasticity
2 **Materials Science for the Experimental Mechanist**
2.1 Structure of Materials
2.2 Properties of Materials
3 **Mechanics of Polymers: Viscoelasticity**
3.1 Historical Background
3.2 Linear Viscoelasticity
3.3 Measurements and Methods
3.4 Nonlinearly Viscoelastic Material Characterization
3.5 Recognizing Viscoelastic Solutions if the Elastic Solution is Known
4 **Composite Materials**
4.1 Strain Gage Applications
4.2 Material Property Testing
4.3 Micromechanics
4.4 Interlaminar Testing
4.5 Textile Composite Materials
4.6 Residual Stresses in Composites
5 **Fracture Mechanics**
5.1 Fracture Mechanics Based on Energy Balance
5.2 Linearly Elastic Fracture Mechanics
5.3 Elastic–Plastic Fracture Mechanics
5.4 Dynamic Fracture Mechanics
5.5 Subcritical Crack Growth
5.6 Experimental Methods of Fracture Mechanics
6 **Active Materials**
6.1 Background
6.2 Piezoelectrics
6.3 Ferroelectrics
6.4 Ferromagnets
7 **Biological Soft Tissues**
7.1 Constitutive Formulations – Overview
7.2 Traditional Constitutive Relations
7.3 Growth and Remodeling – A New Frontier
8 **Electrochemomechanics of Ionic Polymer–Metal Composites**
8.1 Microstructure and Actuation
8.2 Stiffness Versus Solvation
8.3 Voltage-Induced Cation Distribution
8.4 Nanomechanics of Actuation
8.5 Experimental Verification
8.6 Potential Applications
9 **A Brief Introduction to MEMS and NEMS**
9.1 Background
9.2 MEMS/NEMS Fabrication
9.3 Common MEMS/NEMS Materials and Their Properties
9.4 Bulk Micromachining versus Surface Micromachining

32.2 Implantable Biomedical Devices
32.3 Biologically Inspired Materials and Systems
33 **High Rates and Impact Experiments**
33.1 High Strain Rate Experiments
33.2 Wave Propagation Experiments
33.3 Taylor Impact Experiments
33.4 Dynamic Failure Experiments
34 **Delamination Mechanics**
34.1 Theoretical Background
34.2 Delamination Phenomena
35 **Structural Testing Applications**
35.1 Past, Present, and Future of Structural Testing
35.2 Management Approach to Structural Testing
35.3 Case Studies
35.4 Future Trends
36 **Electronic Packaging Applications**
36.1 Electronic Packaging
36.2 Experimental Mechanics in the Field of Electronic Packaging
36.3 Detection of Delaminations
36.4 Stress Measurements in Silicon Chips and Wafers
36.5 Solder Joint Deformations and Strains
36.6 Warpage and Flatness Measurements for Substrates, Components, and MEMS
36.7 Transient Behavior of Electronics During Shock/Drop
36.8 Mechanical Characterization of Packaging Materials

Literature

Handbook of Experimental Stress Analysis. New York: Springer, 2008. 1083 p.
Razumovsky I.A. Interference-Optical Methods of Solid Mechanics. Berlin Heidelberg: Springer, 2011. 180 p.
Thomas, K.: Handbook of Holographic Interferometry: Optical and Digital Methods, pp. 269–273. Wiley-VCH GmbH & Co. KGaA, Weinheim (2005).
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W. Steinchen, L. X. Yang: Digital Shearography – Theory and Application of the Digital Speckle Pattern Shearing Interferometry (SPIE, Washington 2003)
G. Cloud: *Optical Methods of Engineering Analysis* (Cambridge Univ. Press, Cambridge 1998)
R. Jones, C. Wykes: *Holographic and Speckle Interferometry*, 2nd edn. (Cambridge Univ. Press, Cambridge 1989)
Patterson, E.A., "Digital Photoelasticity: Principles, Practice, and Potential", *Strain*, **38**(1), 27–39, 2002.
Ramesh, K., *Digital Photoelasticity—Advanced Techniques and Applications*, Springer, New York, 2000.
Asundi A.K. Matlab for Photomechanics. Amsterdam: Elsevier, 2002. 199 p.
Searle G.F.C. Experimental Elasticity. A Manual for the laboratory. Cambridge: Cambridge University Press, 2013. 206 p.
Sciamarella C.A., Sciamarella F.M. Experimental Mechanics of Solids. Willey, 2012. 776.

Recommended Literature

1) Sciamarella C.A., Sciamarella F.M. Experimental Mechanics of Solids. Willey, 2012. 776.

Experimental Mechanics of Solids is a comprehensive introduction to the topics, technologies and methods of experimental mechanics of solids. It begins by establishing the fundamentals of continuum mechanics, explaining key areas such as the equations used, stresses and strains, and two and three dimensional problems. Having laid down the foundations of the topic, the book then moves on to look at specific techniques and technologies with emphasis on the most recent developments such as optics and image processing. Most of the current computational methods, as well as practical ones, are included to ensure that the book provides information essential to the reader in practical or research applications. Key features of the book:

- Presents widely used and accepted methodologies that are based on research and development work of the lead author
- Systematically works through the topics and theories of experimental mechanics including detailed treatments of the Moire, Speckle and holographic optical methods
- Includes illustrations and diagrams to illuminate the topic clearly for the reader
- Provides a comprehensive introduction to the topic, and also acts as a quick reference guide

This comprehensive book forms an invaluable resource for graduate students and is also a point of reference for researchers and practitioners in structural and materials engineering.