Small Specimen Test (SST) Methods

presented by

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with contributions from PNNL, ORNL, ANL

Fusion Program Review

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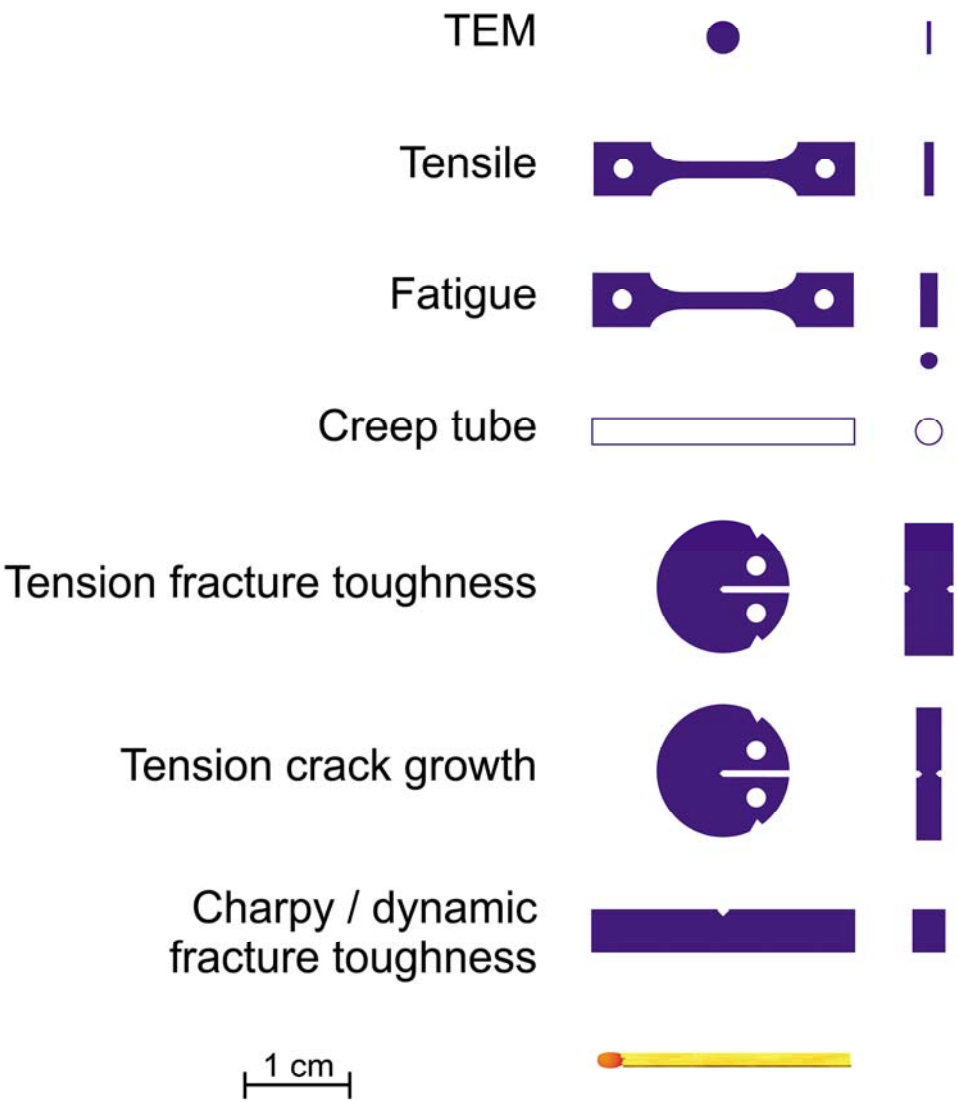
Background

- Numerous small specimen techniques have been developed in the US fusion materials program as well as internationally - generally US the leader
  - » Small volume irradiation facilities (accelerators, IFMIF, fission reactors like HFIR)
  - » Enables test matrices with requisite variable combinations and redundancy
  - » May minimize temperature uncertainty, flux gradient effects, uses limited amounts of materials
  - » Squarely face the issue to test data to structural integrity assessment translation

HFIR specimens ≈ __ cm^3

Proposed specimen geometry for IFMIF



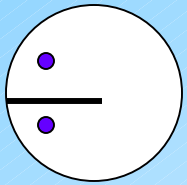
Significant volume reduction (20-125 times) compared to conventional standards

Recent Progress

- Recent efforts directed at combining specimen miniaturization with *understanding* of basic flow and fracture processes and modeling to:
  - » Extract basic properties and insights
  - » Optimize specimens for controlled, single-variable test matrices
  - » Develop multipurpose specimens
  - » Tie to structural integrity assessment
- Briefly review developments in fracture, deformation, new techniques

Fracture

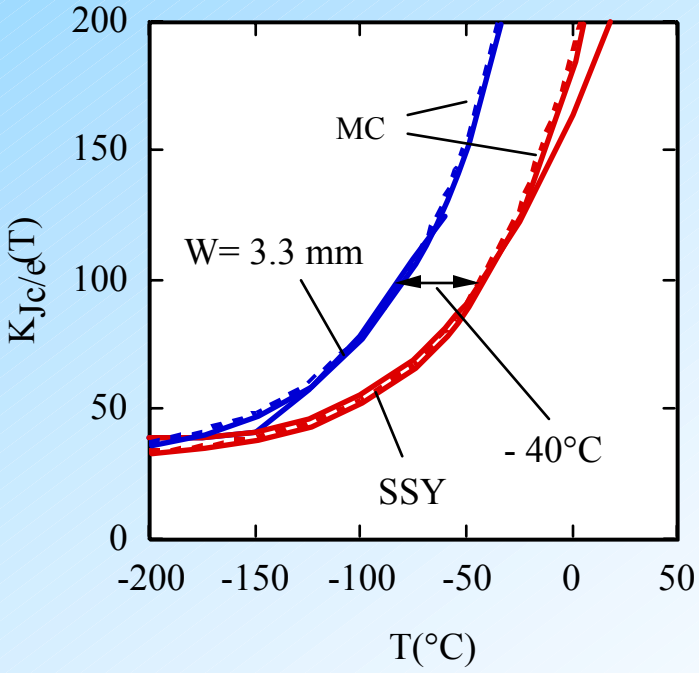
- Emphasizing MC-ΔT method for fracture toughness
- 'Standard' small specimen geometries: 12.4 mm DCT, KLST, and 3.3^2 (or 1.65^2) x 18.3 mm BB



- Use small set generic K(T)-ΔT for size/geometry
- <u>Or</u> make statistical-constraint size & geometry adjustment based on empirically calibrated models
- Has led to even more aggressive miniaturization down to specimens with 0.8 to 2.5 mm^2 cross sections using special pre-cracking techniques

Constraint Effects

- Model prediction of SSY and W = 3.3mm $K_{Jc/e}$ curves based on a specified set of constitutive and local fracture properties.



Subminiature Fracture Specimens

- Standard and sub-miniaturized fracture specimens a cornerstone of US-JAERI and US-MEXT irradiations as well as US-European collaborations (e.g. MACE)
  - » Evaluation of MC-ΔT method for irradiated alloys
  - » Single variable experiments for alloy design
  - » Mechanism studies like effects of He on ΔT_o

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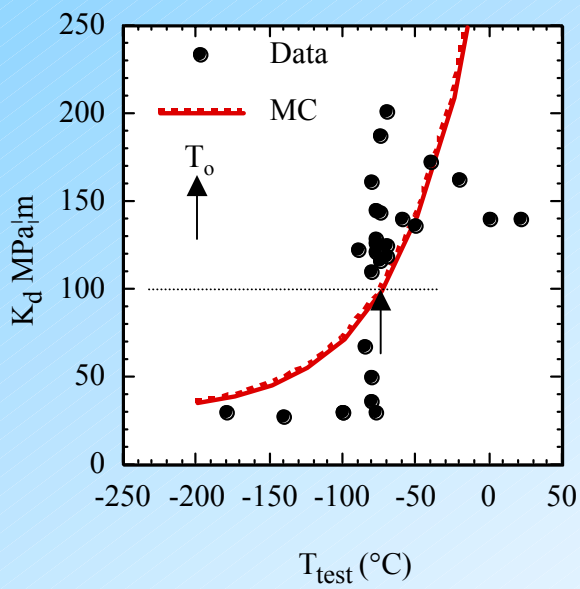
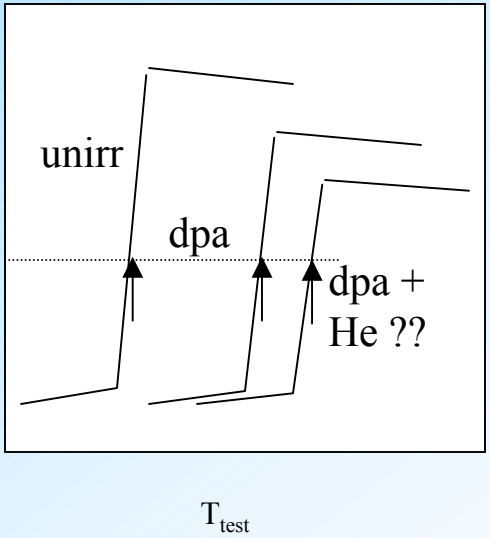
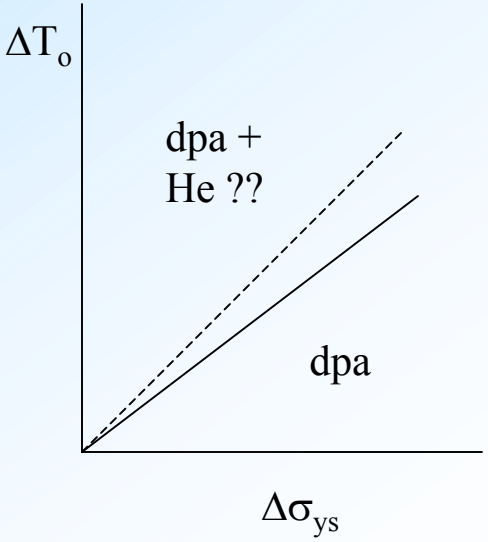
Subminiaturized Bend Bars

- Dynamic (impact) fracture toughness from 1.6x1.6x10 mm bend bars - the ultra-sharp transition facilitates comparative T_o assessments in single variable effects studies (e.g. He effects).





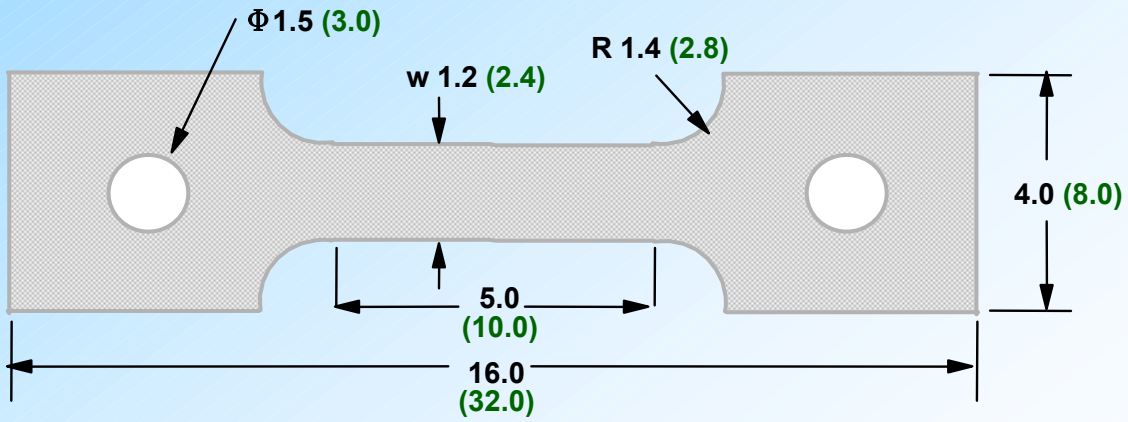


Deformation

- A variety of techniques have been developed and applied to determine various flow properties of irradiated materials:
  - » Miniaturized tensile specimens
  - » Spherical Punch tests
  - » Shear Punch tests
  - » Microhardness, instrumented microhardness,...
- Ongoing work to extend and automate techniques

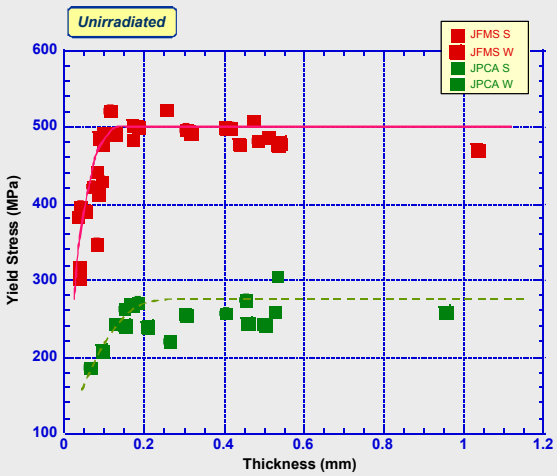
Miniature Tensile Tests

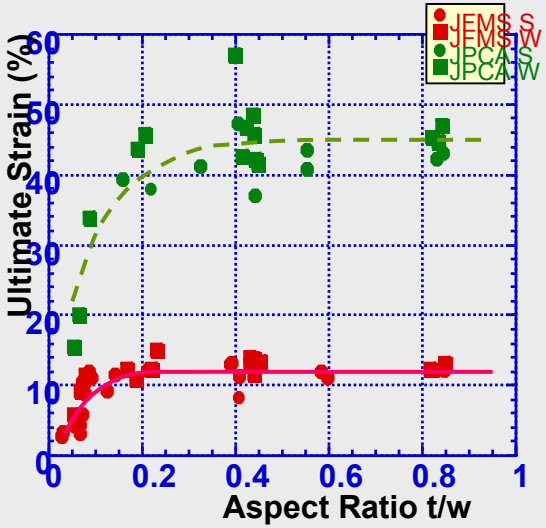
- Mostly flat dogbone geometries
  - » 0.5mm < W < 4.5 mm
  - » 0.05 mm < t < 1 mm
- limits imposed by grain size/number and fabrication defects

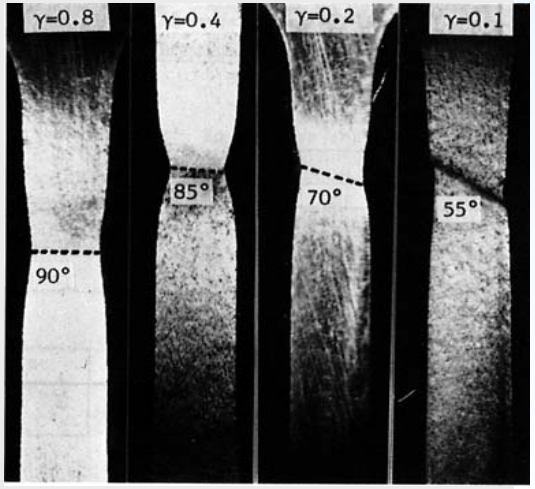


Miniature Tensile Tests

- σ_y depends on thickness but not aspect ratio
- UTS, ε_u and necking angle depend on aspect ratio

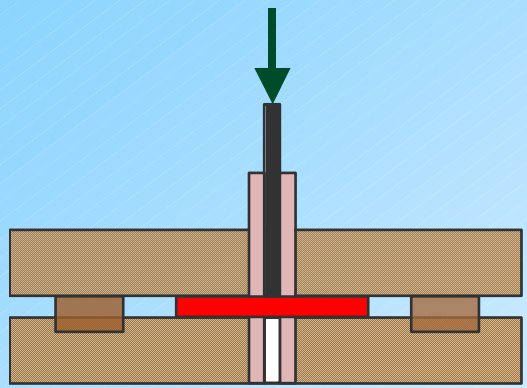


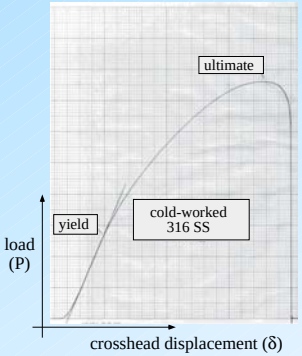


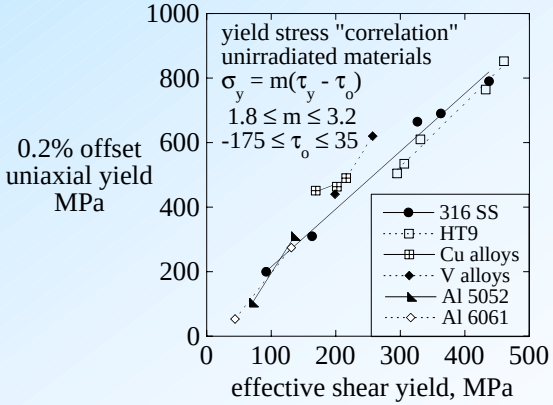


Punch Tests

- Variety ball/flat‘punch’ tests for 3 mmTEM discs
- Shear punch tests (SPT) use flat cylindrical punch

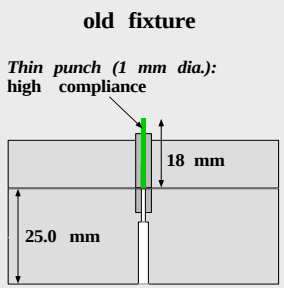


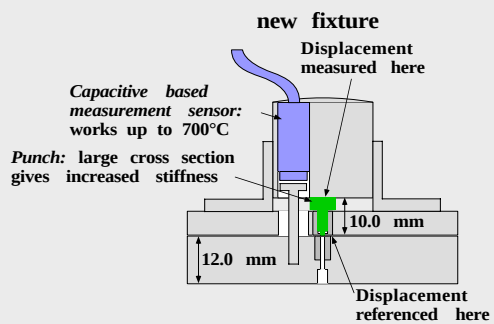


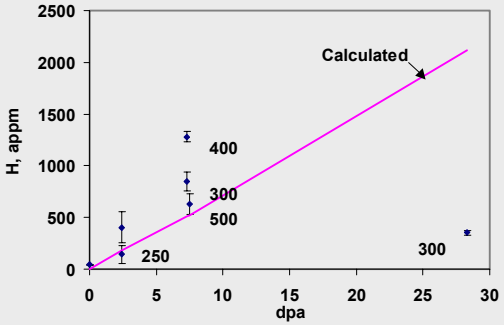


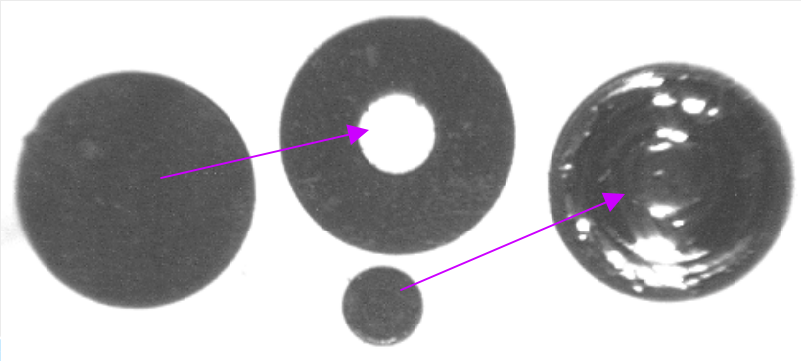
Punch Tests

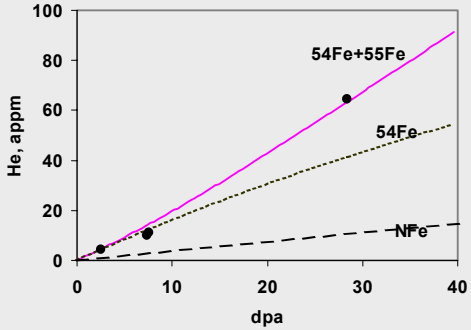
- Recent SPT experimental improvements, FE modeling





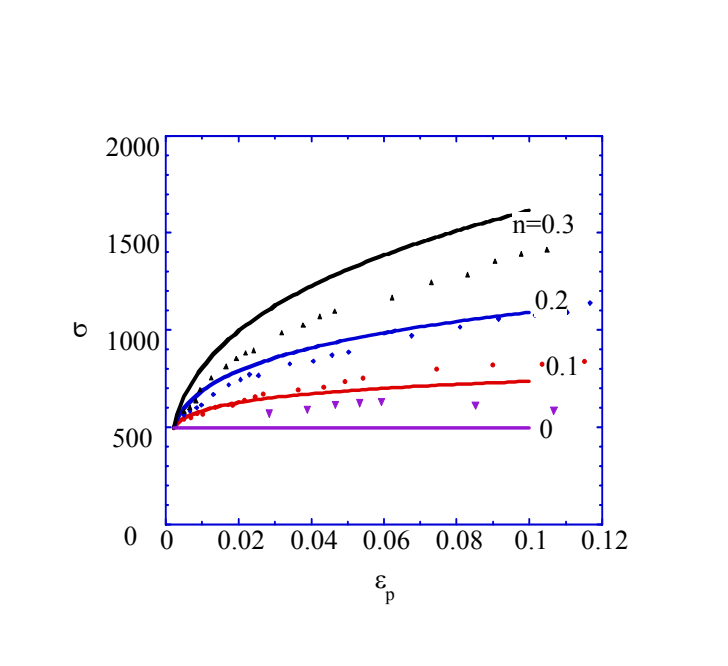






Microhardness

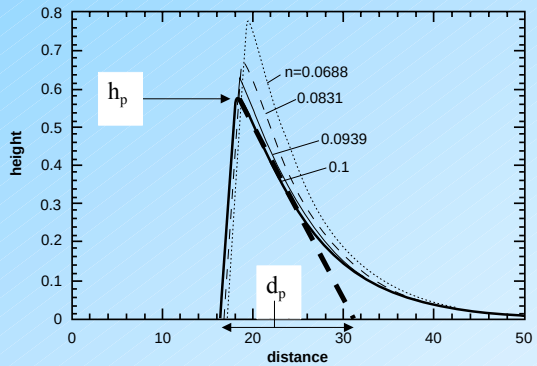
- Empirical microhardness-yield/ultimate stress relations extended to provide $\sigma(\varepsilon)$ data using both indentation pile-up geometry <u>or</u> P-d_t data
- Empirical methods somewhat material specific and shown to have limits at low (and high) strain, strain hardening -- e.g., no generally reliable way to extract σ_{ys}

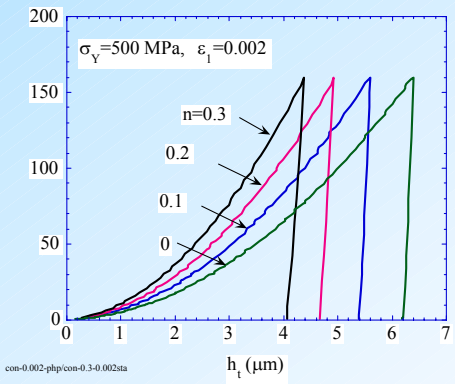


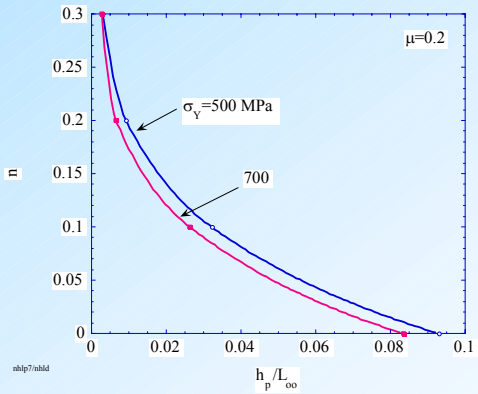
Combined h_p/d_p - P-d_t Method

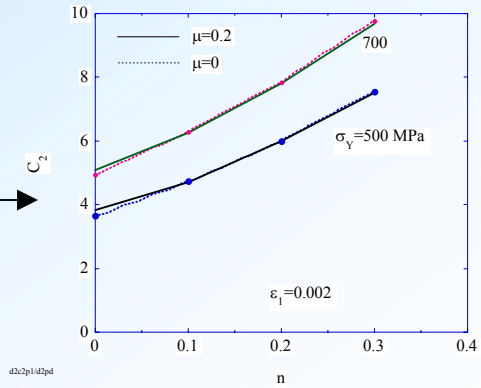
- New iterative procedure to evaluate σ_{ys} [and $\sigma(\varepsilon)$] from combination of pile-up geometry <u>and</u> P-d_t

$$\sigma(\varepsilon) = \sigma_{ys} + k\varepsilon^n$$



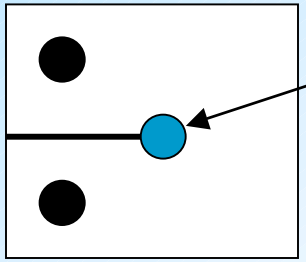






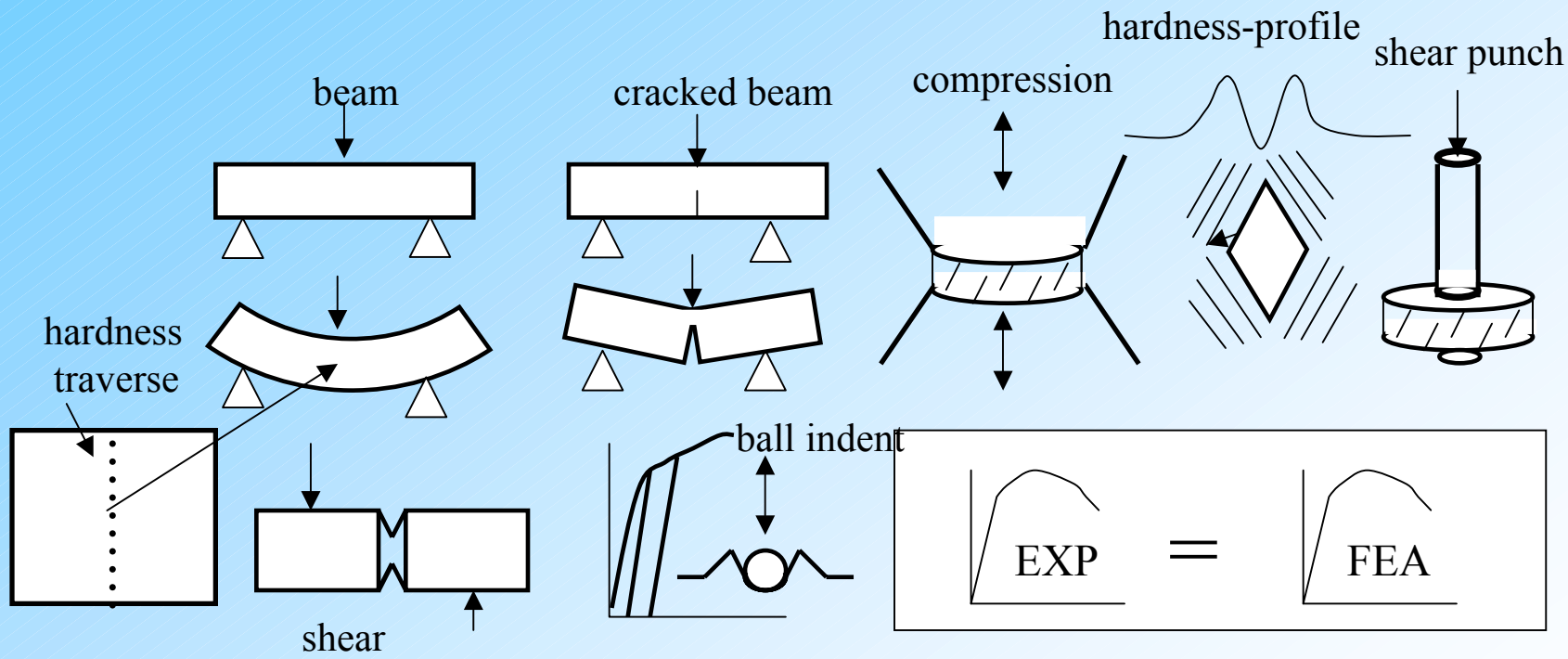
Other Specimens

- Specimens developed for multi-axial stress and alternate flow geometry - e.g., mini-microbeams
- Composite specimens, multipurpose coupons for basic studies (SANS, μH, PIA, TEM,…) combinatorial alloy development - example, diffusion bond + Q&T ^{54}Fe TMS alloy wire for studying effects of He on fracture behavior



process zone wire
from few grams of ^{54}Fe

Alternate Deformation Geometry



Conclusion

- A wealth of opportunity to use SST single variable and basic mechanism studies and integrate with:
  - » Modeling
  - » Nondestructive evaluation
  - » Microstructural and microchemical analysis
  - » Single variable and basic mechanism studies