Composite Material Properties FEA Results and Next Steps

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Properties and Conditions Simulated

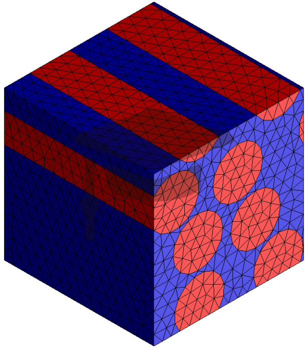
- Properties Evaluated
  - Longitudinal Elastic modulus - Along fiber axis
  - Transverse Elastic moduli - Two axes perpendicular to fiber inclusion
  - Longitudinal and Transverse Shear moduli
  - Larger values are ideal for this application (Stiffer, higher yield strength, aspect ratio(diameter to length))
- Conditions Simulated
  - Periodic boundary conditions
    - Random fiber arrangement
    - Uniform fiber arrangement
  - Different volume and mass fractions of fiber
- Recommended Simulations
  - Delta - Window size proportional to fiber diameter - δ = L/d (window length / fiber diameter)
  - Fiber length in terms of its size proportional to specimen dimensions

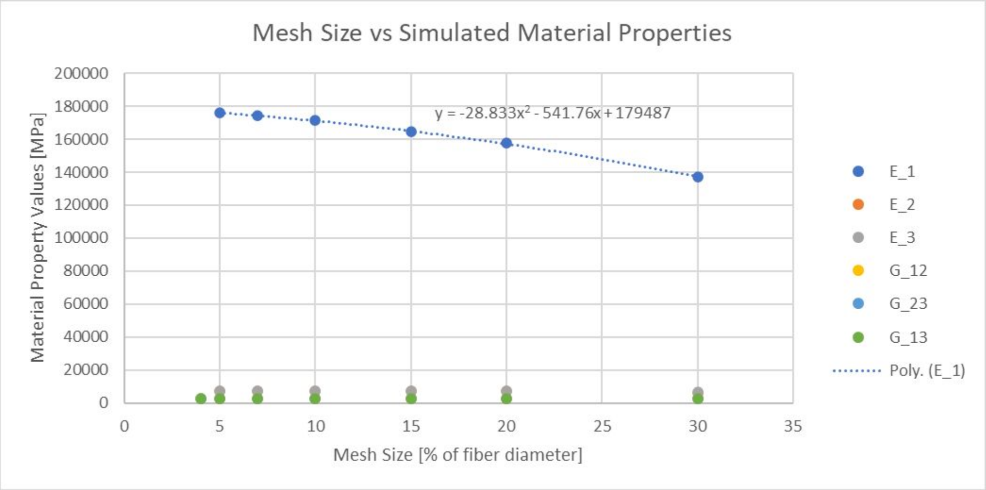
Mesh Size Impact

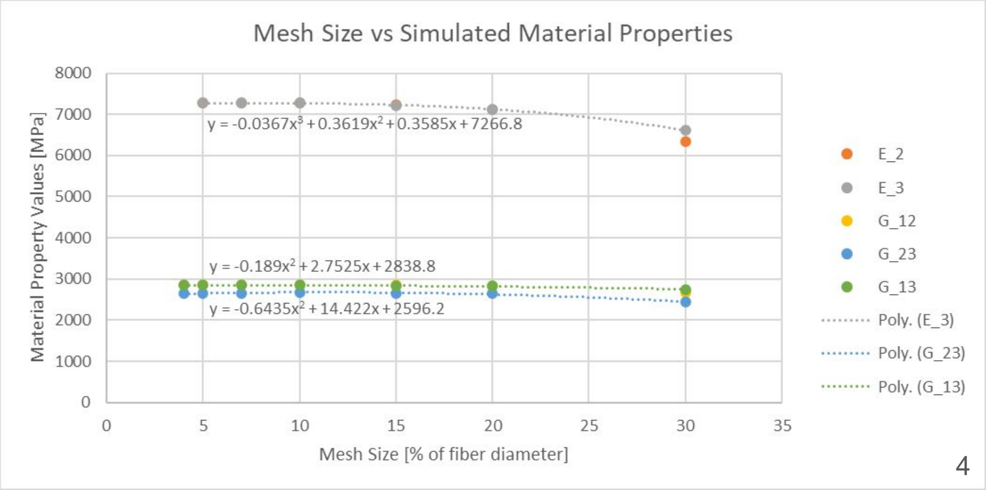
- Measured changes in each property for different conforming(tetra) mesh sizes
- Constants: Delta, volume fraction, uniform arrangement
- Expectation of more accurate results for smaller mesh sizes
  - Determine the mesh size at which properties converge to an accurate value / do not experience significant change with further mesh size reduction
- Mesh types:
  - **Conforming (tetra)** - evaluated mesh
  - Non-conforming (voxel)
  - Conforming extruded (hex-dominated)

Mesh Size Impact

- Properties converge to accurate value as mesh size decreases
- Longitudinal elastic modulus E1 experiences greatest change
- Ideal mesh size for further FEA analysis: **10%** of fiber diameter

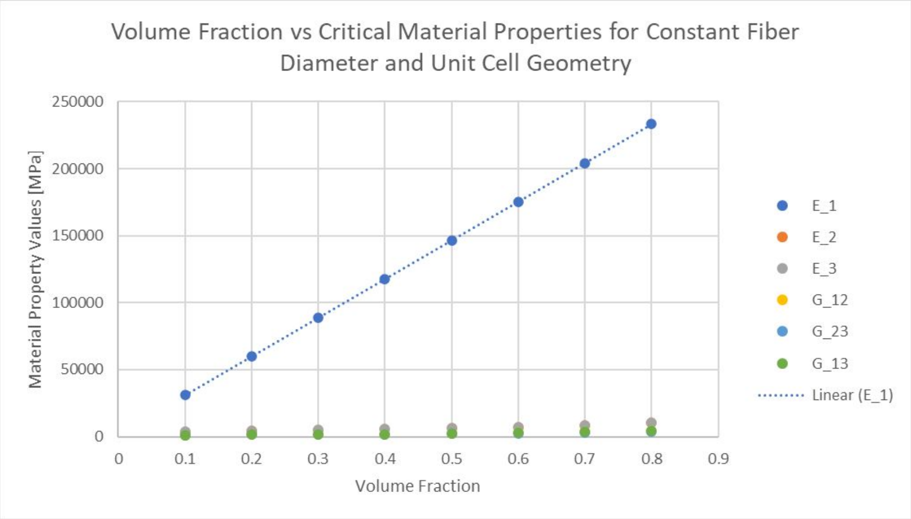


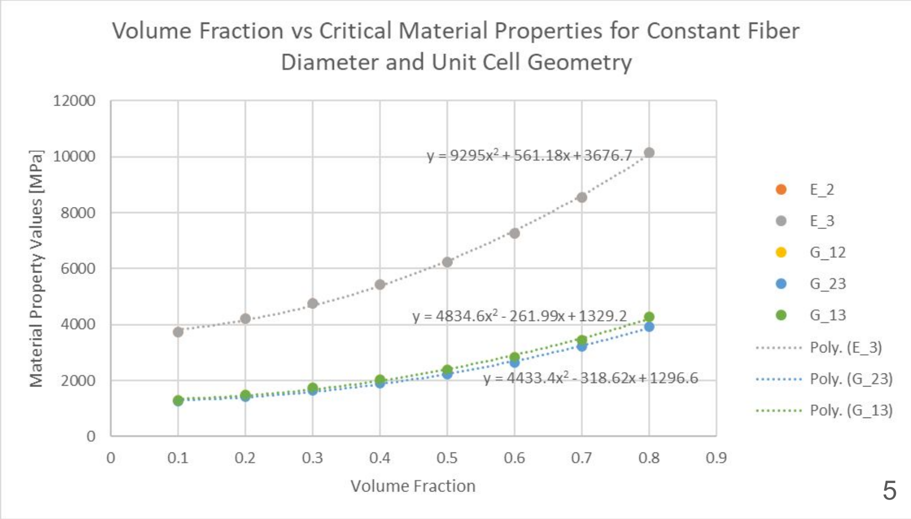




Volume Fraction vs Material Properties - Uniform

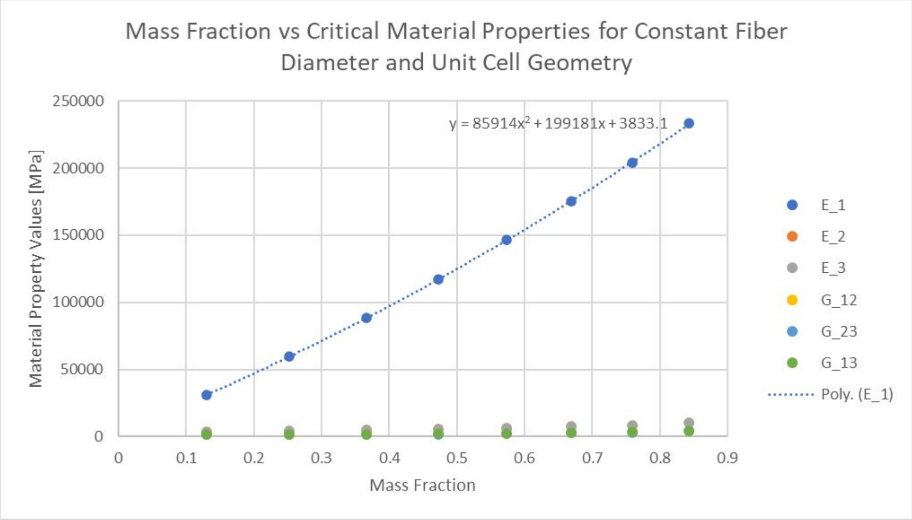
- Steady increase in material properties for higher volume fractions
- Linear relationship between longitudinal E1 and volume fraction
- 2nd order quadratic relationship between other properties and volume fraction

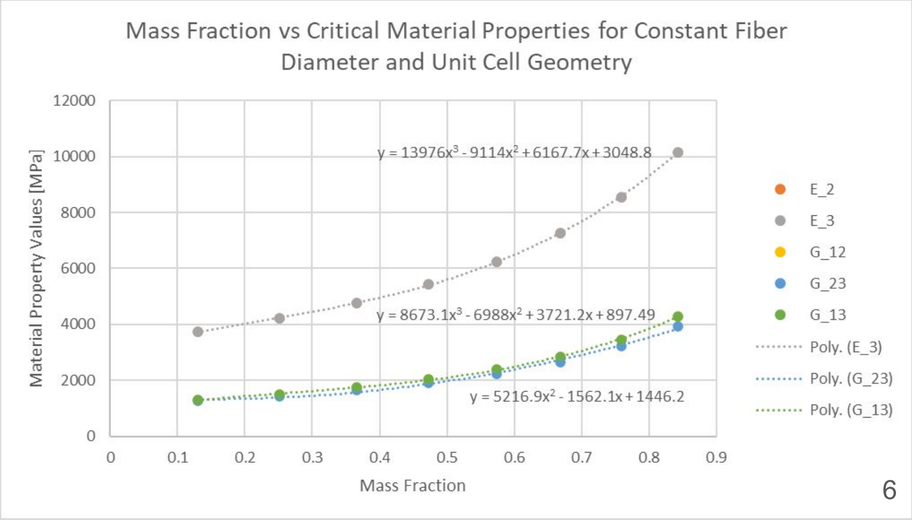




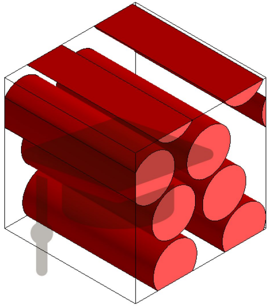
Mass Fraction vs Material Properties - Uniform

- Steeper changes in material properties for rising mass fraction due to relationship between mass and volume from phase density differences
- 2nd order quadratic relationship between principal E1 and volume fraction
- 3rd order quadratic relationship between other properties and volume fraction

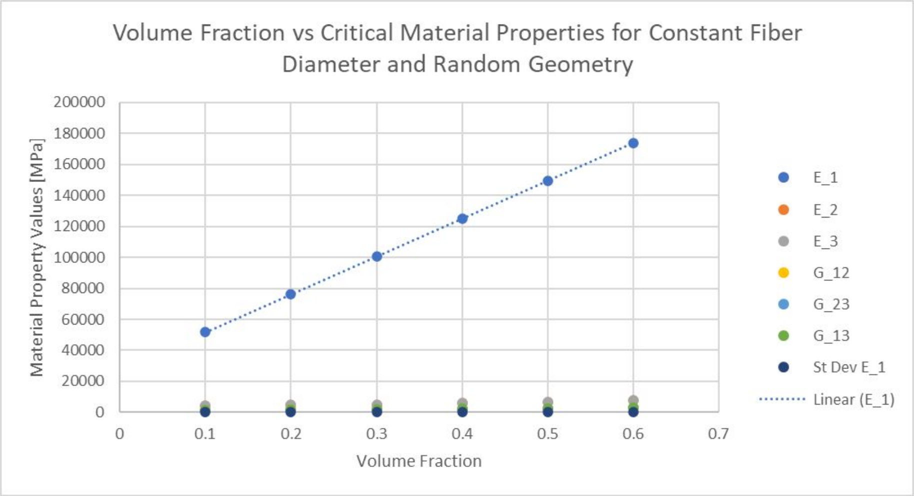


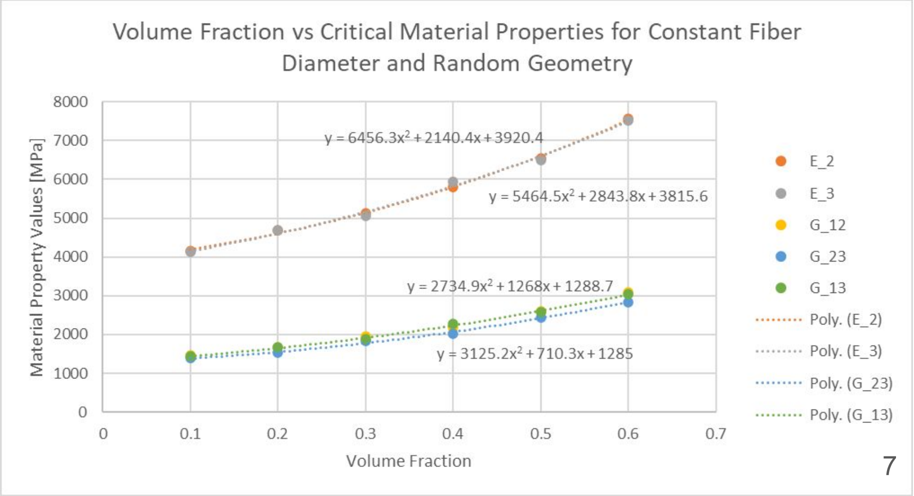


Volume Fraction vs Material Properties - Random

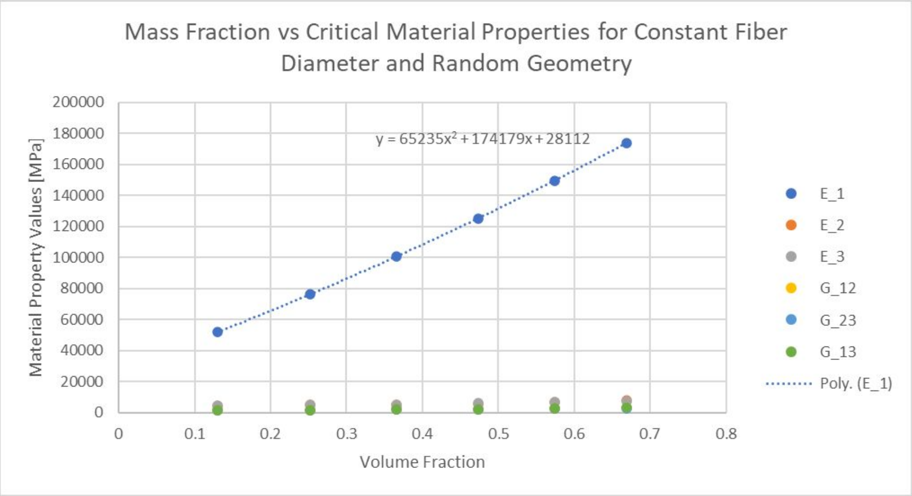


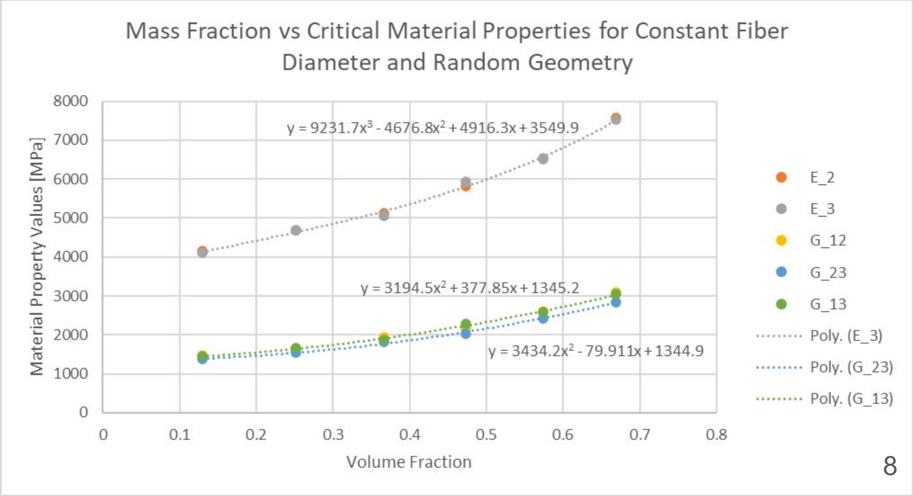
- 3 randomized structure iterations generated for each volume fraction
- Material properties simulated for each randomized structure, averages plotted
- Random unit cell geometry has similar material property trends but values vary from uniform





Mass Fraction vs Material Properties - Random





Variation of Random Results

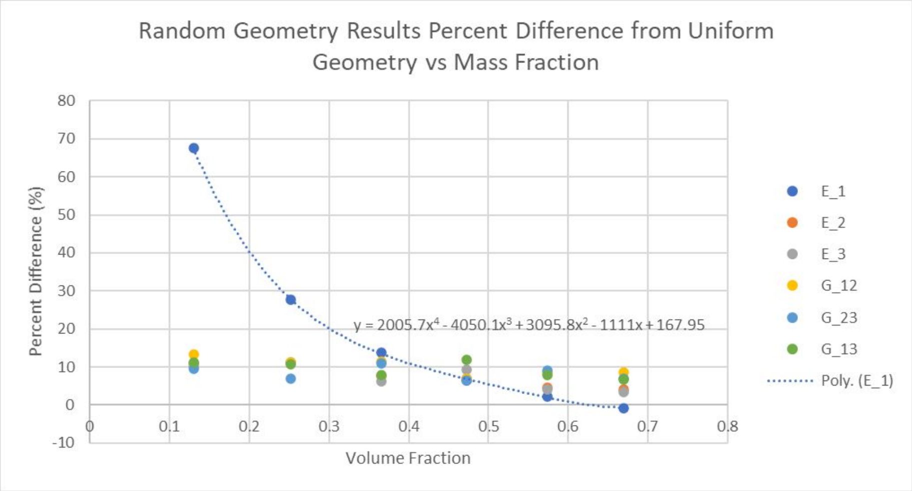
- Took repeat data for 3 random geometry generations at each volume fraction
- Automation is needed to run more trials for each and gain more accurate average and standard deviation data
- Larger delta is expected to yield more accurate averages and smaller standard deviations
- Number of samples needed per delta value for accurate nominal value and standard deviation

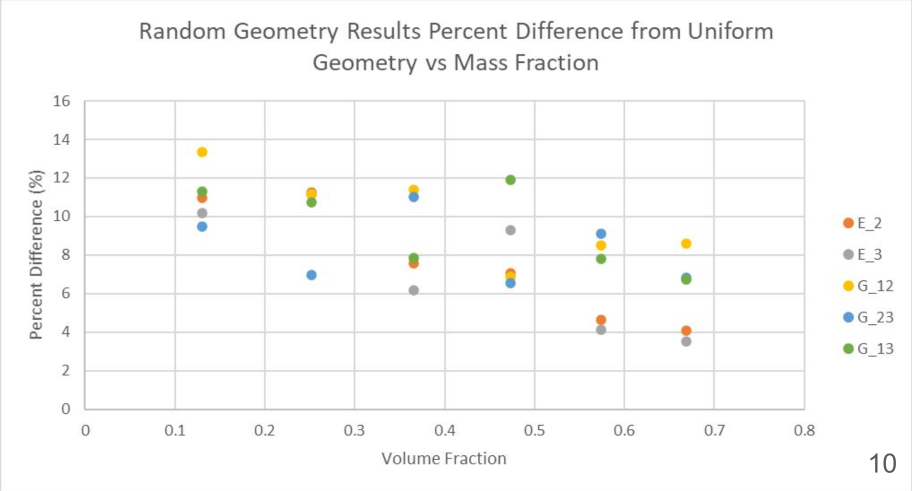
Table 1. Window sizes and corresponding numbers of samples

Window size δ	3	6	12	24	48
Number of samples	300	200	100	50	20

Comparison to Uniform Geometry

- Random geometry yields consistently higher results
- Percent difference is greater at lower volume / mass fraction
- This percent difference may converge to 0 if we increase delta for random geometry analysis or increase sample size





Conclusions

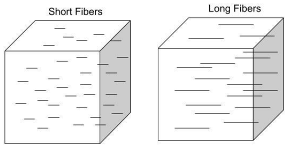
- Results for both uniform and random arrangements demonstrate the material property benefit of an increasing volume fraction
- These results can be used in:
  - Evaluating the capability of any alternate volume fractions considered
  - Choosing a new volume fraction if current volume fraction does not meet defined criteria
- Results are varied for the random arrangement because delta is small
  - Accuracy should increase and variation decrease with testing of increasing delta values
- More trials should decrease the standard deviation of material property results for random arrangement

Table 1. Window sizes and corresponding numbers of samples

Window size δ	3	6	12	24	48
Number of samples	300	200	100	50	20

Next Steps

- Repeat random geometry simulation for delta vs material properties (Abaqus)
  - At what delta does variation become negligible, and are the material property results at this size significantly different from uniform geometry results?
  - Use appropriate sample sizes from table, automated system must be developed
  - Volume fraction becomes a constant, but this can be repeated for different volume fractions
- Evaluate effect of fiber length differences on material properties
  - Potential Abaqus plugin
  - Simulation performed at meso or macro scale due to length of fibers



- Additional analyses for the proposed woven composites and layers
  - Volume fraction, delta, and fiber length can be re-evaluated for meso-scale structures such as woven composites or layers

References

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