Research in Experimental Solid Mechanics

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TEQIP Workshop -
Experimental Solid Mechanics

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Constituents of Experimental Solid Mechanics

Science and Engineering

- Structure-Property Relationship
- Material Response under Different Loading Conditions
- Physical Understanding of Failure
- Deformation Mechanisms
- Environmental Effects
- Failure of Interfaces
- Structure-Fluid Interaction Effects

Macro/Micro/Nano Mechanics

- Mechanical Properties
- Failure and Damage Evolution
- Fracture Mechanics
- Fatigue and Reliability
- Deformation Mechanisms
- Structural Stability
- Dynamic Failure and Fragmentation
- Rate and Pressure Sensitivity

Effect of Micro/Nano Structure

- Anisotropy
- Inhomogeneity
- Polycrystallinity
- Phase Transformations
- Diffusion Processes
- Void Nucleation and Growth
- Amorphous vs. Crystalline

Loading

- Quasi-Static, Dynamic, Cyclic
- Creep and Stress Relaxation
- Thermomechanical
- Electromechanical
- Thermal/Electrical
- Environmental

Macro/Micro/Nano Scale
Experimental Solid Mechanics

Materials of Interest

- Metals, Ceramics, Polymers
- Nanocrystalline Materials
- Bulk Metallic Glasses
- Designer Materials
- Active Materials (Shape Memory, Piezoelectric, Ferroelectric, etc.)
- Nano/CN(T/F) Composites

Experimental Techniques

- Macro/Micro Scale Tension and Compression
- Dynamic Tension and Compression
- Indentation
- Dynamic Mechanical Analysis
- In-situ Experiments
- Digital Image Correlation

Characterization Tools

- Atomic Force Microscopy with DIC
- Optical Microscopy with DIC
- Scanning Electron Microscopy with DIC
- Nanoindentation
- Interferometry
- High Speed Imaging
- Transmission Electron Microscopy
- Electron Back-Scattered Diffraction

Applications

- MEMS and NEMS Sensors
- RF-MEMS and Bio MEMS
- Aerospace Composites
- Military Equipment
- Armor Protection Materials
- Medical Implants
- Cellular Materials

Why do we need experiments on solids?

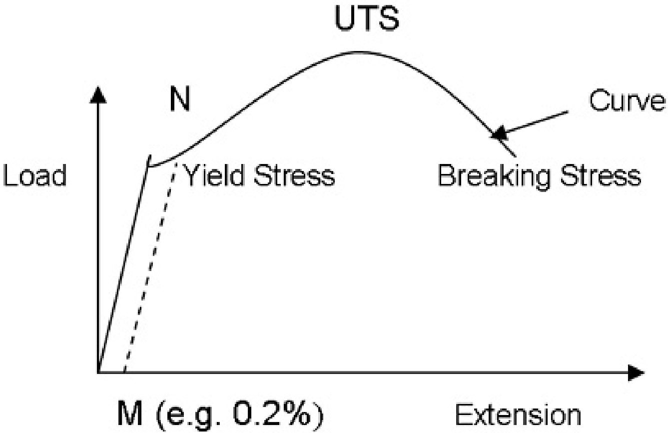
- Measure properties of a solid - modulus, toughness, etc.
- Measure the distribution of stress, strain, displacement, temperature, etc.
- **Understand the physics of deformation and relate it to applied loads as well as microstructure**
- Constitutive models

$$\sigma = f(\varepsilon, \dot{\varepsilon}, T, ...)$$

- Failure in materials and structures as a function of defect (size, density and distribution), geometry (notch, crack, etc.)
- Validation of theoretical/numerical results
    - Macroscopic properties
    - Strain and stress distribution

Why do you need an experiment?

For most ductile materials, stress vs. strain curves are generated to extract mechanical properties as well as yield surfaces

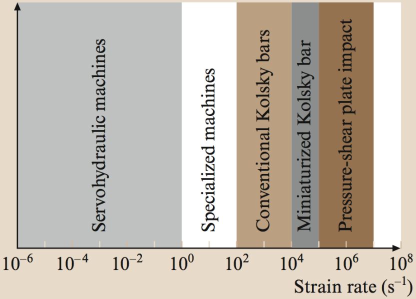


Dynamic Deformation Kolsky Bar Experiements

- The need for dynamic deformation arises because, the material response is sensitive to loading rate
- For example, car crash, metal forming, metal forging, bullet proof jackets, etc.
- Two issues under dynamic deformation are material inertial and wave propagation
- So, when doing high strain rate experiments to understand the response, it is important to separate the inertial and applied external forces

videos

High Strain Rate Experimental Techniques



[1]

- Quasi-static strain rates - $< 10^{-3}s^{-1}$
- Intermediate strain rates - $> 10^{-3}s^{-1}$
- High strain rates - $> 10^{2}s^{-1}$
- Very high strain rates - $> 10^{4}s^{-1}$
- Ultra high strain rates - $> 10^{6}s^{-1}$

- The choice of experimental technique determines the strain rate range accessible for different materials
- Material properties that affect that the strain rate include, density, wave speed, yield strength, etc.
- The specimen geometry also changes between the techniques to ensure that uniform stress state exists during the experiment

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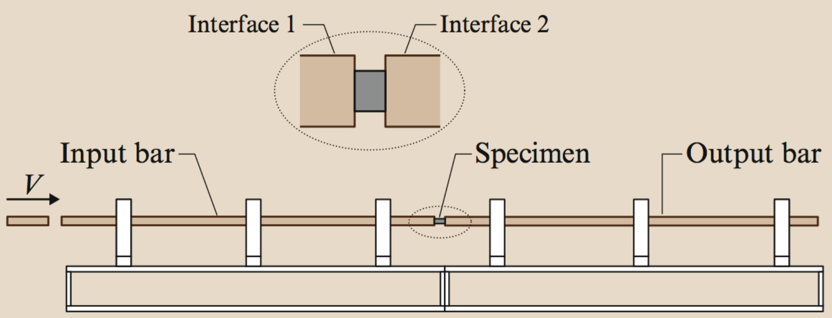
[1] *Ramesh, Experimental Mechanics Handbook, 2009*

Kolsky Bar Experiment - Compression



[2]

- Stress wave is generated by launching a projective onto the input bar
- Strains are measured in the input and the output bar
- Alignment of the bars and projectile are very important
- The bars need to move freely in the supports in their length direction

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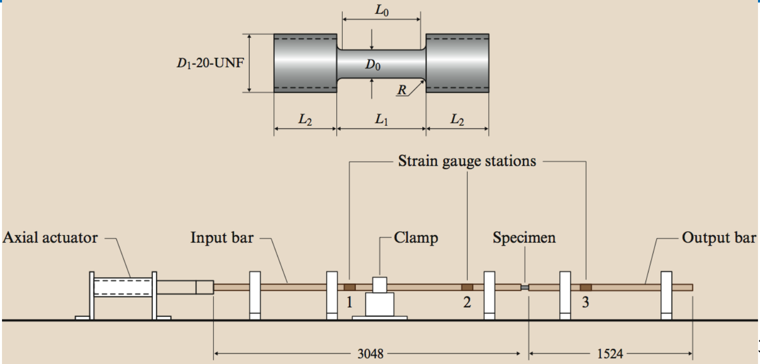
[2] *Ramesh, Experimental Mechanics Handbook, 2009*

Kolsky Bar Experiment - Tension



[3]

- A tensile pulse is generated by the sudden release of tensile strain stored in the bar using a clamp
- The pulse shape and wave form characteristics are influenced by the clamp design
- Finite element analysis is required for specimen design

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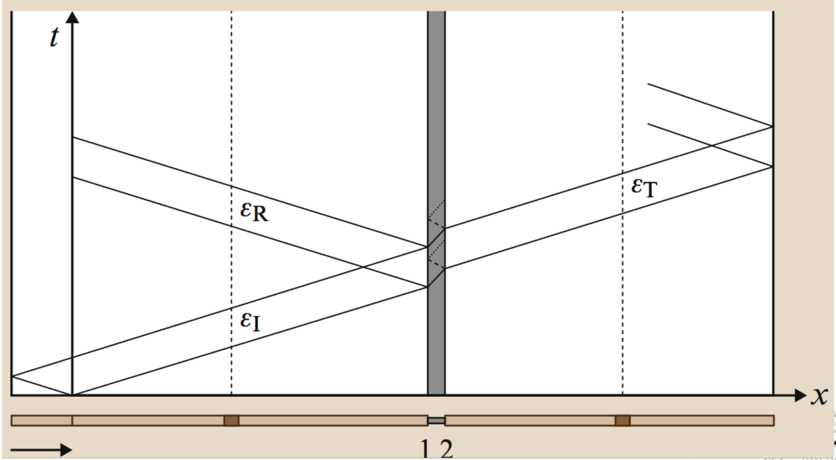
[3] *Ramesh, Experimental Mechanics Handbook, 2009*

Tension/Compression x - t Diagram



[4]

- Lagrangian or x-t diagrams are extremely useful in the analysis of Kolsky bar experiments

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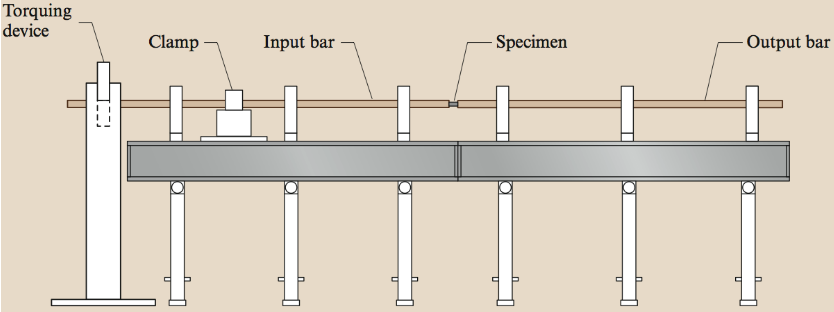
[4] *Ramesh, Experimental Mechanics Handbook, 2009*

Kolsky Bar Experiment - Torsion



[5]

- In a torsion bar a torsional (shear) wave is propagated in the bars and the specimen
- Torsional bars do not required dispersion correction
- Large strains can be generated in a torsional bar
- Bending waves need to avoided during operation
- Finite element analysis is required for the specimen design

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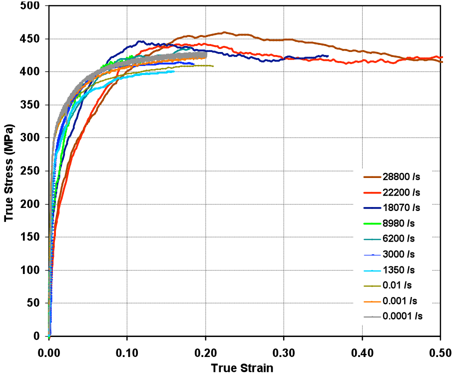
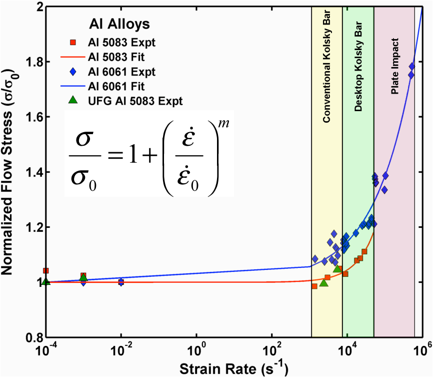
[5] *Ramesh, Experimental Mechanics Handbook, 2009*

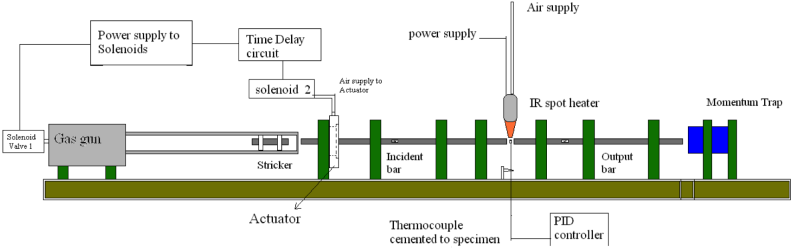
Dynamic Strength of Armor Materials



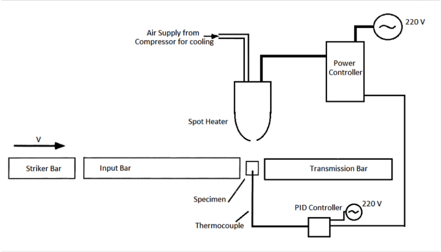


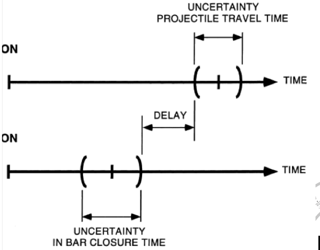
- Dynamic strength, failure, rate-dependence and fracture in metals and ceramics

High Temperature Dynamic Deformation



[6]





[7]

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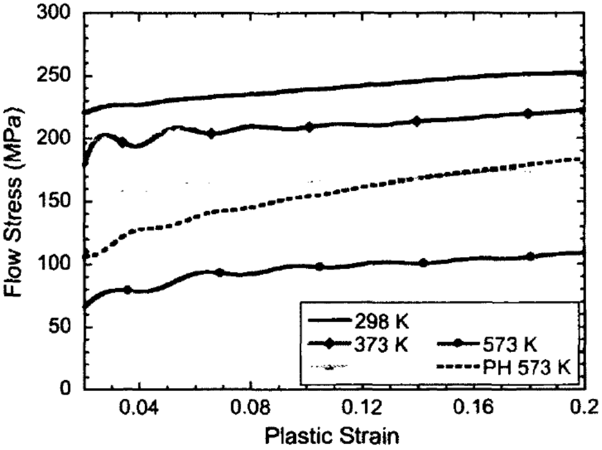
[6] Pare, Jonnalagadda, 2014

[7] Lennon and Ramesh, 1997

High Temperature Dynamic Deformation



[8]

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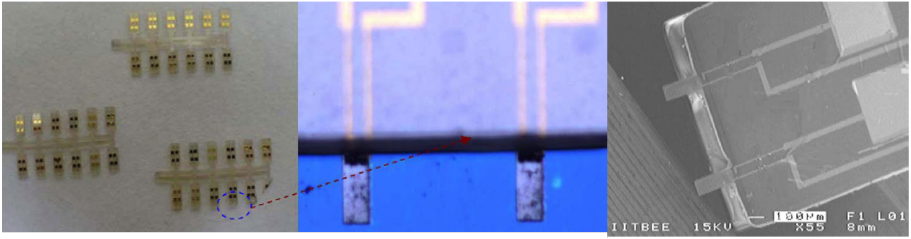
[8] Huskins et al. (2010)

Micro/Nano Scale Experiments

- Macro, Micro (< 100), Nano ($< 100nm$) length scales often refer to the geometrical or the micro structural length scales involved
- The interest in going down the scale is to take advantage of the difference in physical behaviour at micro and nano scale, e.g., gravitational forces, surface tension, etc.
- From a mechanical behaviour of materials perspective, micro/nano scale experiments consider geometric as well as materials length scales
- Geometric: size of the structure
- Material: Grain size

Microscale Experiments on Polymers



[9]

- Recently trend in MEMS devices is the use of polymeric materials due to their simple and low temperature fabrication
- Need to understand the mechanical behaviour of these polymers including their viscoelastic response

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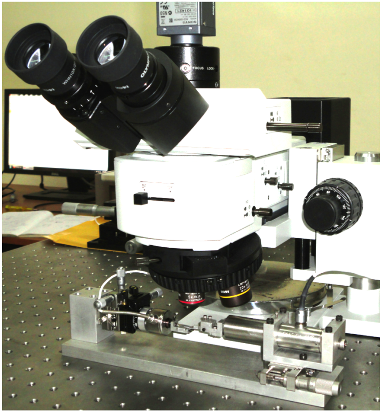
[9] Seena et al. 2010, 2011

Microscale Experiments on Polymers


[10]

In situ experiments can extract full field deformation during the entire experiment and this can enhance our understanding of the deformation of solids

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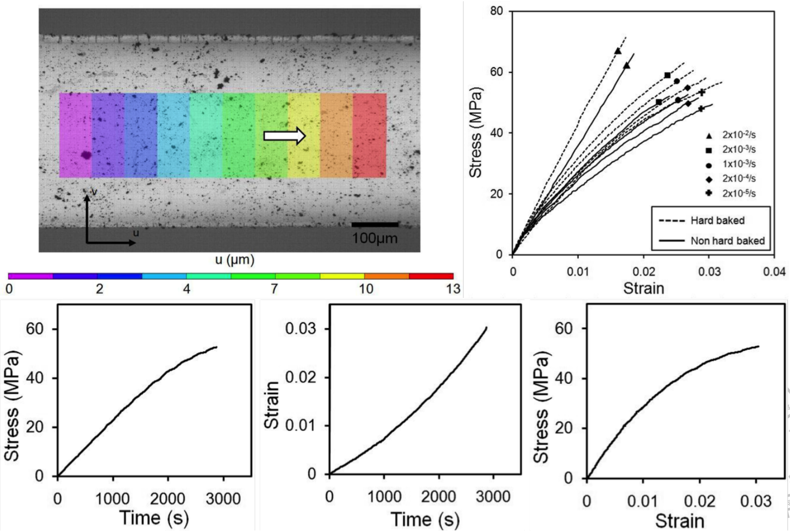
[10] Jonnalagadda et al. 2008, 2010

Microscale Experiments on Polymers



[11]

Important Considerations When Doing Experiments!

- Qualitative vs quantitative
- Assumptions used while conducting an experiment
- Resolutions of the measuring instruments
- Verification/benchmarking of results
- Observations during an experiment can lead to new discoveries