Nonlinear Finite Element Modeling of Metal Matrix Composite Laminates

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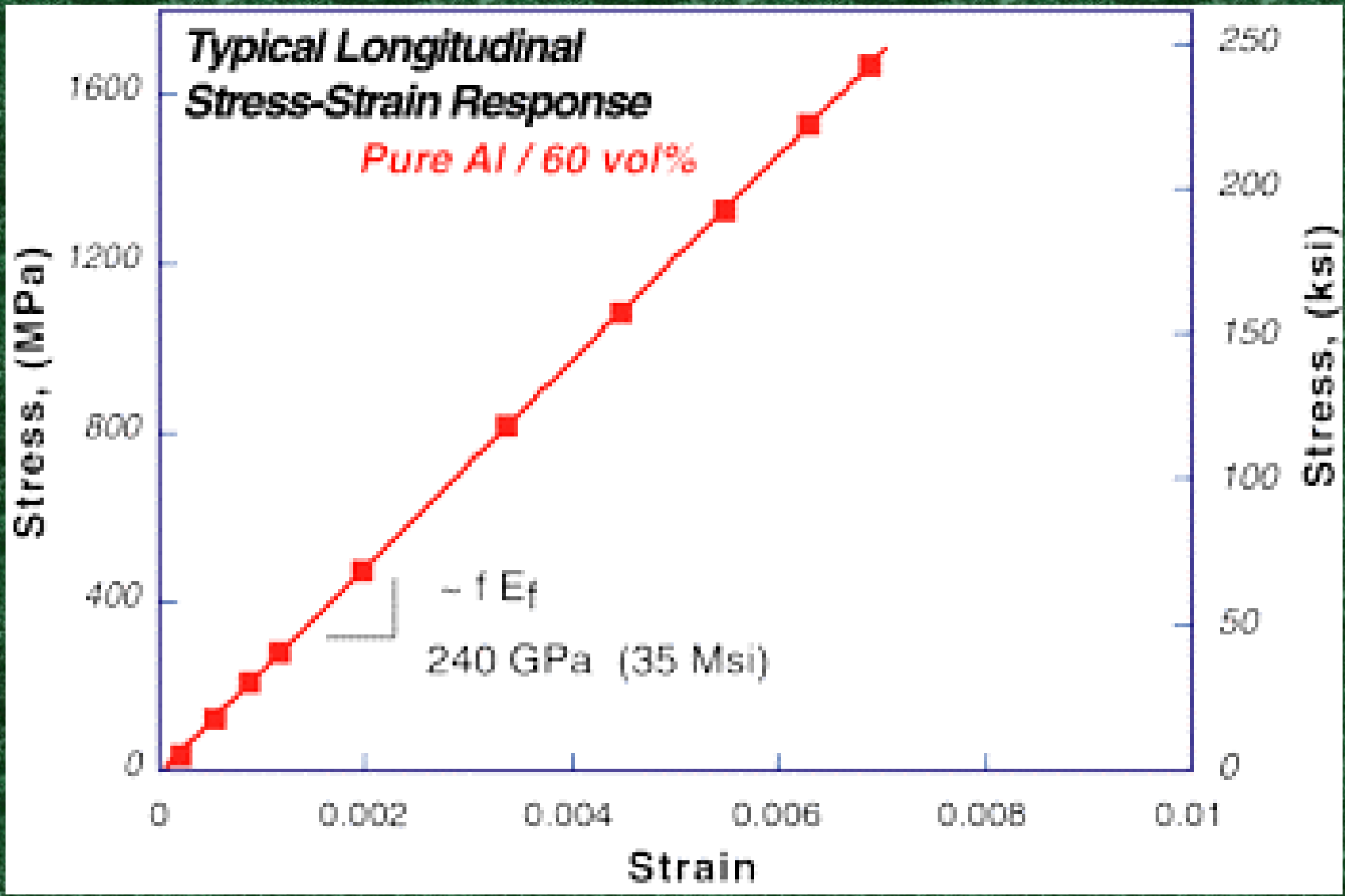
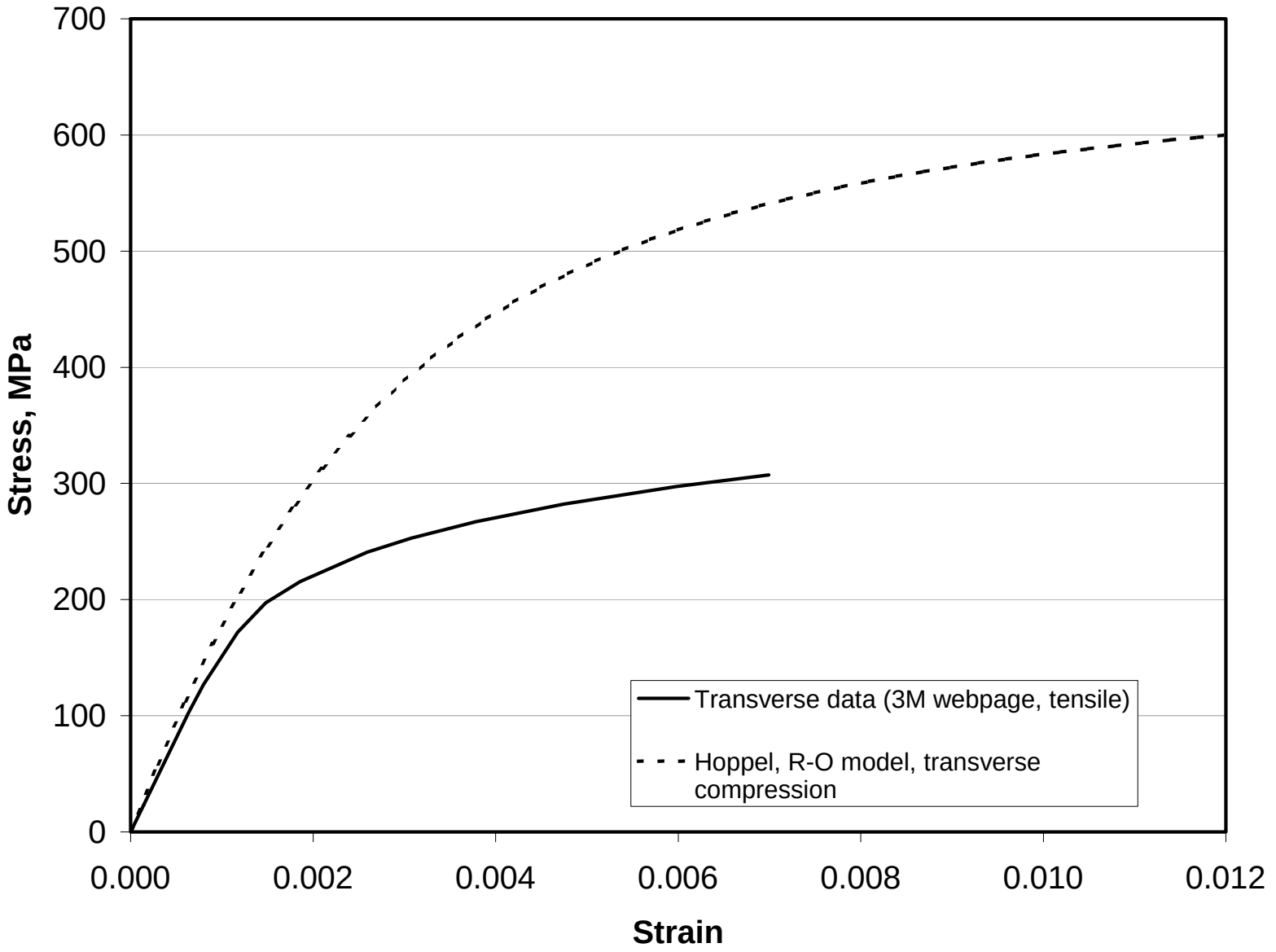
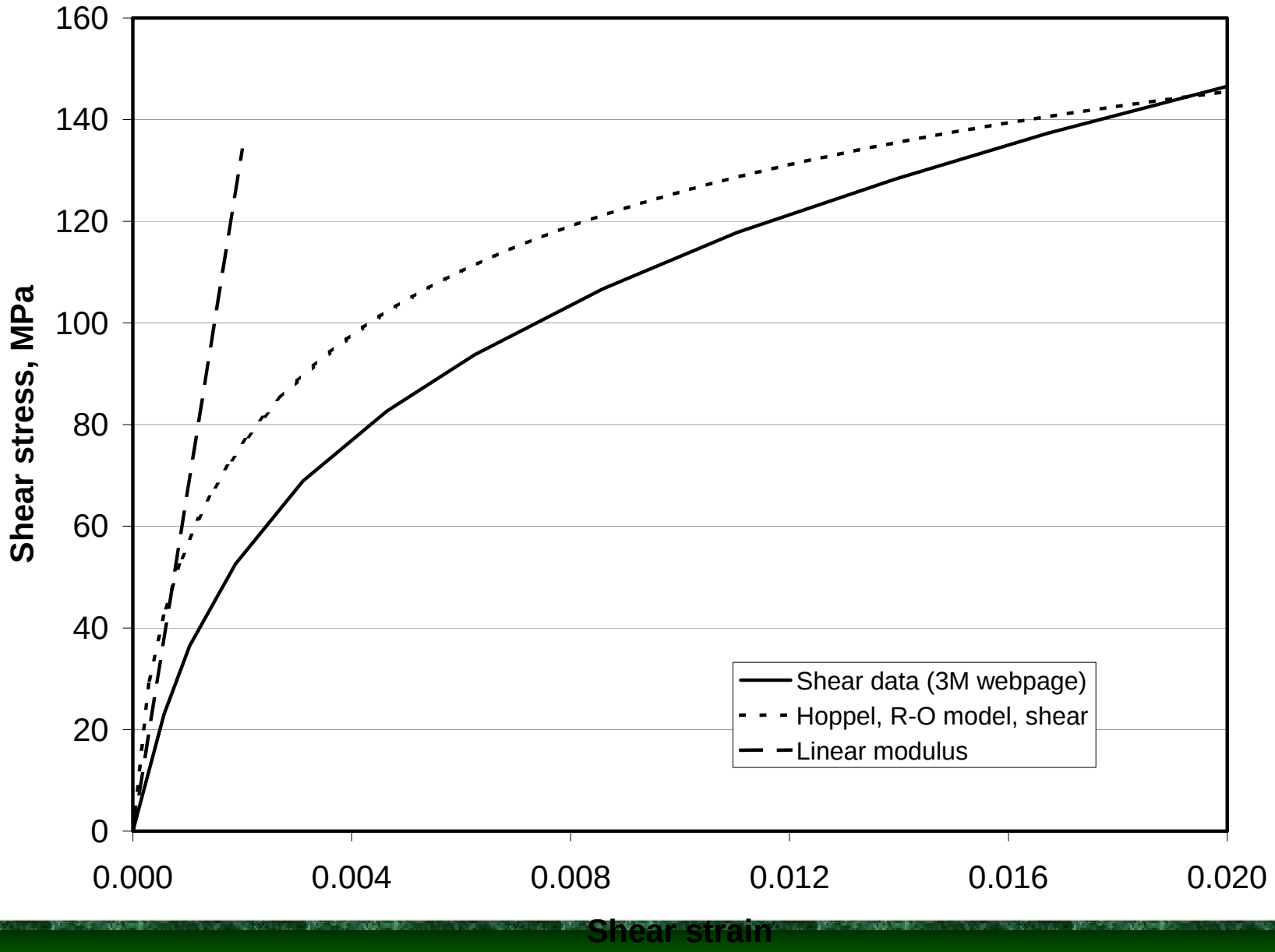
Nonliner, Inelastic Material Behavior of Metal Matrix Composites Makes Finite Element Modeling Difficult

- Especially True for
  - Cyclic Loading
  - Laminates with Multiple Ply Orientations


Typical Longitudinal
Stress-Strain Response
Pure Al / 60 vol%
~ f Ef
240 GPa (35 Msi)
Stress, (MPa)
Stress, (ksi)
Strain
1600
1200
800
400
0
250
200
150
100
50
0
0
0.002
0.004
0.006
0.008
0.01


700
600
500
400
300
200
100
0
Stress, MPa
0.000
0.002
0.004
0.006
0.008
0.010
0.012
Strain
Transverse data (3M webpage, tensile)
Hoppel, R-O model, transverse compression


160
140
120
100
80
60
40
20
0
Shear stress, MPa
0.000
0.004
0.008
0.012
0.016
0.020
Shear strain
Shear data (3M webpage)
Hoppel, R-O model, shear
Linear modulus

We have used ANSYS to Model

- Normal ANSYS Elements allow
  - Hardening Model choices
    - Kinematic (Bauschinger)
    - Work Hardening
    - Ratcheting-Shakedown
- However, only a few combinations work with Anisotropic Properties and only a few elements allow anisotropic and nonlinear

HILL Option

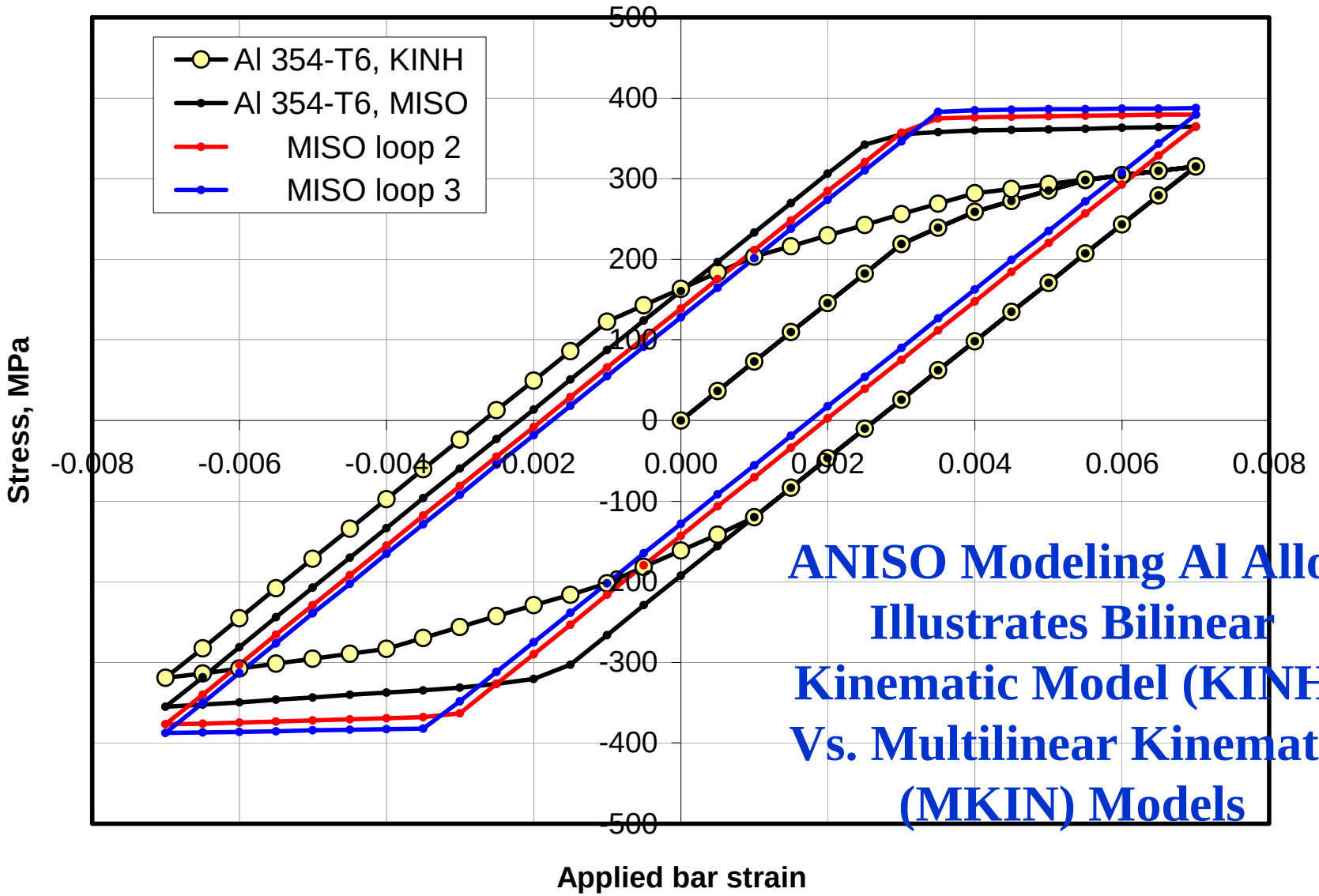
- Von Mises yield criteria to account for orthotropic Material properties
- Can be combined with some other options
- BUT
- Only one Stress-Strain curve input
  - X, Y, Z, XY, YZ, &XY are ratios of the one
  - Tension curve MUST equal the compression
- So HILL won't work for MMC

ANISO Option

- Work Hardening is the ONLY option
  - Documentation therefore recommends not to use for cyclic loading
- But, it does offer different Ten. Vs. Compr
  - But they aren't really independent
  - Compatibility Requirement
    - If Ten. Vs. Compr. Behavior is diff. On two axis, it must be diff. On the third
    - If Compr. Yield is higher on two axis is must be lower on the third
    - i.e. – zero sum to 1e-6 tolerance.

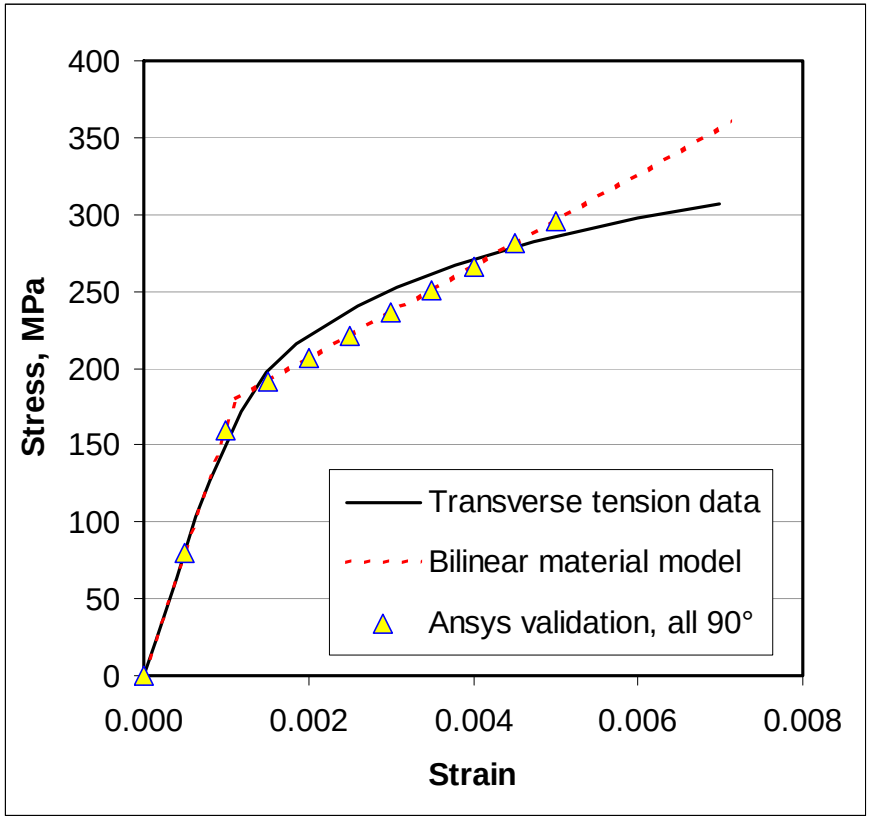
Limited Elements Work

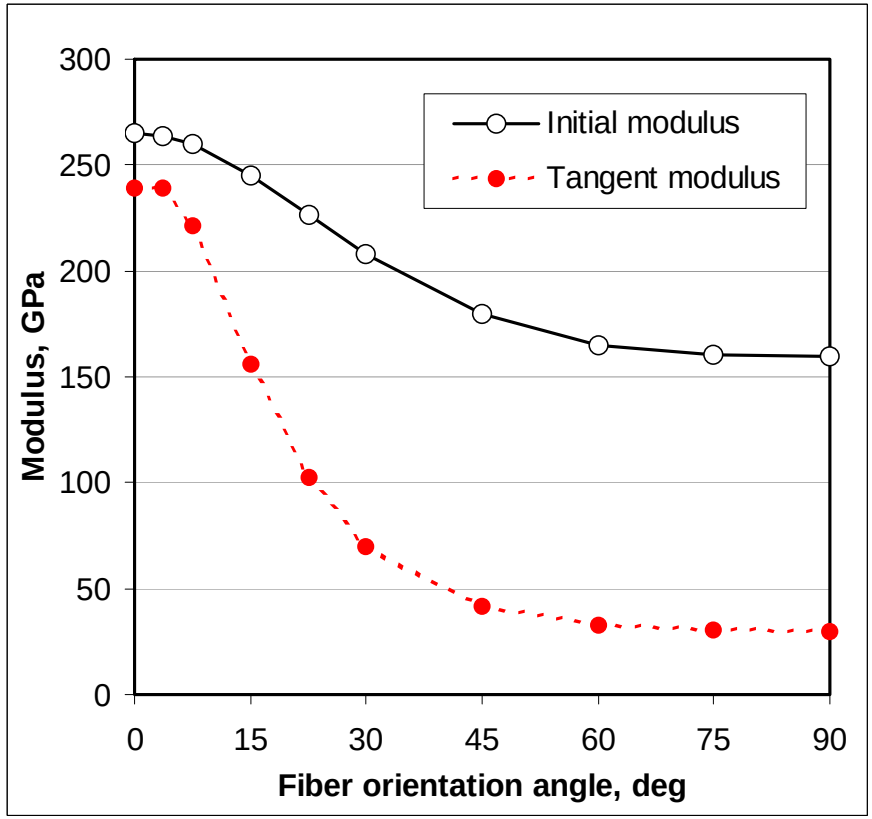
- None of the Shell or Laminate element types work with nonlinear, orthotropic
- Therefore, each composite ply must be modeled separately.



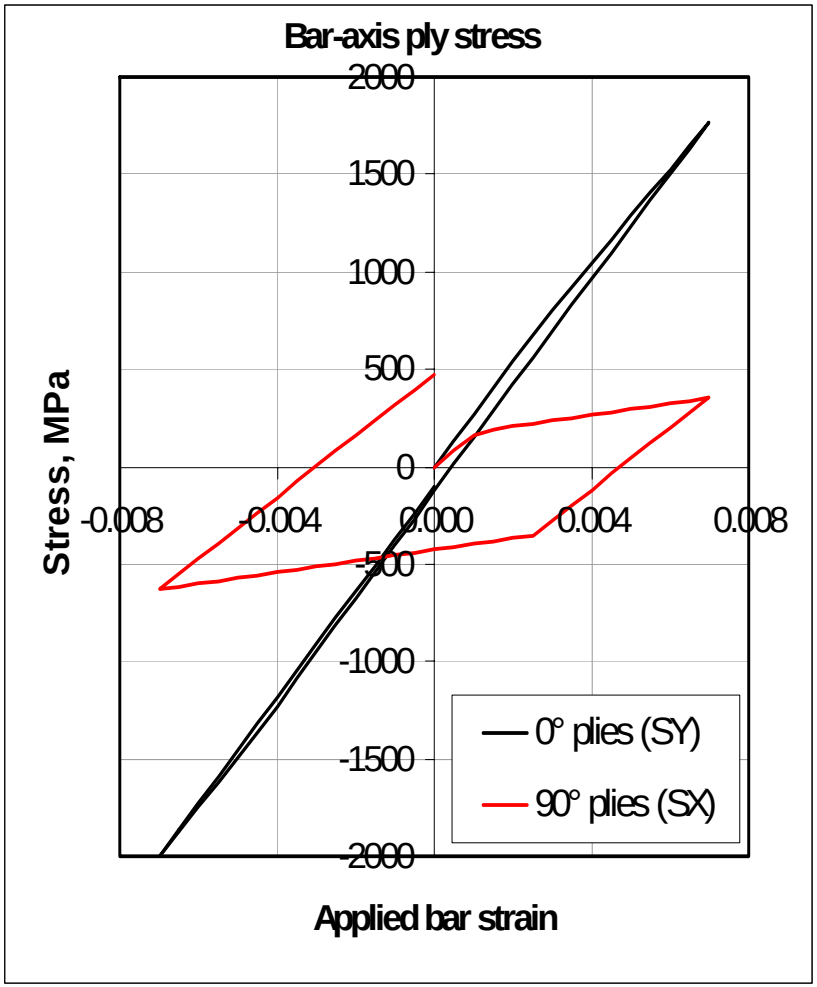
ANISO Modeling Al Alloy Illustrates Bilinear Kinematic Model (KINH) Vs. Multilinear Kinematic (MKIN) Models

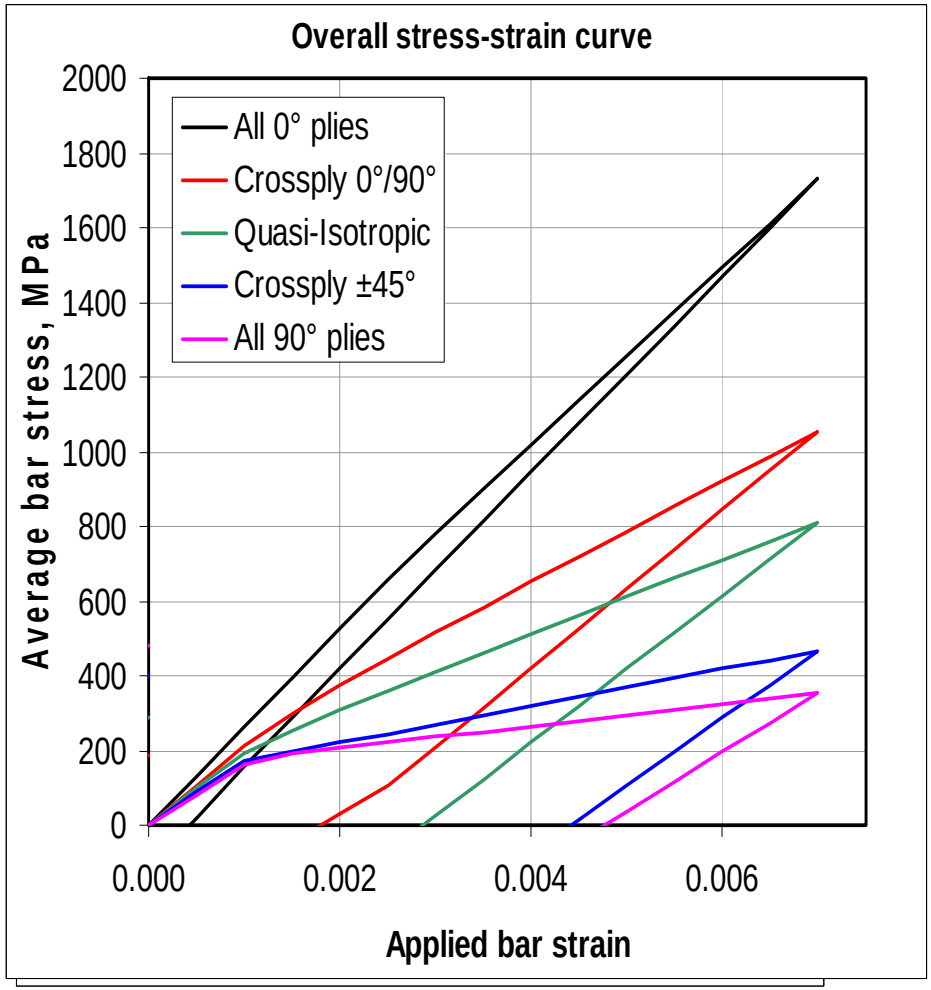
Next ANISO with Bilinear Kinematic Hardening Used to Model Individual Plies of Composite at various Ply Angles.





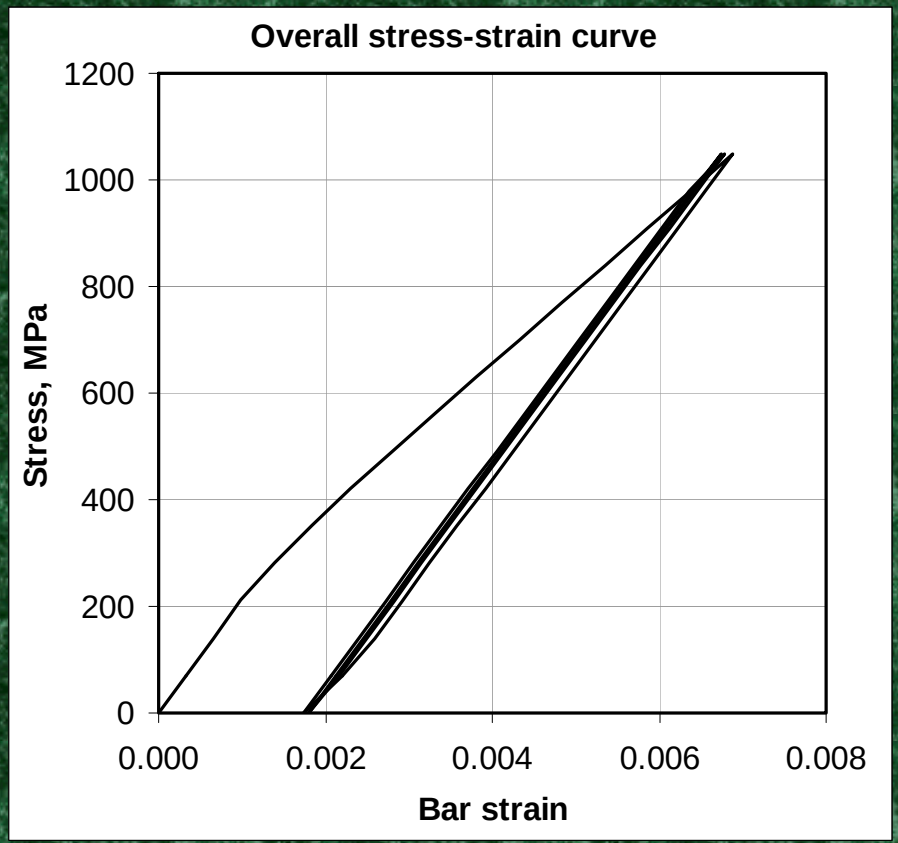
Next (Strain) Cyclic Loading Was Attempted

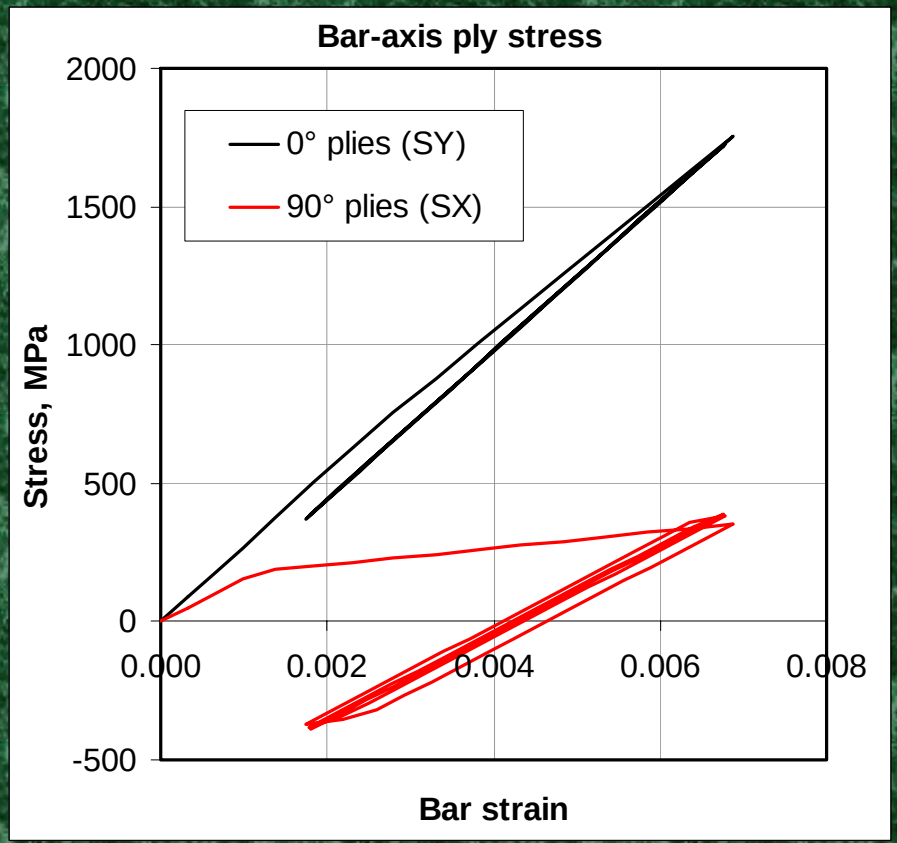




Work Hardening Model causes Stress-Strain Loops to Grow

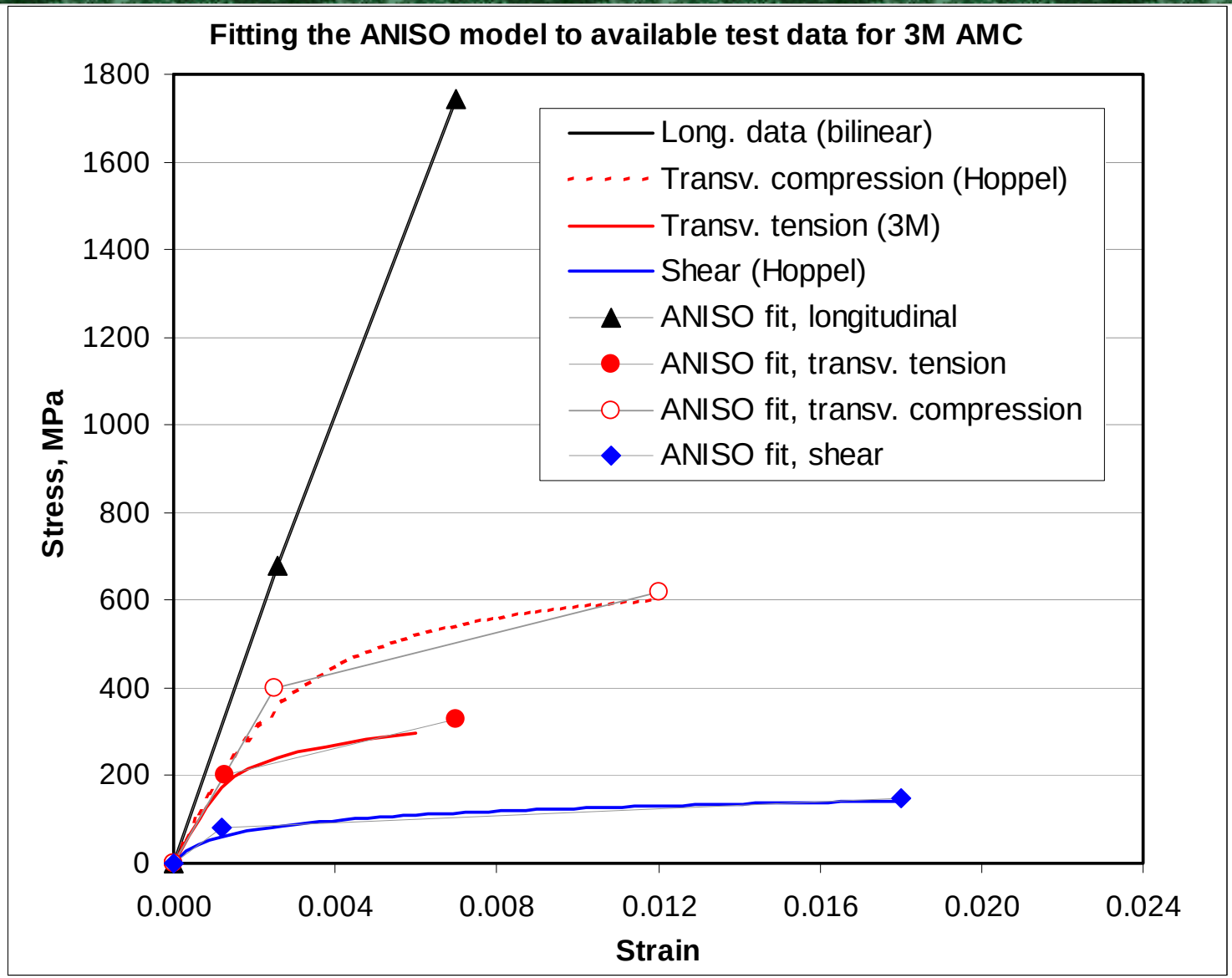
Stress Loading Produces a Different Result



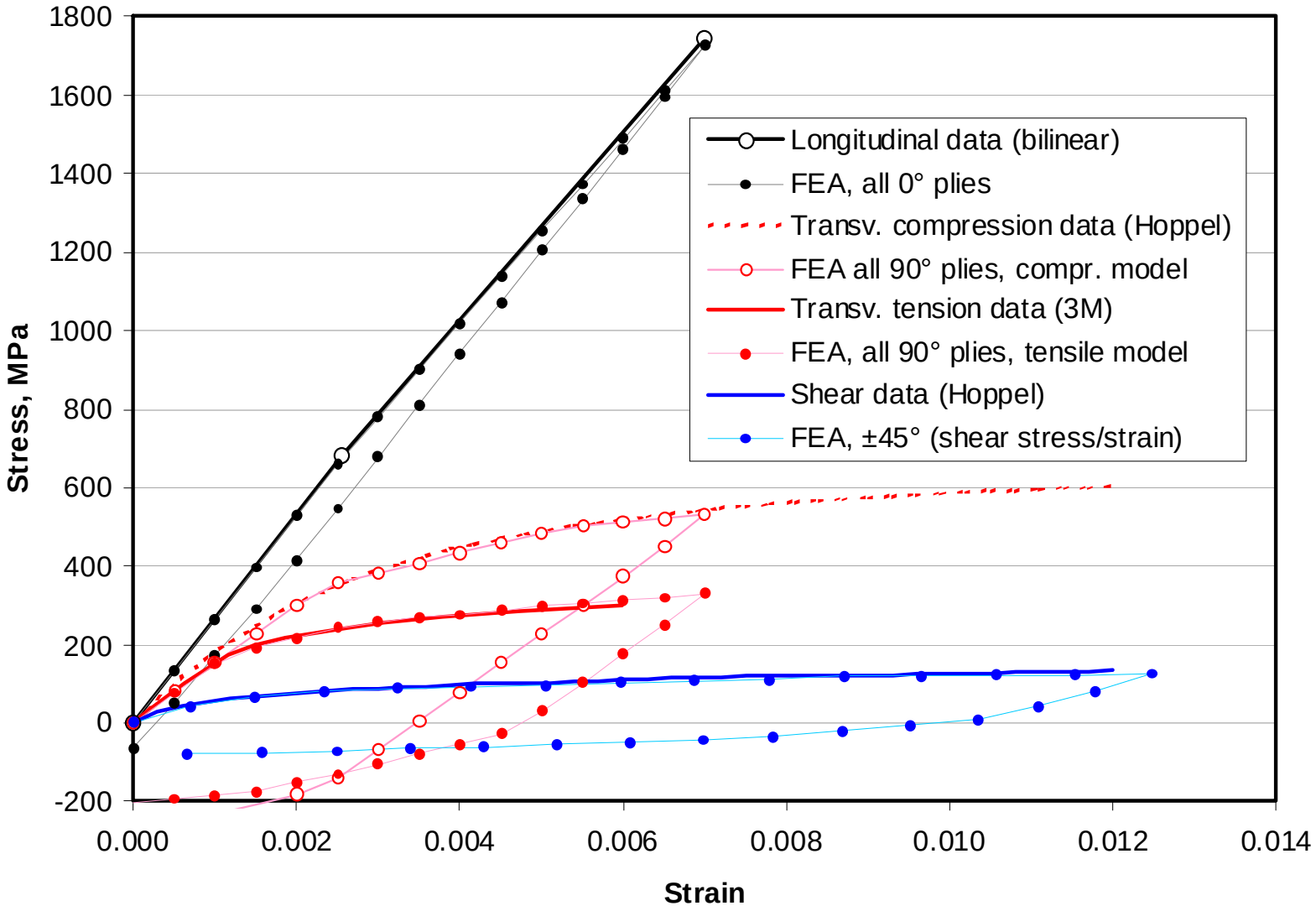


Similar Work Using the HILL Stress-Scaling Material Option

- **Allows Material Models Which differ in each axis and are More complex that BiLinear**
- **But, Can't Model Both Tension & Compression**
  - **Model can be Either but not Both**


Fitting the ANISO model to available test data for 3M AMC
Stress, MPa
Strain
1800
1600
1400
1200
1000
800
600
400
200
0
0.000
0.004
0.008
0.012
0.016
0.020
0.024
Long. data (bilinear)
Transv. compression (Hoppel)
Transv. tension (3M)
Shear (Hoppel)
ANISO fit, longitudinal
ANISO fit, transv. tension
ANISO fit, transv. compression
ANISO fit, shear

Results for HILL + KINH material model for AMC, single strain-driven cycle, and comparison to actual test data



Shortcomings

- ANSYS Work illustrates that modeling is possible, but:
  - Extensive Work is Required
  - Available models have Severe Limitations
  - Not Feasible for Day-to-Day analysts and designers
  - Not suffecient Material Data to correlate

What we Need

- Automated or Simplified Tools that allow modeling nonlinear, orthotropic materials that have both tension and compression
- Direction on what testing is needed to find Material Constants for building the above models.
- Test Data of more complex geometries to verify correlation.