MECHANICS OF POLYMER SOLIDS AND FLUIDS

ChBE/MSE/ME 7771
Tuesdays, Thursdays: 5:00 pm – 6:15 pm
Van Leer C457

Instructor: Karl I. Jacob, MRDC 4509
e-mail: karl.jacob@mse.gatech.edu, Phone: (404) 894-2541
Please use Canvas for all email communications.

Learning/Teaching Objectives:

(1) Provide students in Polymer Science & Engineering, Chemical Engineering and Materials Science and Engineering and Mechanical Engineering with a basic knowledge of the behavior of polymeric solids
(2) Enable students to use fundamental principles to solve real manufacturing problems related to plastic flow
(3) Provide students in Polymer Science and Engineering, Chemical Engineering, Materials Science and Engineering and Mechanical Engineering with a thorough and comprehensive background of polymeric flow as non-Newtonian fluid mechanics and rheology.
(4) Enable students to use fundamental principles to solve real manufacturing problems and rheology for polymers
(5) Introduce computational techniques to simulate problems in rheology

Prerequisites: Basic courses on mechanics of solids and fluids; exposure to differential equations, tensor algebra and calculus, and computer programming are helpful, although not required.

Reference Books:

Theory of Elasticity, Sokolnikoff
Theory of Elasticity, Timoshenko
Mechanical Properties of Solid Polymers, I. M. Ward
The Mathematical Theory of Plasticity, Hill
Plasticity, Theory and Application, Mendelson
Foundations of Solid Mechanics, Y.C. Fung
Advanced Fracture Mechanics, M. F. Kanninen and C. H. Poplar
The Structure and Rheology of Complex Fluids, R. G. Larson
Introduction of Fluid Dynamics, S. Middleman
Transport Phenomena, R. B. Bird, W. E. Stewart, E. N. Lightfoot
Principles of Non-Newtonian Fluid Mechanics, G. Astarita, G. Marrucci
An Introduction to the Mechanical Properties of Solid Polymers 2nd Edition, I. M. Ward (Author), J. Sweeney, Wiley

Dynamics of Polymeric Liquids, Vol I, 2 nd edition, R. B. Bird, R. C. Armstrong, O. Hassager, Wiley-Interscience

Handouts from various solid mechanics books will be given. The last two books are ones directly related to this course, especially the last one. It is a very good book, but somewhat expensive. But there are cheaper options such as renting.

Two main sections:

Foundations of Mechanics, constitutive equations of solids and fluids, and flow (20-30%)

(1) Basic Framework for Solid Mechanics

Indicial notation, force balance & momentum balance, state of stress, principal stresses

(2) Constitutive Equations for Solids (stress-strain behavior of polymers)

Material symmetry & anisotropy, large deformation & non-linearity

(3) Failure Conditions for Polymers, Yield and Post Yield Behavior (Flow of Solids)

Yielding, three-dimensional yield conditions, especially Tresca and von Mises yield criterion
Plasticity, flow rule, loading & unloading behavior, consistency condition
Strain hardening
Mullins and Payne effects in polymer systems

Dynamics of polymer solution and melt (non-Newtonian fluids – 70 to 80%)

(1) Framework of Fluid Mechanics

Mass and momentum balance equations; energy equations; kinematics; and boundary conditions.

(2) Non-Newtonian Fluids

Structure of Polymeric Fluids
Flow Phenomena in Polymeric Fluids
Material Functions
- Steady Shear Flow
- Small Amplitude Oscillatory Flow
- Inception of Steady Shear Flow
- Cessation of Steady Shear Flow

Sudden Shearing Displacement
Creep
Constrained recoil
Constitutive Equations

(3) Generalized Newtonian Fluids

Concept of Generalized Newtonian Fluids
Viscometric Flow
Power law, Ellis, Carreau-Yashuda, Bingham plastic fluids, etc.

(4) Numerical Methods

Calculus of Variations
Weighted Residual Method
Finite Element Method
Applications using commercial software
Development of computer programs (just introduction due to lack of time)

(5) General Linear Viscoelastic Fluids

Generalized Maxwell Fluid
Jeffrey's Model
Differential and Integral Representations
Turn Table Experiment

(6) Convected and Corotational Models for Polymeric Fluids

Convected Derivatives
Upper Convected Models
Lower Convected Models
Jaumann Co-rotational Models
Ordered Fluids
Criminale-Ericksen-Filbey Fluids
Reiner-Rivlin Fluids, etc

(7) Quasi-Linear Differential Models for Polymeric Fluids

Convected Maxwell Model
Oldroyd's Fluid A and B
White-Metzner Fluid
Oldroyd 8-Constant Model
Giesekus Fluid
Johnson-Segalman Fluids, etc.

(8) Integral Forms

Single Integral Constitutive Equations
Quasi-Linear Integral Models
Non-Linear Integral Constitutive Equations
    K-BKZ Equation
    Rivlin-Sawers Equation
    Doi-Edwards Equation
Memory Integral Expansions

(9) Introduction to the Kinetics of Polymeric Liquids

Dumbbell, bead-spring chain, bead-rod-spring models

(10) Anisotropic Polymeric Fluid Flow (*Time permitting)

Introduction to liquid crystals, anisotropic (LC) flow, pattern formation, Ericksen-Leslie theory, molecular theory of Leslie viscosities, introduction to nematic and smectic crystal flow.

(11) Numerical Applications (*Time permitting)

Solution to Boundary Value/Initial Value Problems
Development of Computer Algorithms
Simulation using POLYFLOW, FIDAP, etc.
    Fiber Spinning
    Mold Filling, etc.

(12) Current Developments (*As time permits)

Grading Policy:

Two in-class tests.
Finals: In-class comprehensive, but only 1 and ½ hours long.
One 4x6 inch index card is allowed during the tests, writing both sides is allowed

Composite score calculation: 5 % Homework, 30 % for each quiz, 30 % Finals
There will be five random very short quiz (probably taking five minutes or less) each with one point (total 5 points). For the quiz, only a genuine effort will be graded, no requirement for correct answers.

HW is graded primarily for demonstrating the thought process and effort, not necessarily for correct answers.

	Scores between	*Letter grade*
Grading Policy:	90 – 100	A
	80 – 89	B
	70 – 79	C
	60 – 69	D etc.

However, if the class average is below 80, scores will be scaled to bring the class average to 80 and the highest score to 100. If the class average is above 80, scores won't be curved, unless the highest score is well below 100 (below 90 for example).

Important dates:

Fall Break: Oct 14,15
Withdrawal Deadline: Oct 26, 4:00 pm.
Final Exam: Seems like there is requirement from the Registrar's office, no time slots for T, Th 5:00 pm class. We will have to pick one from the time corresponding to T 5:00 pm class or Th 5:00 pm class.
Tentative dates of tests: September 26 and October 31, to be confirmed within the first week of classes.

If anyone had to miss one test for an approved excuse, the score for that test will be replaced by the scaled (based on the class average) scores from other tests.

Any changes in syllabus, if required, will be announced with adequate notice.