Analysis and Design of Textile−Reinforced FRPs

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Background

Structural FRP composites are being considered for usage in civil infrastructure applications.

Perceived Advantages:

- **lightness**
- **durability**
- **damping characteristics**

Perceived Disadvantages

- **mechanical performance characteristics**

Research Objectives

Find better arrangements of fibers in composites to improve overall mechanical performance.

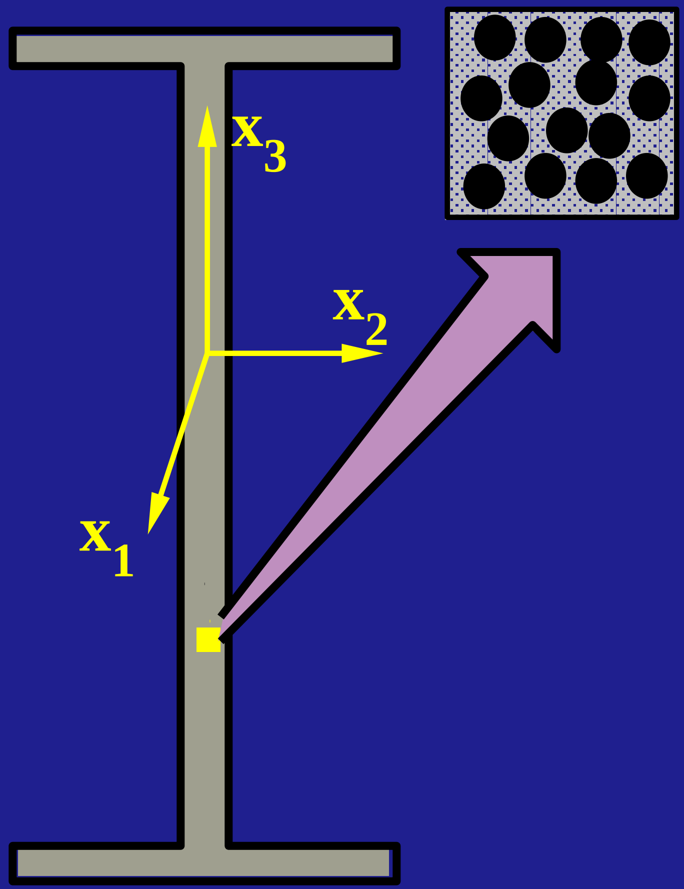
Explore possibilities systematically using analytical/computational methods.

Improve methods for analysis of composite materials.

Prototype and test the best material designs to verify.

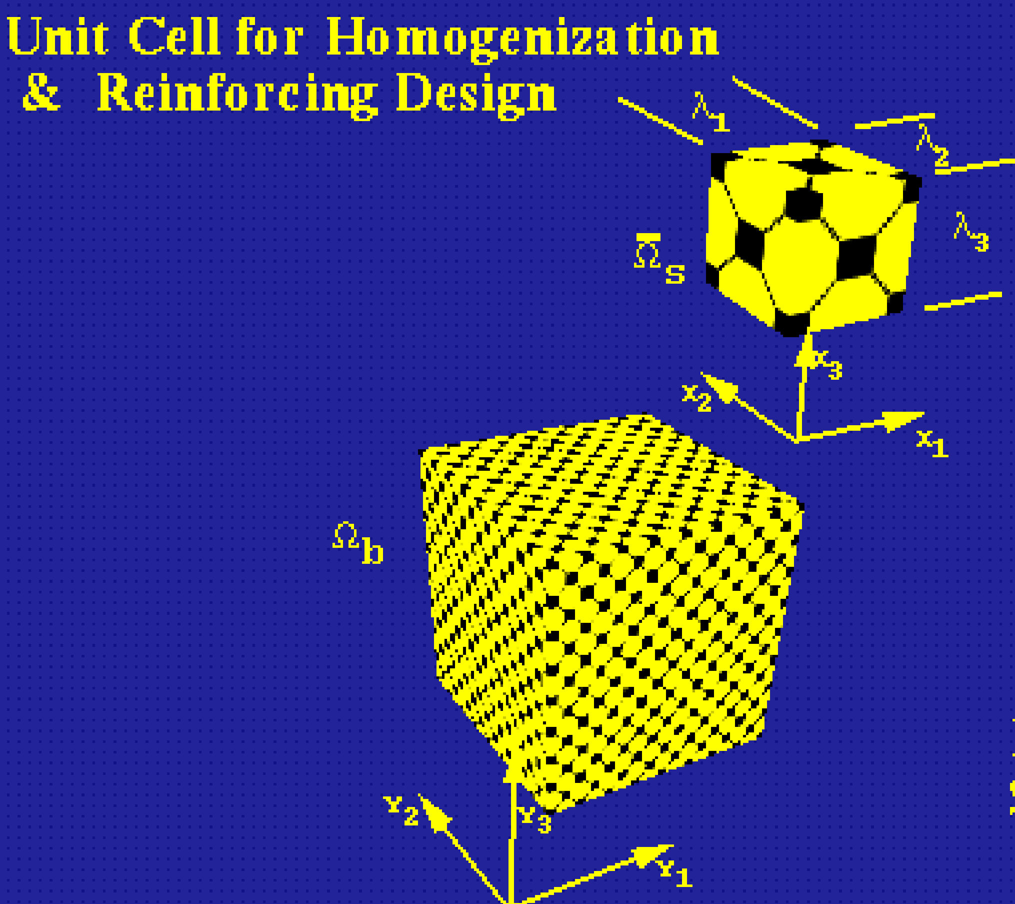
Stiffnesses & Strengths of Aligned Fiber Composites are Highly Anisotropic

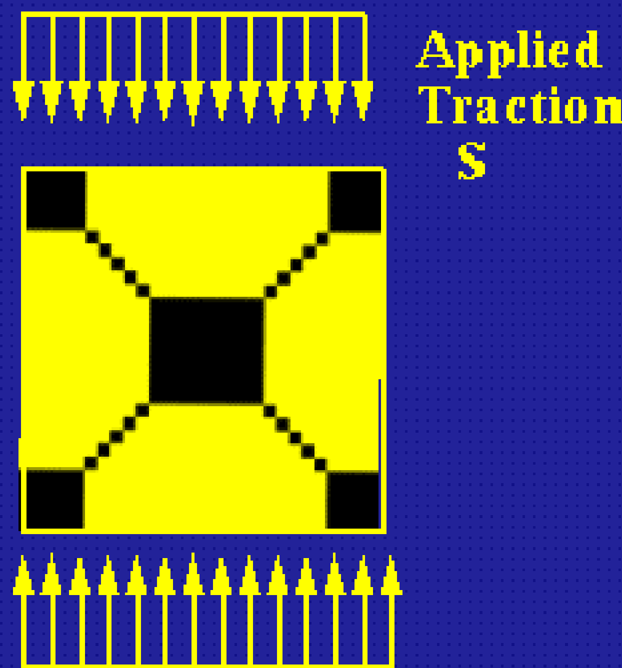
Elastic Moduli (GPa)	Glass (50/50)	Graphite (50/50)	Steel
C_{1111}	38.29	129.0	268.8
C_{2222}, C_{3333}	8.81	10.4	268.8
C_{1212}, C_{1313}	3.32	3.57	76.9
C_{2323}	2.60	2.67	76.9



Analytical/Computational Tools Used

A. Homogenization: For a given composite, solve unit cell problem(s) to calculate effective strengths & stiffnesses.





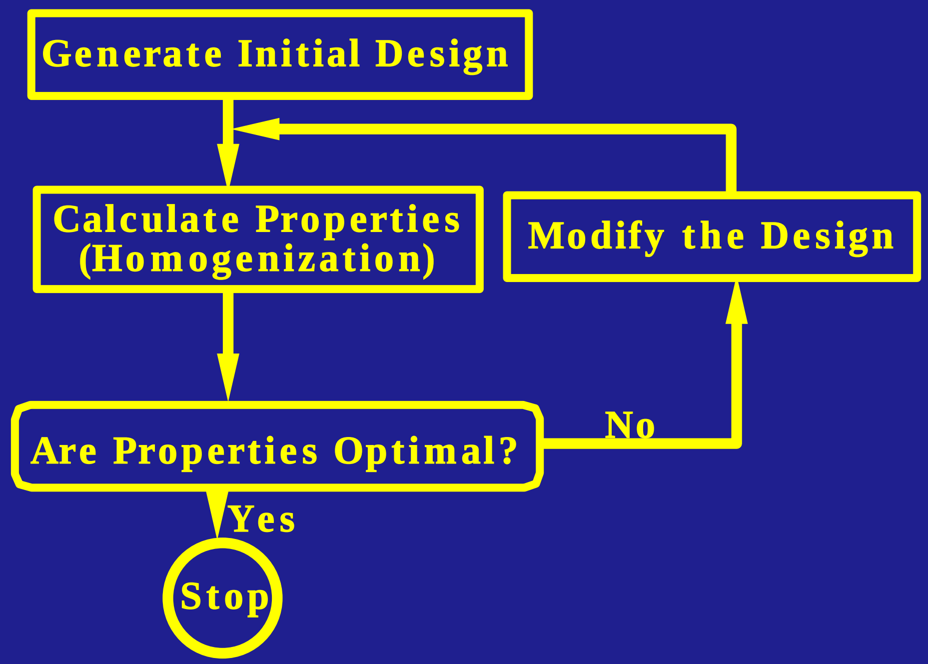
$E = \langle \varepsilon(X) \rangle$: Macro Strain

$S = \langle \sigma(X) \rangle$: Macro Stress

B. Material Topology Optimization

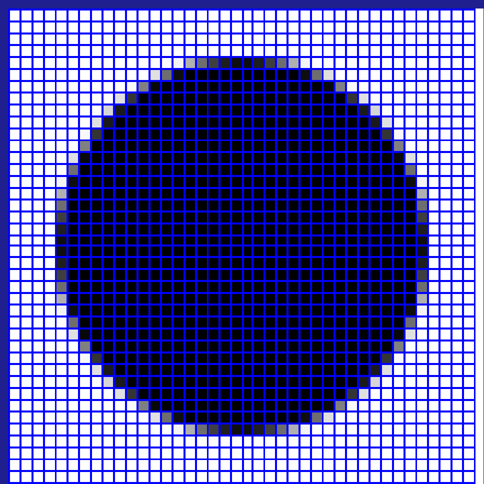
Optimize material arrangements to enhance mechanical performance.

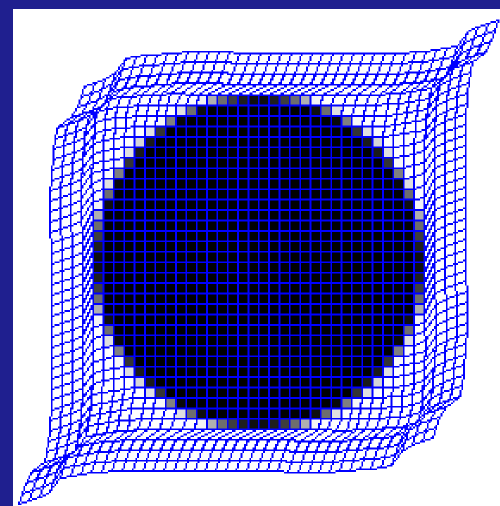
Properties associated with each material arrangement are calculated using homogenization.



Example: Compliance Minimization of a Boron−Epoxy Composite

Original Design

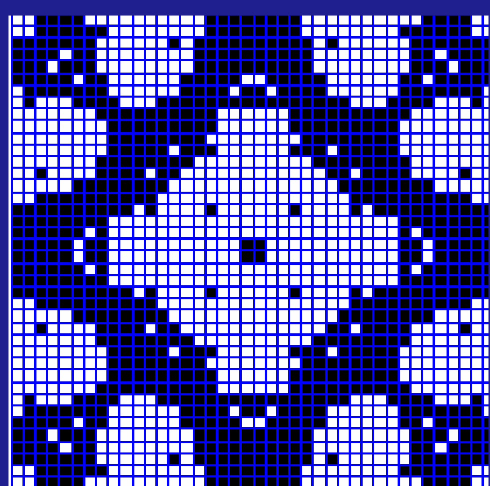


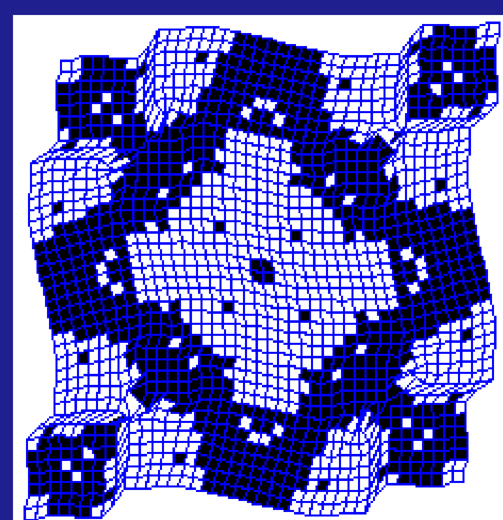


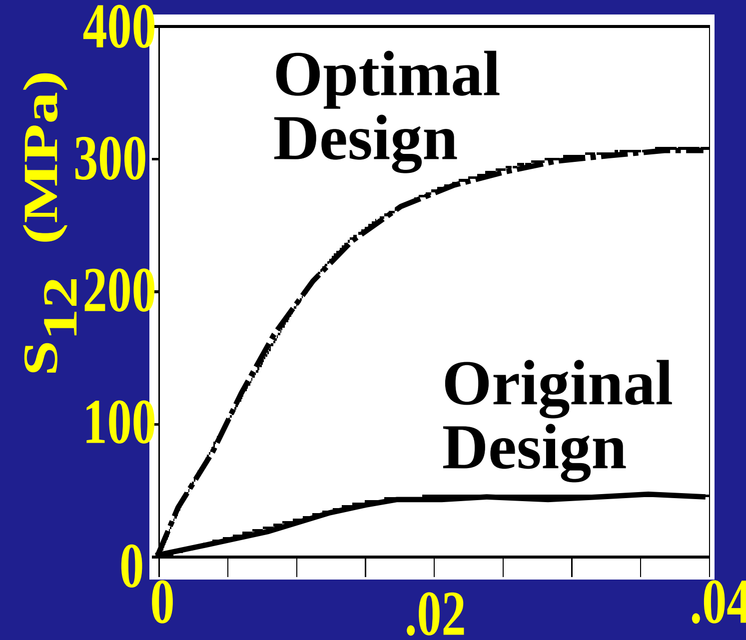
Undeformed Cell

Deformed Cell

Optimal Design

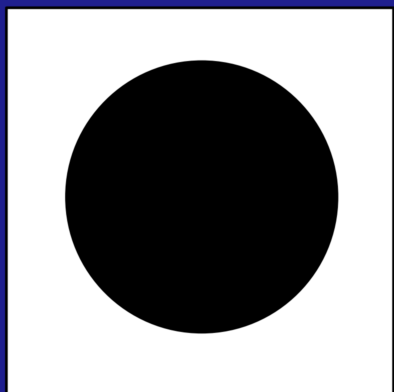




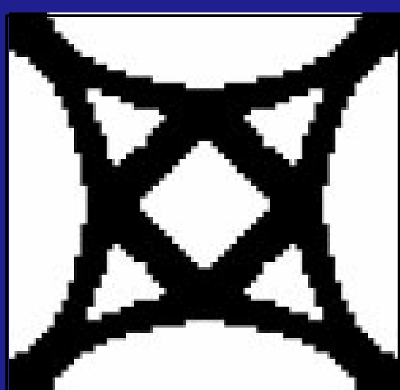


Results of Material Topology Optimization

40% graphite
60% epoxy

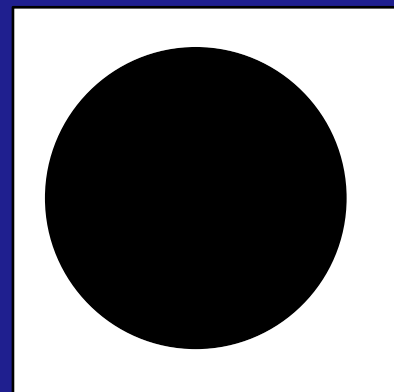


C_{2323} = 2.09GPa
C_{2222}, C_{3333} = 7.96GPa
C_{1111} = 104GPa

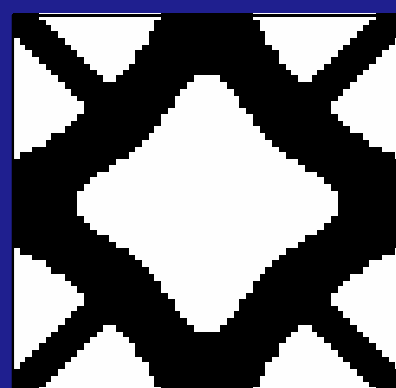


C_{2323} = 28.5GPa
C_{2222}, C_{333} = 39.5GPa
C_{1111} = 109GPa

50% graphite
50% epoxy

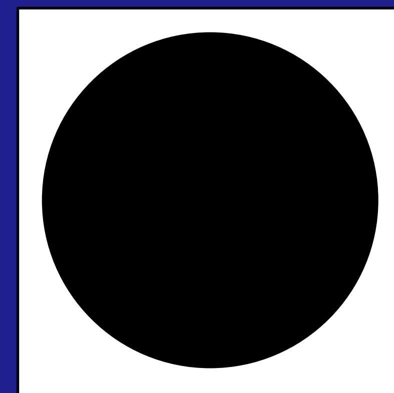


C_{2323} = 2.67GPa
C_{2222}, C_{3333} = 10.4GPa
C_{1111} = 129GPa

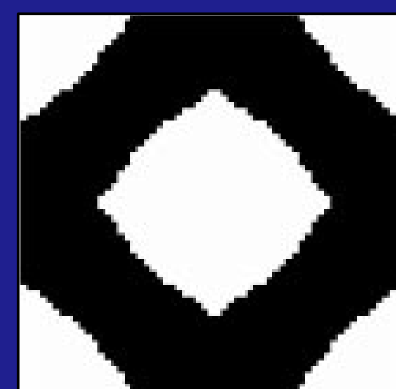


C_{2323} = 35.2GPa
C_{2222}, C_{3333} = 48.2GPa
C_{1111} = 135GPa

60% graphite
40% epoxy



C_{2323} = 3.60GPa
C_{2222}, C_{3333} = 15.1GPa
C_{1111} = 155GPa



C_{2323} = 47.30GPa
C_{2222}, C_{3333} = 76.9GPa
C_{1111} = 163GPa

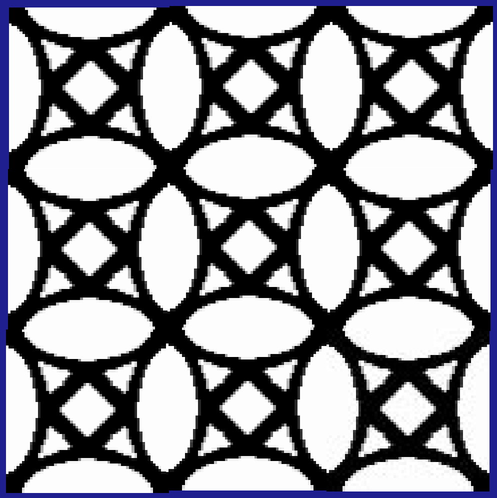
Significance of Results

Demonstrate necessity of getting fiber material to behave multi−axially.

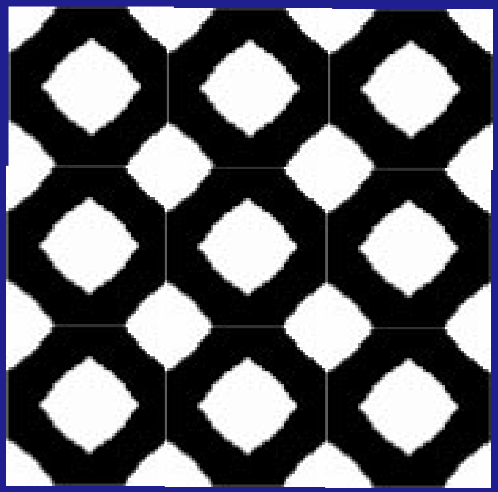
Demonstrate advantages of integration & continuity of fiber material in three orthogonal directions.

Some material arrangements are fairly complex, and others are much simpler (more manufacturable).

Complex Arrangement

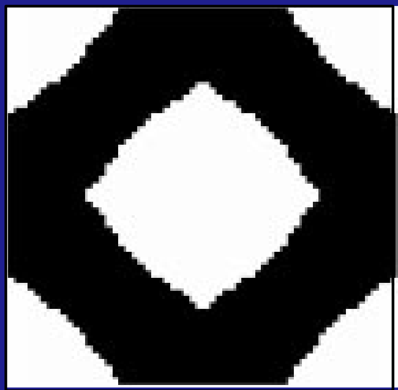


Simpler Arrangement



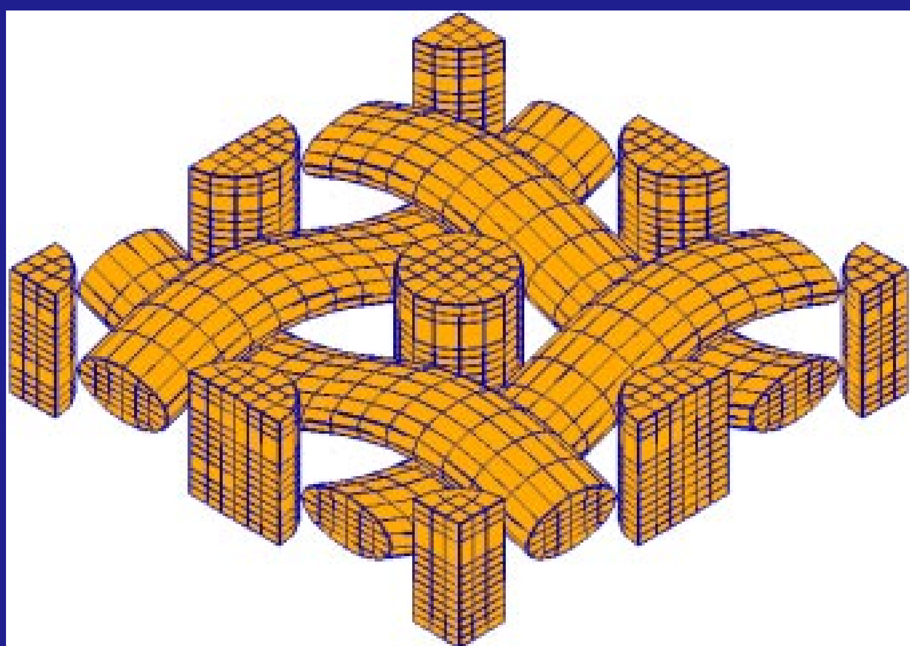
Manufacturability Concerns

- Re−designed composites contain continuous, monolithic, glass or graphite phases.
  - ➛ LCVD for small scale parts/structures
  - ➛ Infeasible for large scale structural composites
- Current trend is toward textile reinforcing
  - ➛ Gives 3−D reinforcing (weaker anisotropy)
  - ➛ Capabilities for producing 3−d weaves & meshes are developing rapidly
- Designed material arrangements are therefore approximated as textiles and re−analyzed.

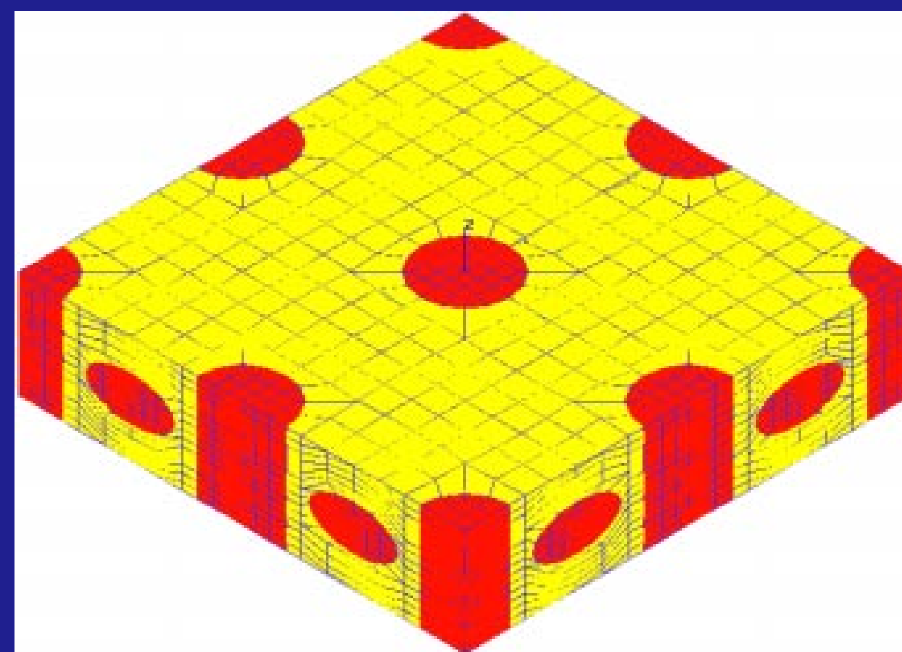


Desired Material Arrangement (unit cell)

Textile Composite Approximation

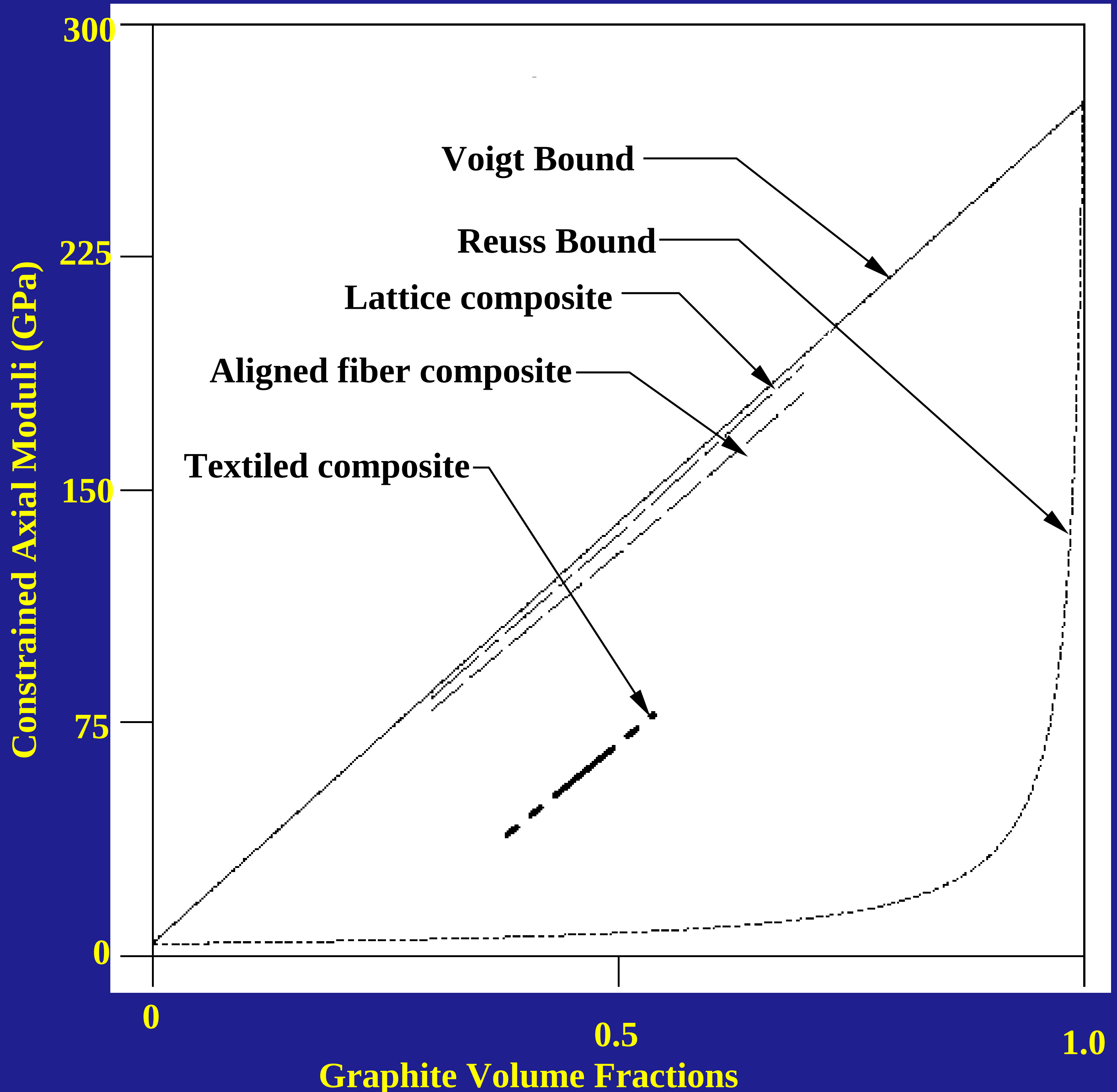


a) Graphite plane weave with longitudinal infills.

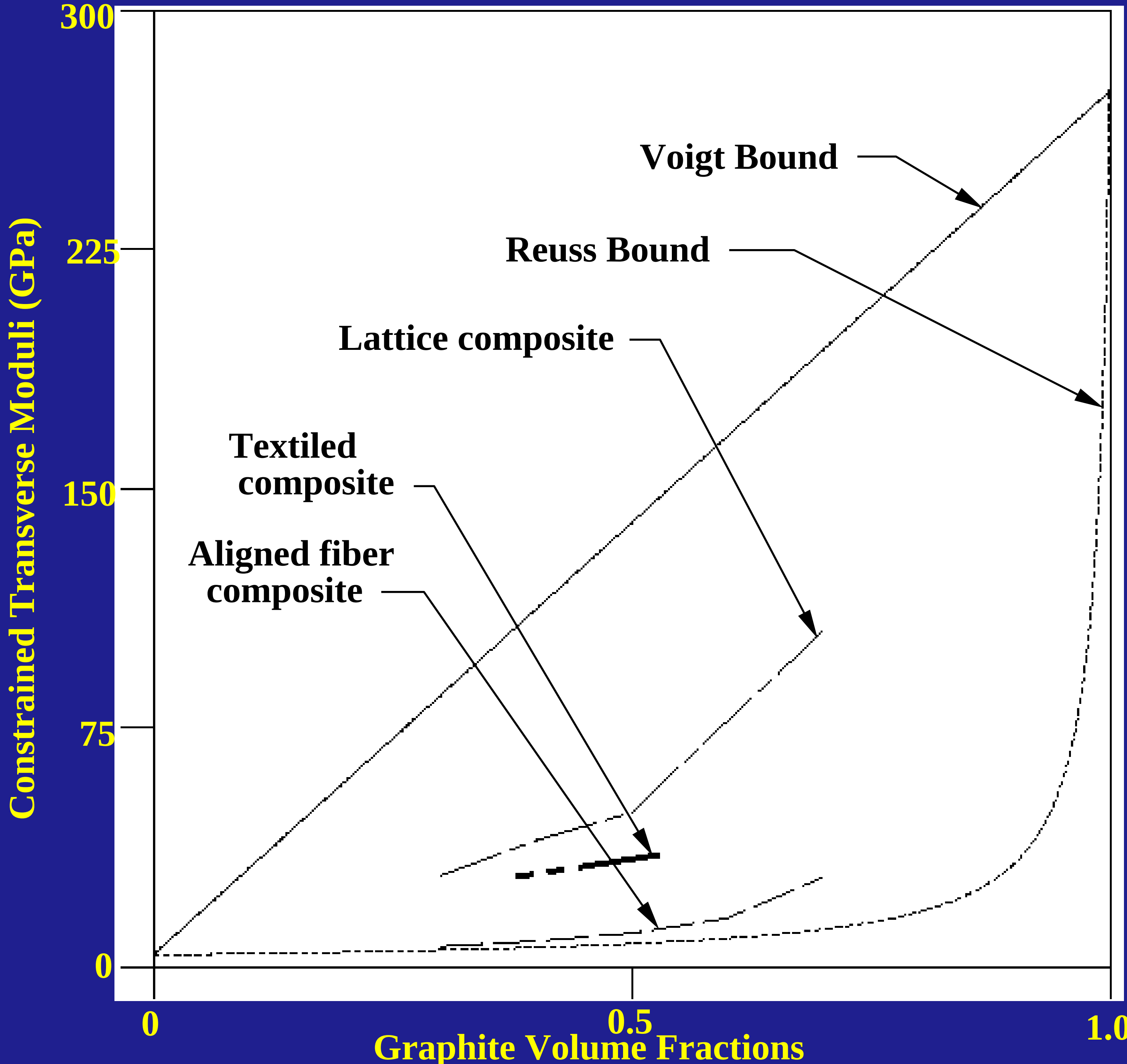


b) Graphite−epoxy unit cell.

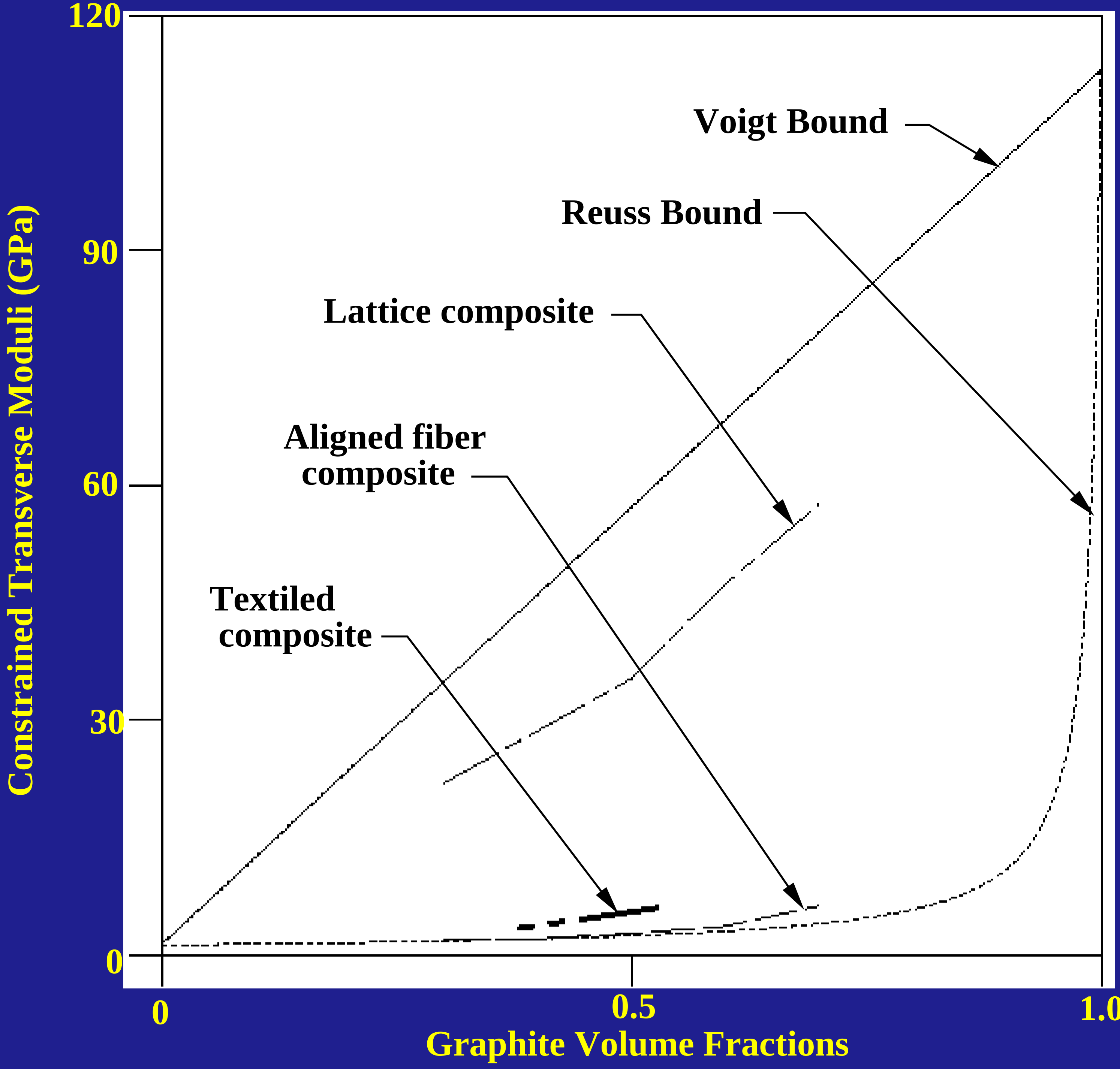
Comparative Axial Stiffnesses (C_{1111})



Comparative Transverse Stiffnesses (C_{2222}, C_{3333})



Comparative Shear Stiffnesses (C_{2323})



Summary of Findings (to date)

Non−axial properties are improved significantly with usage of textile reinforcing.

There are tradeoffs, however.

Reductions in axial stiffnesses are ~45%;

Textiles considered thus far do not achieve desired level of "integration". Shear properties need further improvement.

Additional textile schemes that approximate continuous reinforcement must be considered.

Achieving high density of reinforcing phase can be difficult in textiles.

Creation of FEM textile models is a challenge, but significant progress has and is being made.