Carbon Fiber Mechanical Properties: Reconciling Models and Experiments

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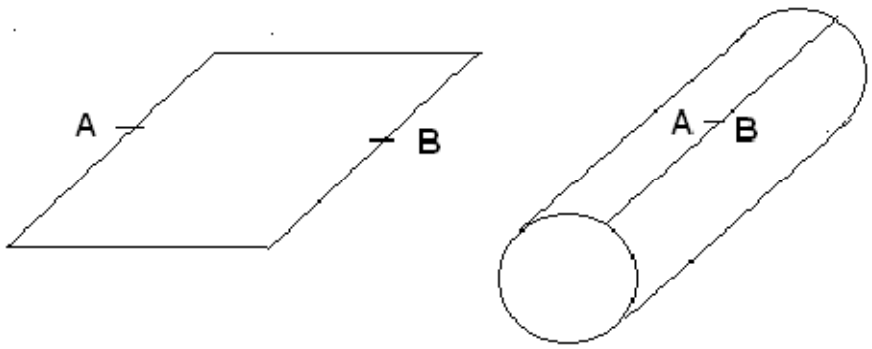
Outline

Carbon Fiber Mechanical Properties: Models vs. Experiments

A: Where we are (A)

B: Where we could be (B)

C: How best to bridge A and B



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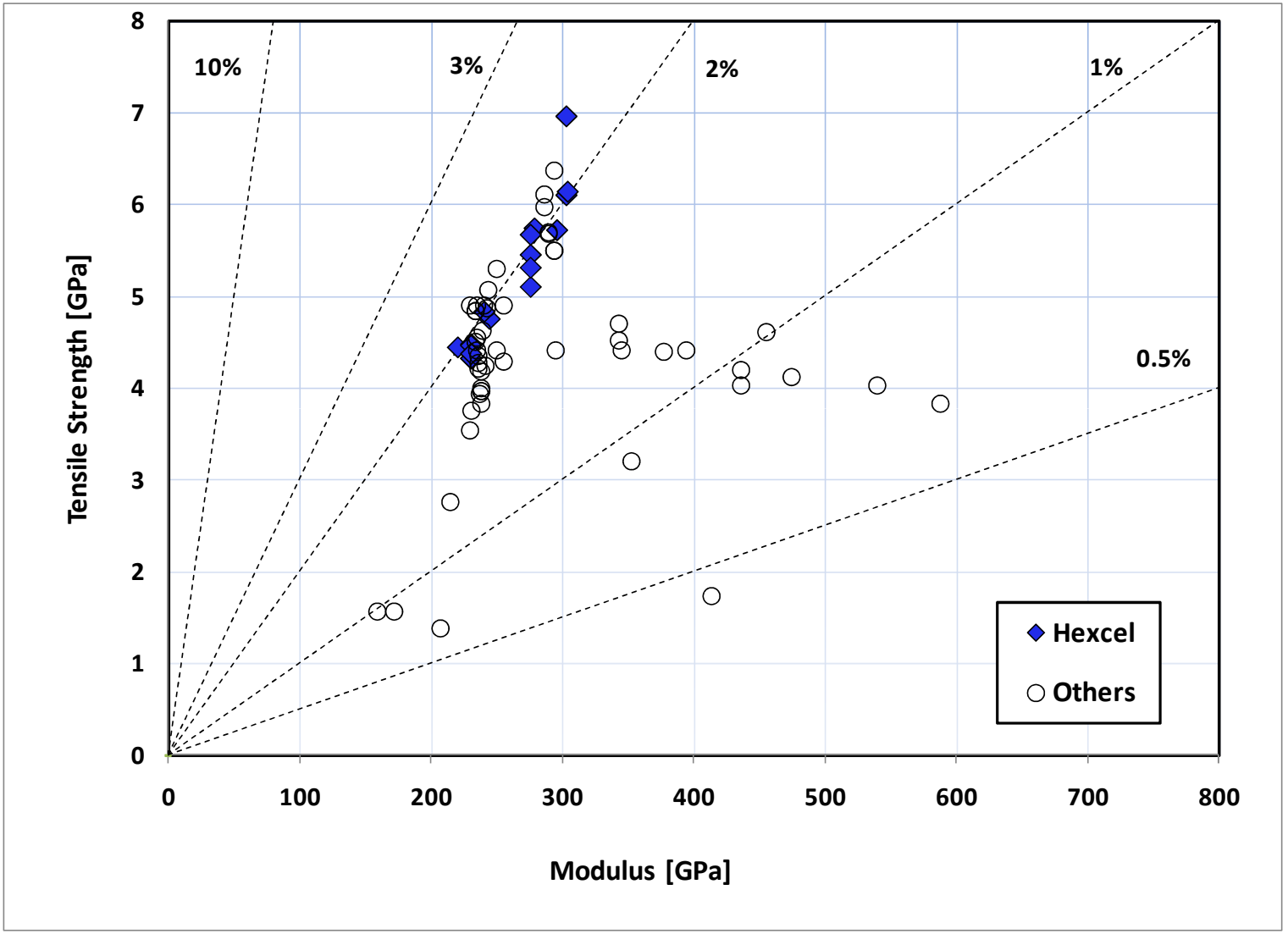
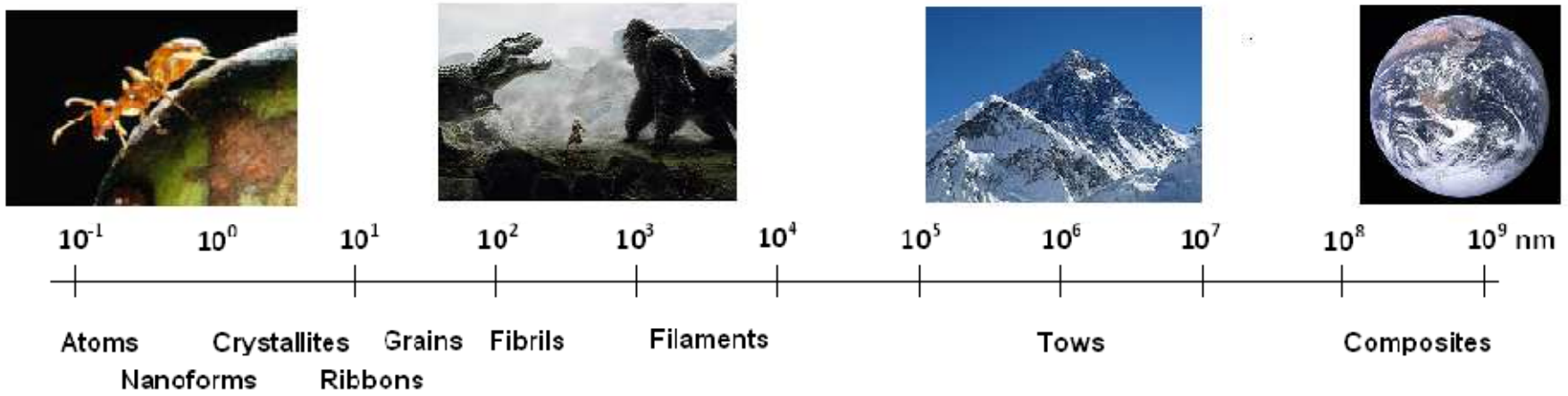
Mechanical Properties of Commercially Available Carbon Fibers



Scale of Models and Experiments



- Carbon structures span over 10^{10} in length scale
- Theoretical models predict extremely high mechanical properties at small length scales
- Recent experiments support theoretical predictions
- Need to transfer gains to larger scales

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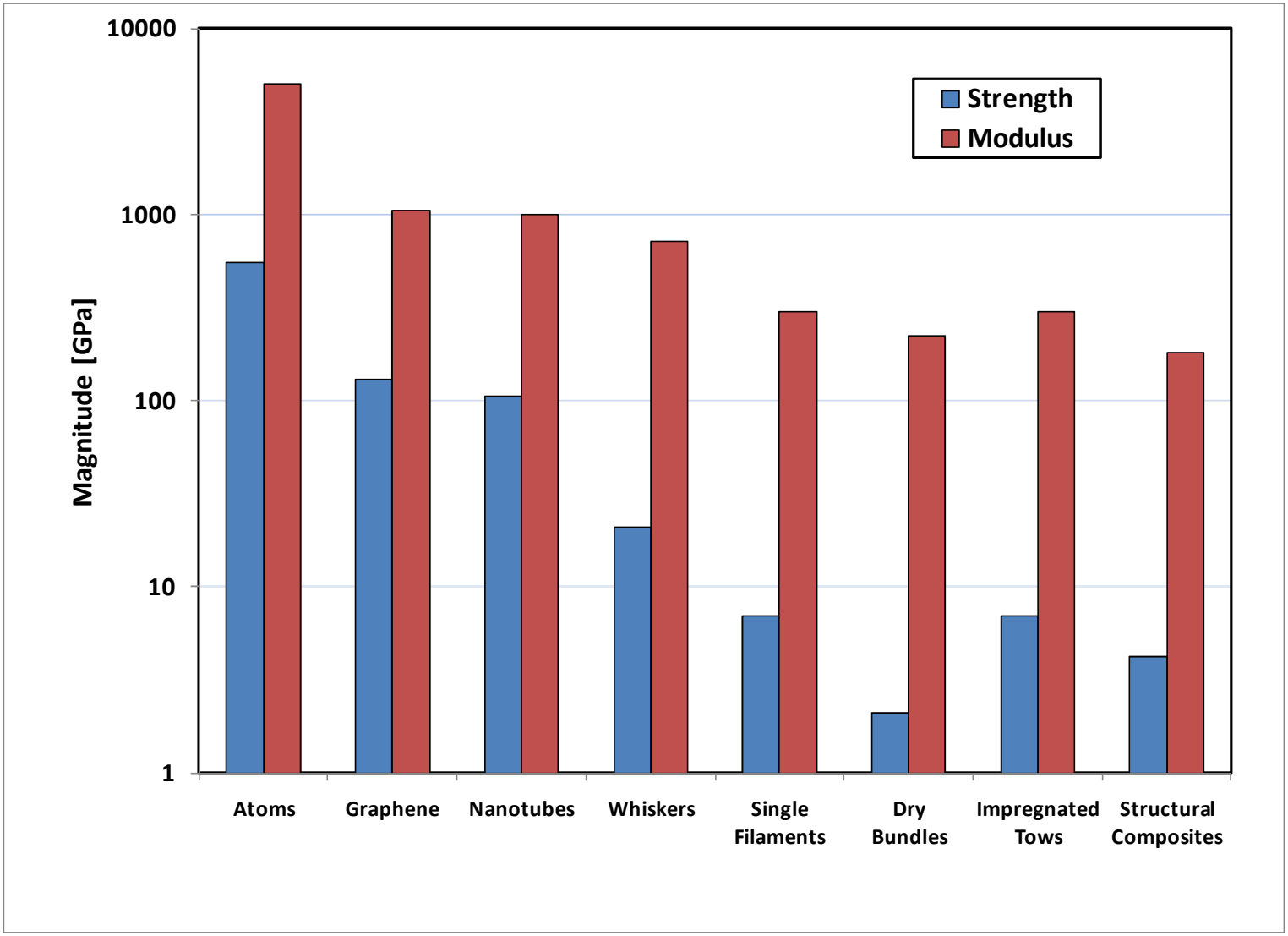
Mechanical Properties of Solid Carbon Forms



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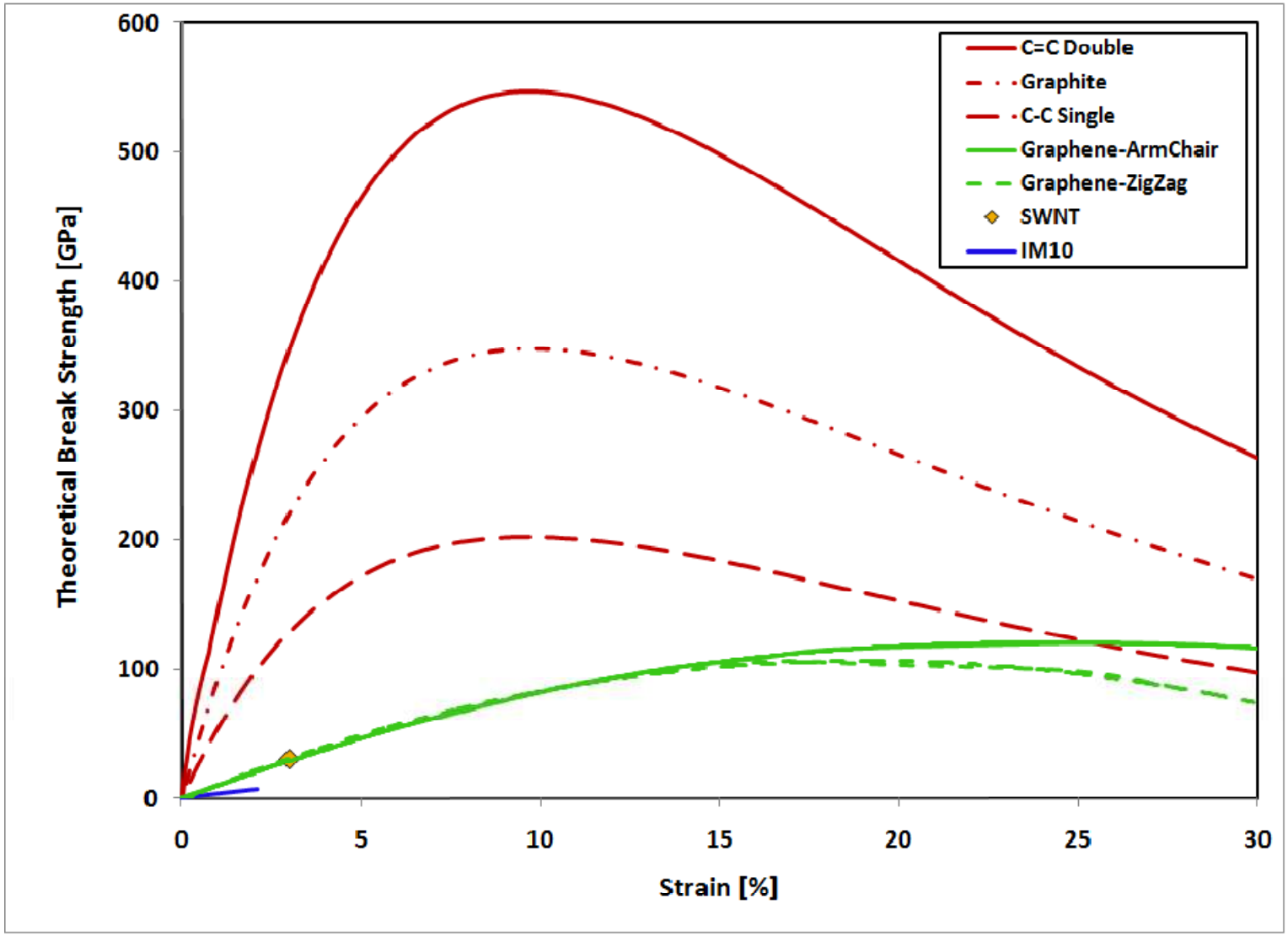
Maximum Theoretical and Practical Limits



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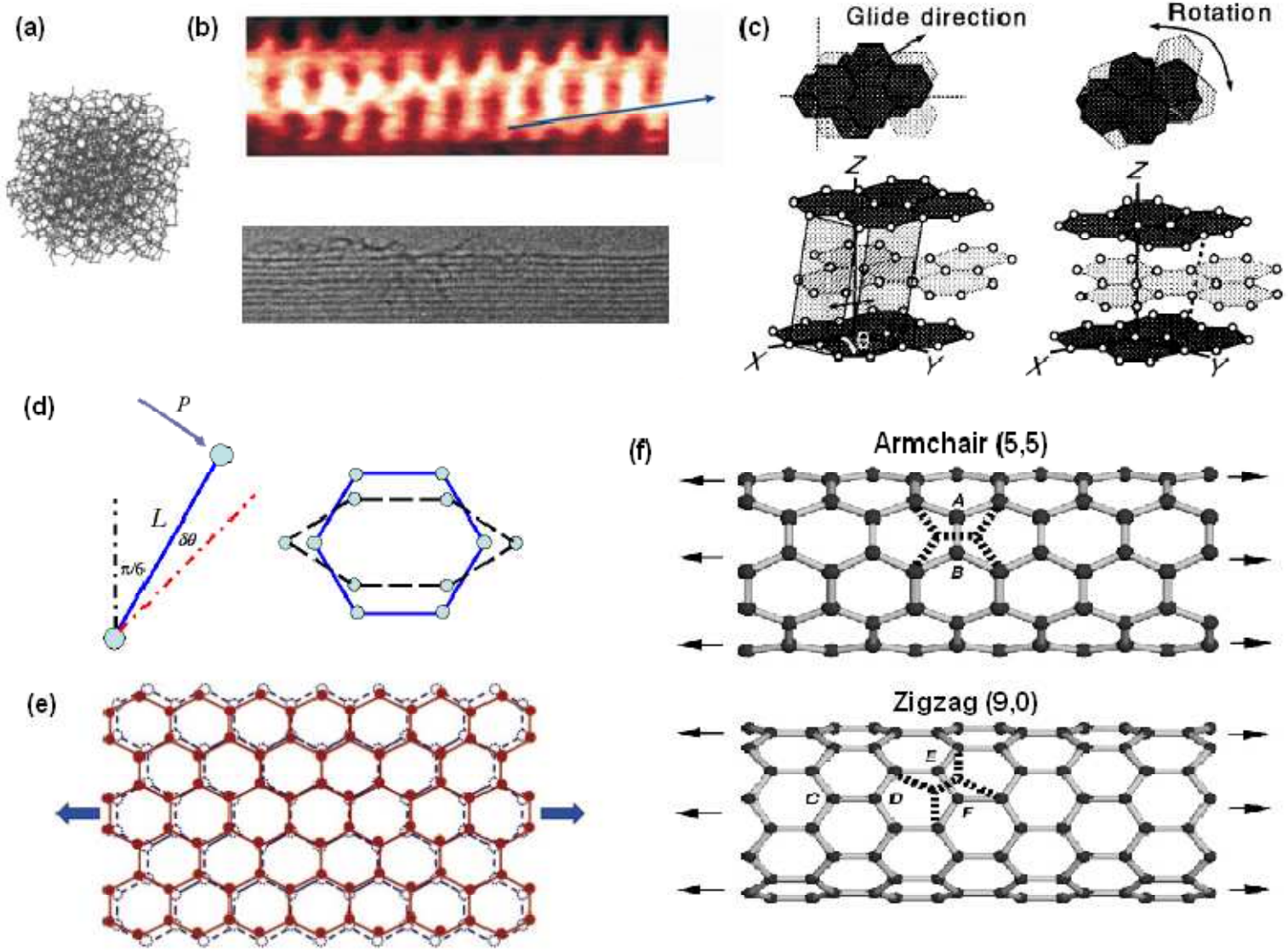
C-C Bonds Under Strain

Ab Initio, Molecular Dynamics and Finite Element Analyses



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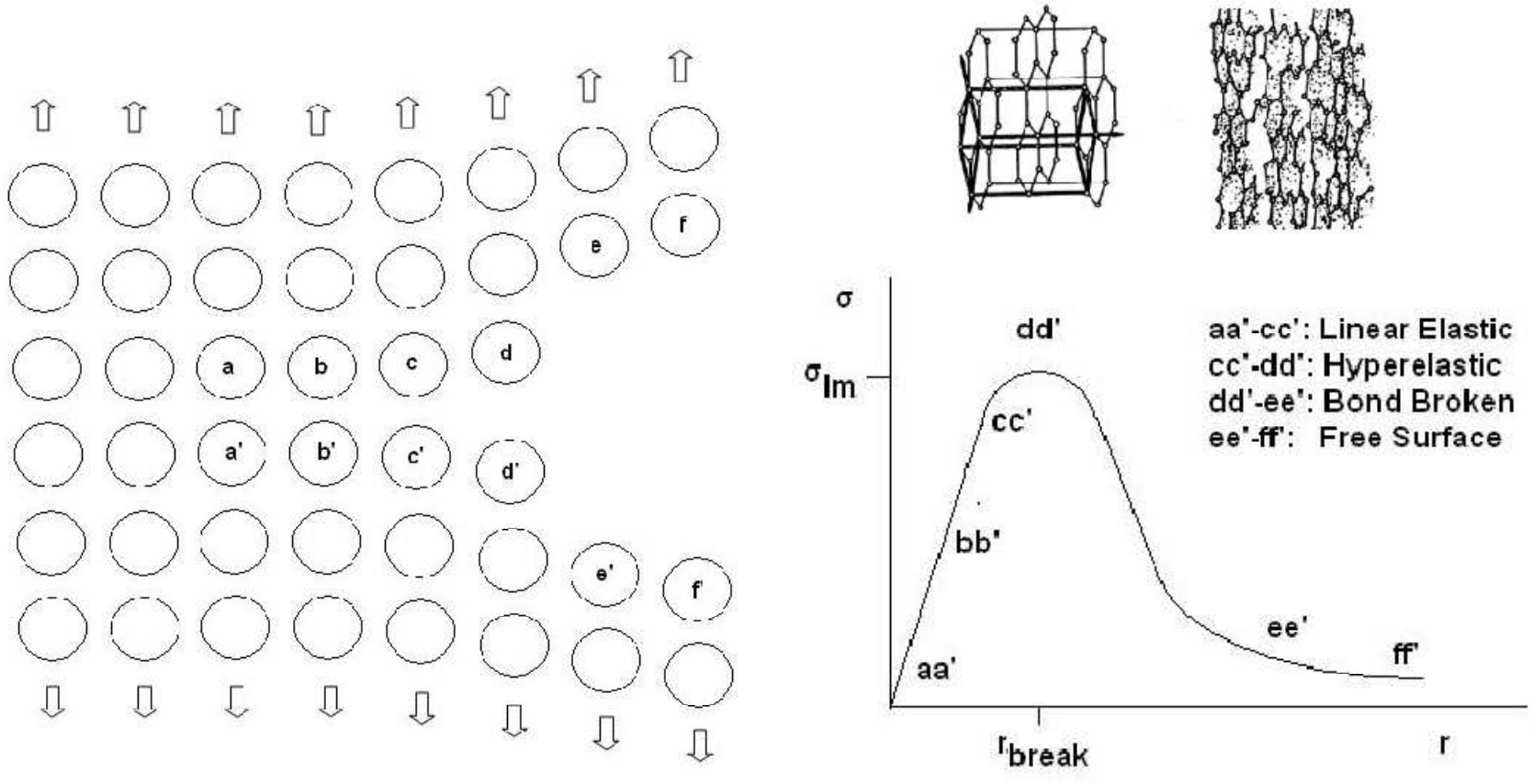
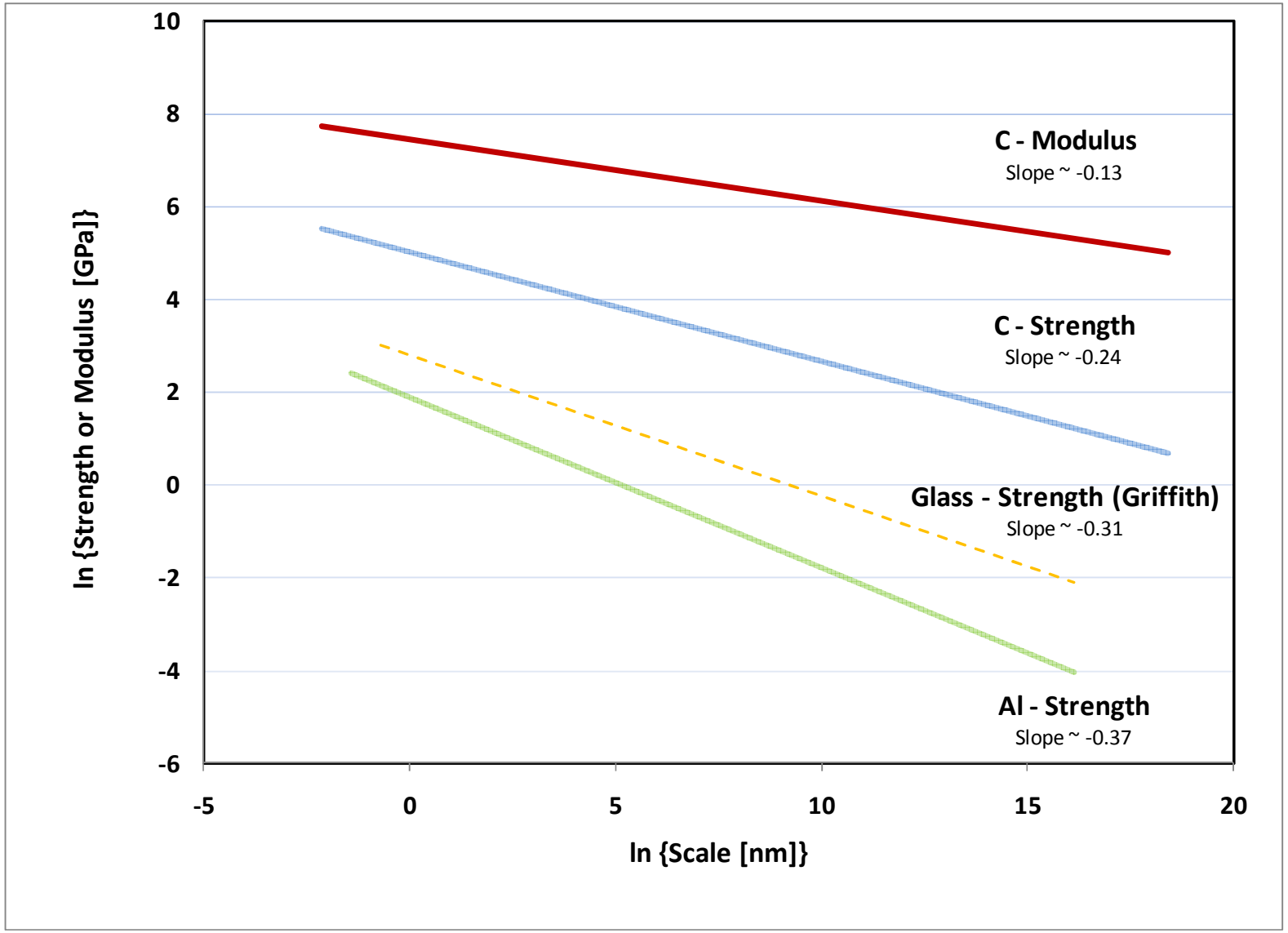
Atomistic Approach to Brittle Failure



- Transition from nano-scale (atomic bonds) to micro-scale
  ➔ thermodynamic energy balance (Griffith)

Mechanical Property Variation with Scale

Geometric Link ➔ Fractal Dimension (Mandelbrot)



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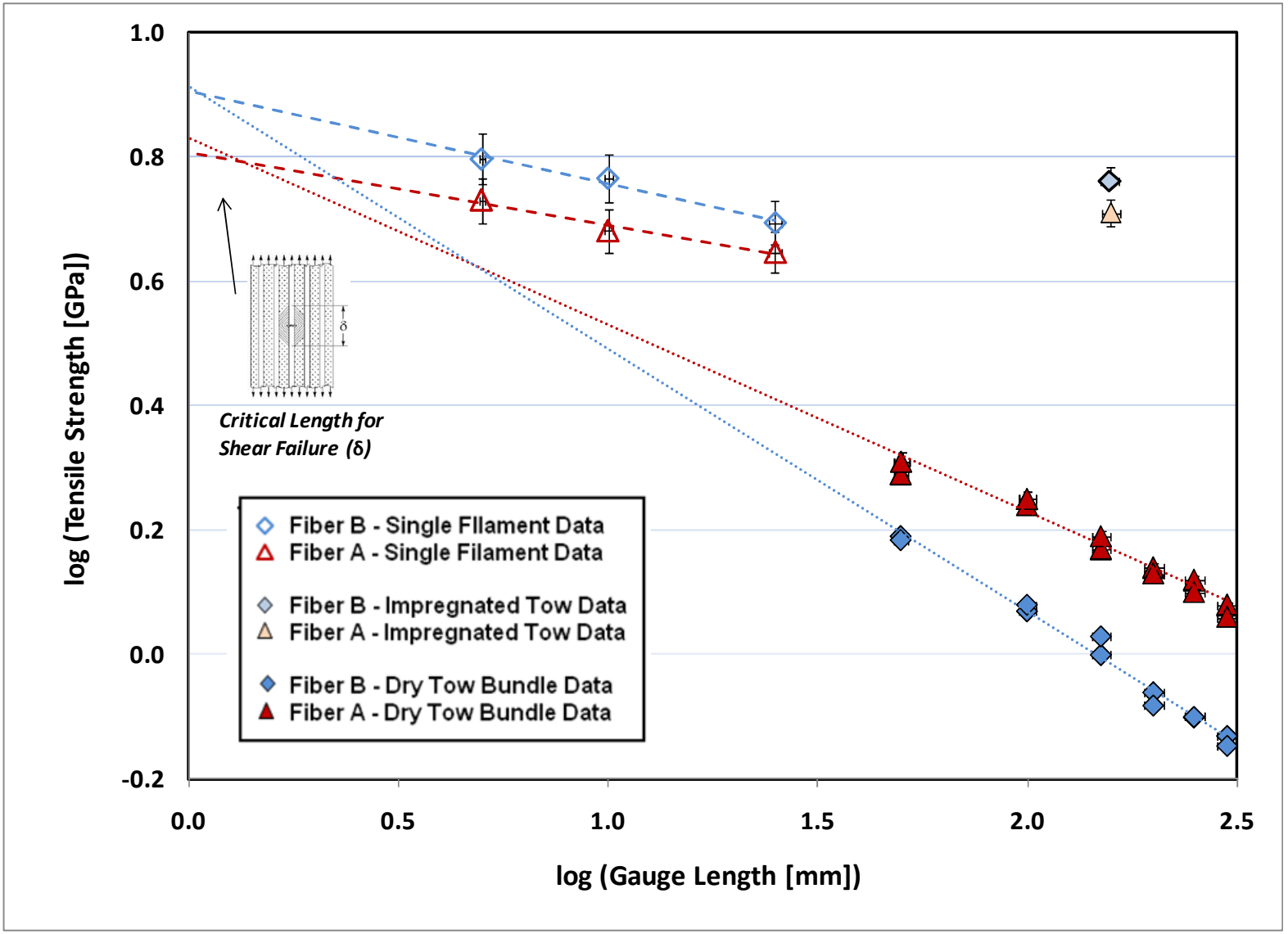
Carbon Fiber Tensile Strength

Comparison of Test Methods



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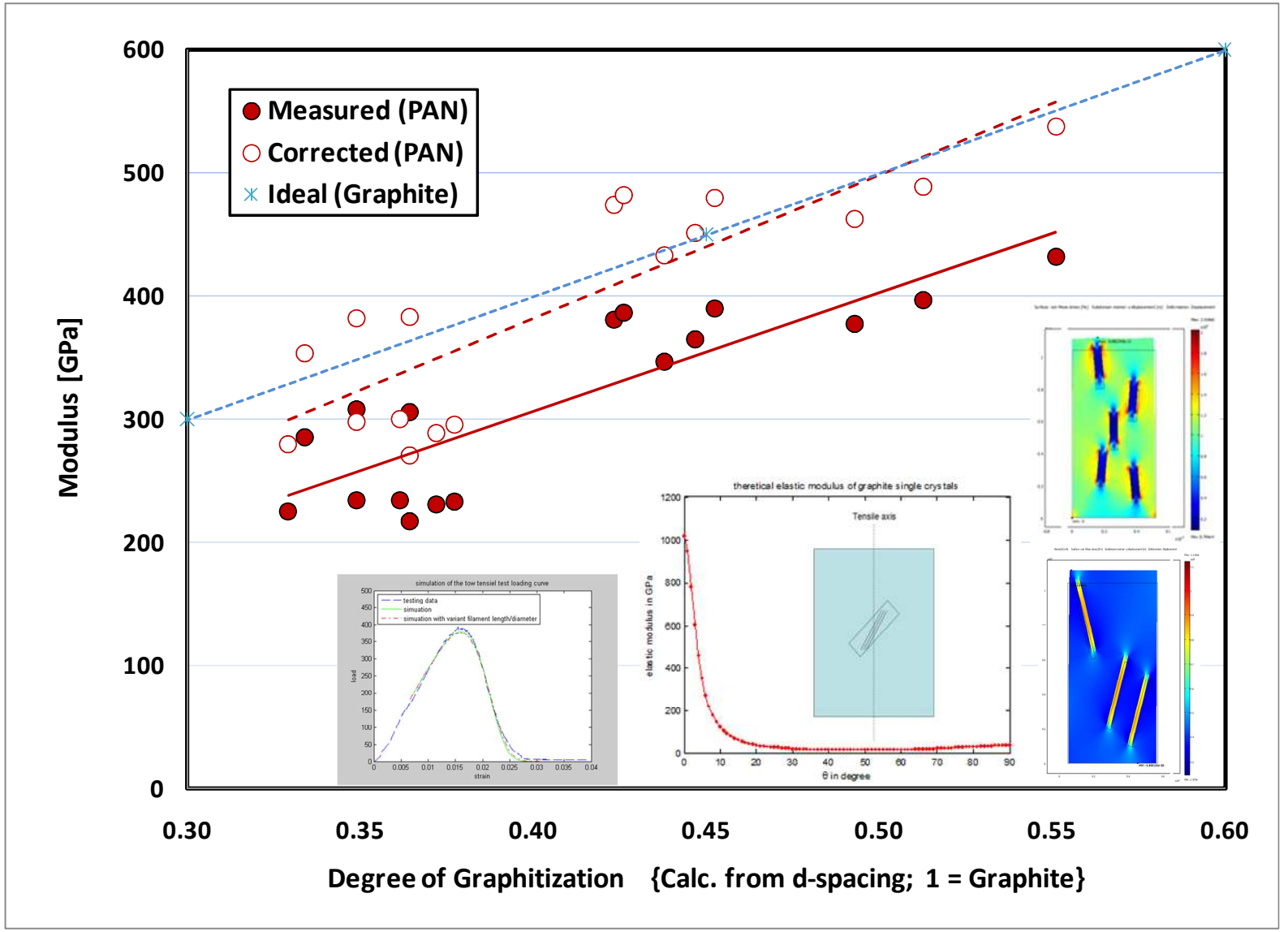
Modulus Measurement and Modeling



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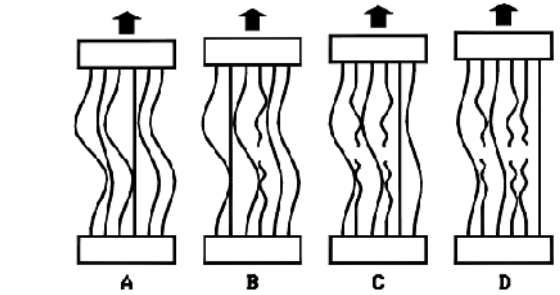
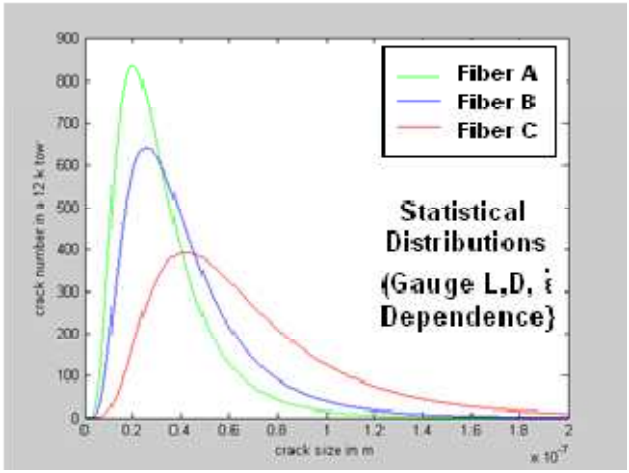
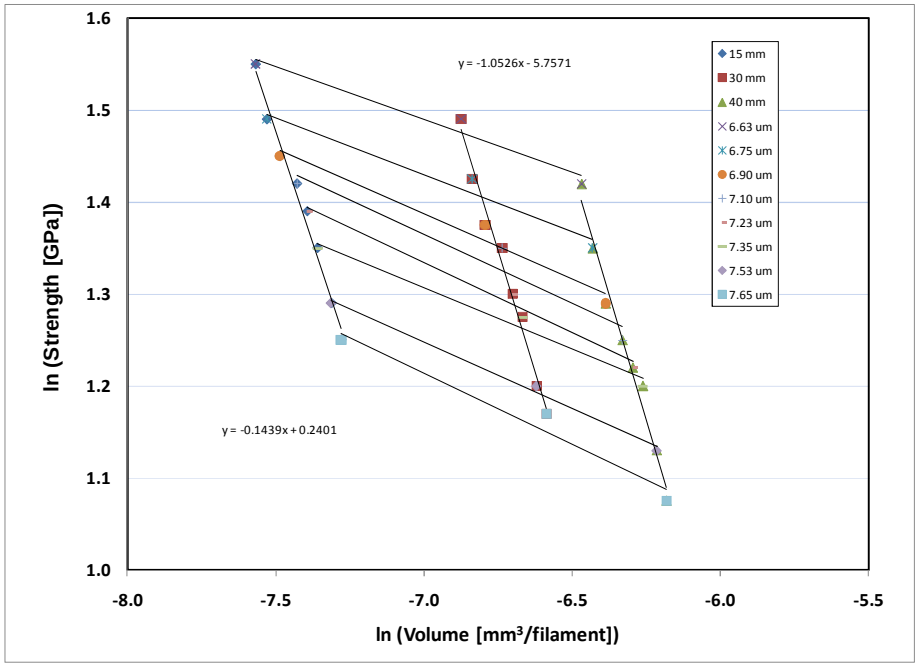
Strength Measurement and Modeling







- Average Load vs. Volume scatter ➔ Filament Diameter Variability
- Decoupling strength contributions shows filament strength is more sensitive to changes in transverse (diameter) than axial (length) dimensions
- Differences impact data interpretation from gauge-dependent (e.g., Weibull) vs. gauge-Independent tests

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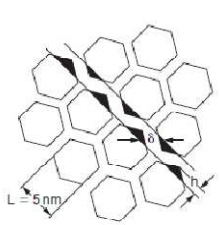
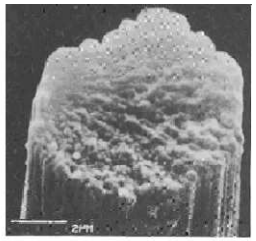
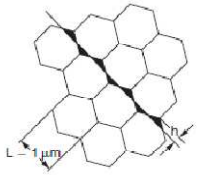
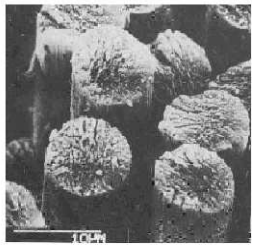
Statistical Flaw Distributions

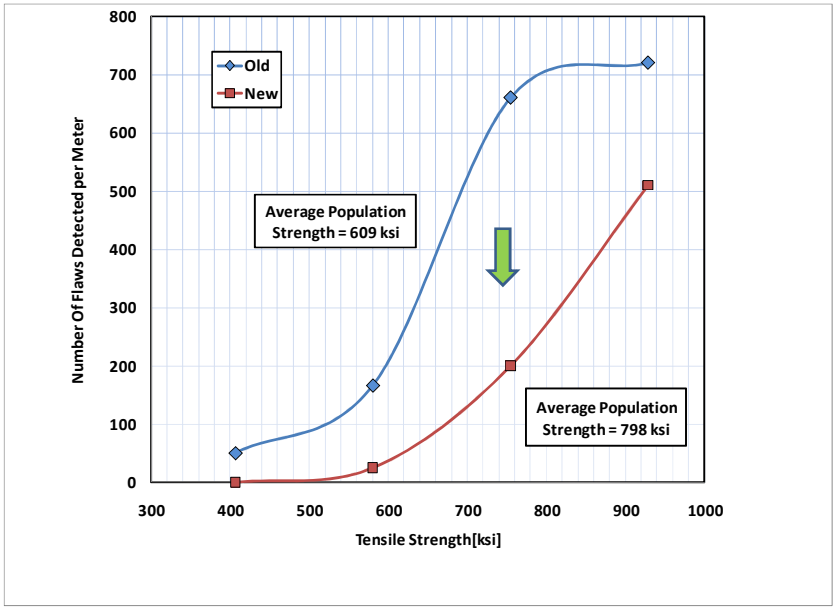
Excluding Clustering/Orientation/Other Effects ➔ Molecular Dynamics

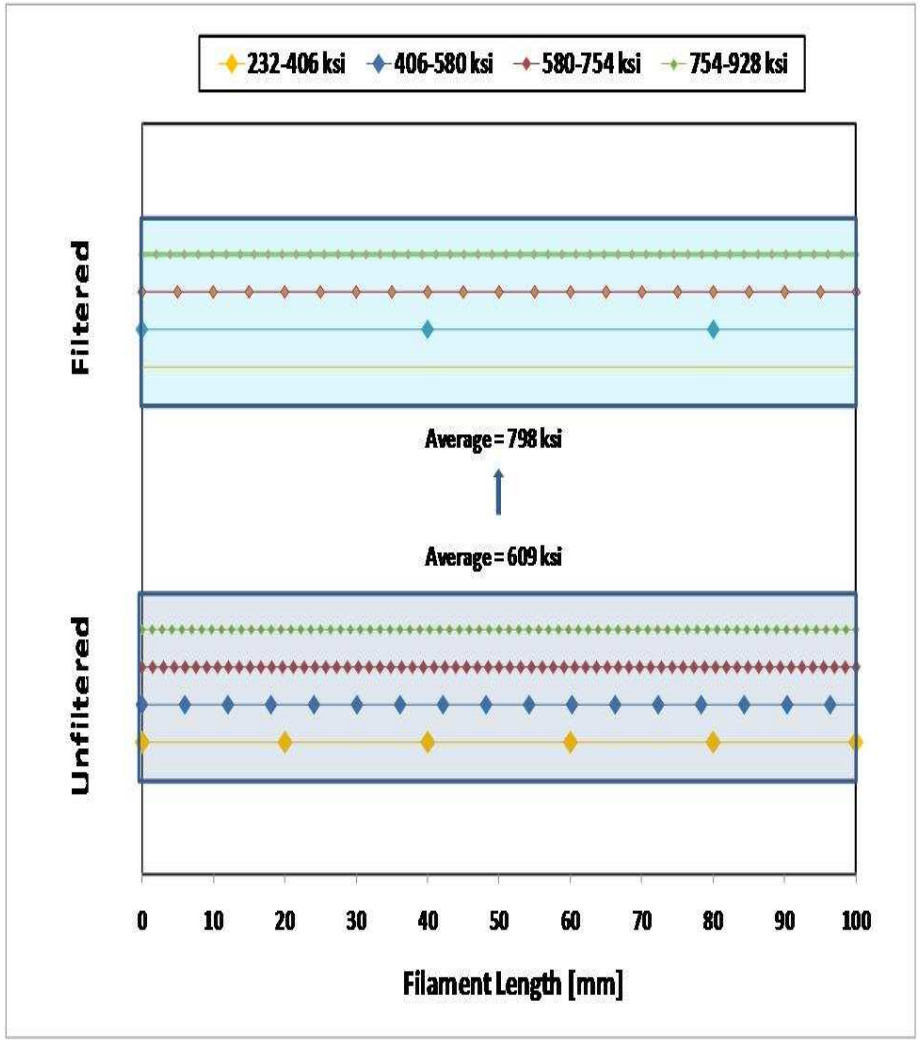












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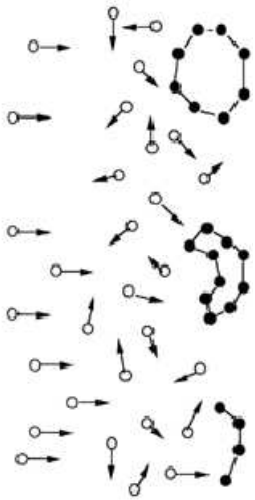
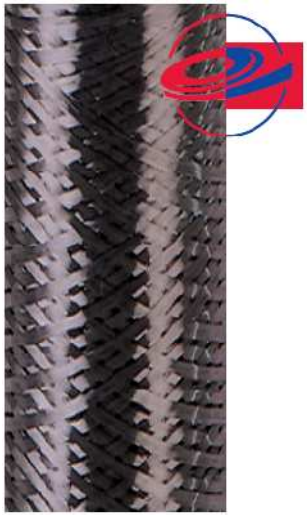
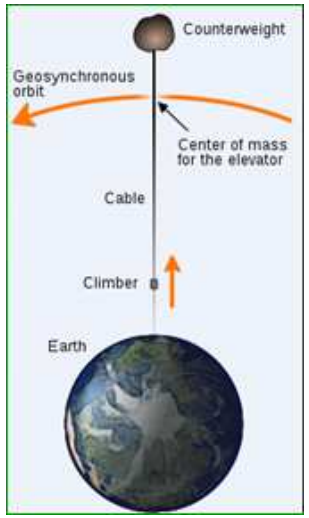
Summary and Conclusions

- Models and experiments show key scale transitions for carbon fiber structure and mechanical properties in composites.
- Below 100 nm, experimentally measured properties approaching theoretical upper limits are already being reported.
- Above 1 mm, carbon fibers are tested and modeled with statistical approaches.
- Improving carbon fiber mechanical properties demands careful consideration of experimental and theoretical details over wide length scales.







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