# PDC 2: Mechanics and Reliability of Lead-Free Solder Joints

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**Abstract:** This course will cover an overview of the experimental characterization and modeling approaches used for the mechanical behavior and reliability of lead-free solder materials used in electronics assembly and packaging. Emphasis will be placed on making the subject matter applicable by practicing semiconductor packaging engineers, and several example case studies will be incorporated from the automotive, aerospace, and computing industries. Topics to be covered include composition and microstructure of solders, methods used for mechanical characterization, experimental stress-strain and creep test data for lead free solders, material properties, constitutive models (elastic, plastic, creep, viscoplastic), mechanical response of single grain solder joints and associated modeling approaches, cyclic stress-strain behavior and fatigue laws, microstructural evolution and aging effects, thermal cycling reliability test data for various components, damage accumulation during cyclic loading, and finite element modeling methods for solder joint reliability. Several recent developments will be addressed including low temperature soldering and microbumps in advanced packaging. A detailed list of topics is presented in the outline below.

## Outline:

1. Introduction to Solders Used in Electronic Packaging
    a. Composition and Microstructure
    b. Sn-Pb, SAC Alloys, SAC+X Alloys, Sn-Bi, Sn-Ag, etc.
    c. Low Temperature Solder (LTS) and SAC-LTS Mixed Solder Assemblies
2. Experimental Test Methods for Solder Mechanical Behavior
    a. Uniaxial and Shear Mechanical Testing (Stress-Strain, Creep)
    b. Nanoindentation Testing and Small Solder Joint Testing
3. Lead-Free Solder Mechanical Behavior (Bulk Solders)

a. Uniaxial and Shear Stress-Strain Behaviors
    i. Literature Data for Important Lead-Free Solders
    ii. Material Properties (Modulus, Poisson’ s Ratio, Yield Stress, UTS)
    iii. Empirical Models, Temperature and Rate Dependencies
b. Creep Behavior
    i. Literature Data for Important Lead-Free Solders
    ii. Material Properties (Creep Rate)
    iii. Empirical Creep Rate Models, Stress and Temperature Dependencies
c. Constitutive Models
    i. Elastic, Elastic-Plastic, Creep, Viscoplastic (Anand)
    ii. Practical Application in Finite Element Codes and Industry Case Studies

4. Lead-Free Solder Mechanical Behavior (Single Grain Solders)
    a. Nanoindentation Data (Modulus, Hardness, Creep)
    b. Single Grain Mechanical Testing
    c. Anisotropic Behavior of Tin (Elastic, Plastic)
    d. Constitutive Modeling (Elastic, Crystal Plasticity)
    e. Case Studies and Practical Application to Advanced Packaging
5. Cyclic Stress-Strain Behavior
    a. Temperature and Strain Range Dependencies
    b. Constitutive Modeling and Fatigue Laws
6. Effects of Aging and Damage
    a. Isothermal Aging Effects
        i. Microstructure Evolution
        ii. Stress-Strain and Creep Behaviors

iii. Changes to Constitutive Models and Fatigue Laws

b. Damage Due to Cyclic Loading

i. Microstructure Evolution

ii. Stress-Strain and Creep Behaviors (Bulk)

iii. Changes to Constitutive Models and Fatigue Laws

7. Solder Joint Reliability

a. Conventional Approaches Using Finite Element Analysis

i. Constitutive Models (Anand, Creep Law)

ii. FEM Meshing, Volume Averaging, Convergence

iii. Failure Prediction

iv. Case Studies from Industry

b. Advanced Approaches Using Finite Element Analysis

i. Evolving Microstructure and Damage Mechanics

## Lecturer Biography:

Jeffrey C. Suhling received his Ph.D. degree in Engineering Mechanics in 1985 from the University of Wisconsin. He then joined the Department of Mechanical Engineering at Auburn University, where he currently holds the rank of Quina Distinguished Professor and Department Chair. Prior to becoming Department Chair, he served as Center Director for the NSF Center for Advance Vehicle Electronics (CAVE). His research interests include applications of solid mechanics to electronics packaging, including emphasis on lead free solders and silicon sensors. In IEEE, Dr. Suhling has been a member of the Electronics Packaging Society for the past 30 years. He has served in several EPS leadership roles including Vice President, Education (2019-2022), Vice President, Finance (2023-2004), and President Elect (2025).