Woven Bamboo Composites

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Introduction

- Composites often used for high strength to weight ratio.
- Carbon Fiber popular material for woven and unwoven fiber reinforcement.
- Problems due to cost and environmental concerns.
- Bamboo proposed as alternative.
- Investigation of Bamboo by physical and computational experimentation.

Figure 1: Bamboo Stalks
source:www.ignorancia.org

Motivation

- Carbon Fiber Woven composites
  - High Strength
  - Low Weight
  - High Fatigue Lifetime
- Problems
  - Expensive
  - Derived from Petroleum products
  - High Energy cost to produce
- Proposed Solution: Replace Carbon Fiber weave with woven Bamboo Fibers

Environmental Impact

- Energy cost of Carbon Fiber: 420MJ/kg.
- Calculated cost of Bamboo Fibre Weave: 72MJ/kg.
    - Bamboo cost is bench cost, would decrease for large scale manufacturing.
- Lower energy mean lower. greenhouse emissions for energy.
- Composite derived from natural crop means it is renewable.

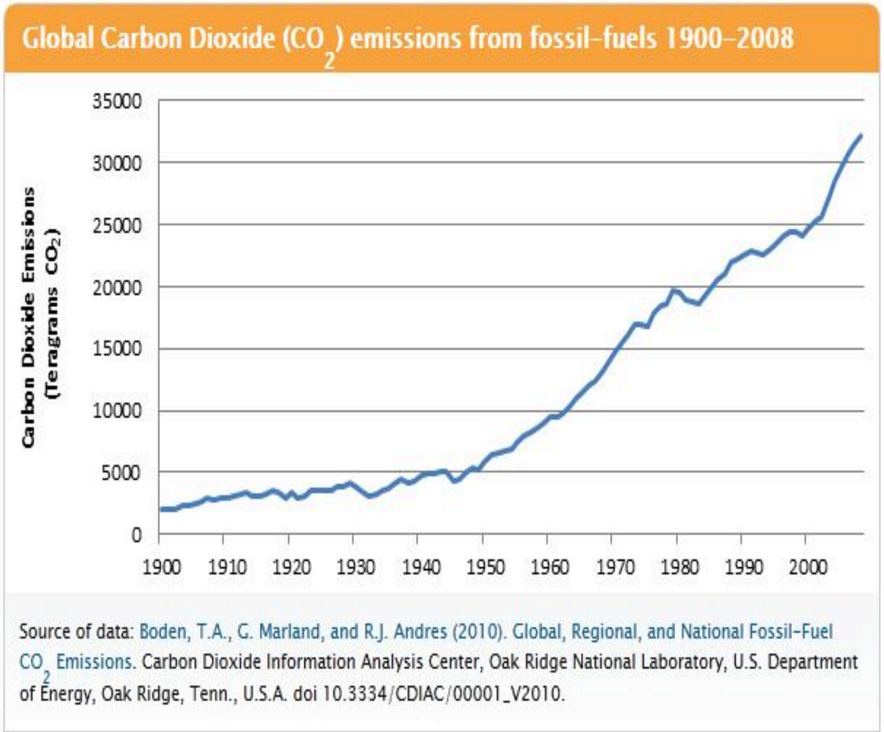


Figure 2: CO_2 emissions by year
Source: epa.gov/climatechange

Relation to MSE

- Properties: Composite Materials
  - Composed of Matrix material and reinforcement particles or fiber.
  - Allows limited control of stiffness and ductility of material.
    - Controlled by volume fraction of matrix and reinforcement.

$$E_c = E_f * V_f + E_m * V_m$$

Equation 1: Elastic Modulus of a composite

Source: Fundamentals of Materials Science, Callister

- Structure: Woven Layer
  - Designed composite more complicated due to woven structure.
  - Theoretically, stronger material due to increased displacement resistance from the weaving.

Finite Element Modeling

- Method for solving Partial Differential Equations (PBEs).
- Subdivides larger section into smaller sections that allow approximation of larger cumulative solution.
- Allows analysis of complex geometries.
- Construction of Elements using nodes.
  - Discrete points in structure that define elements and can be controlled. Called Meshing.
- Need to define proper boundary conditions.
  - Model dependent.

Building Finite Element Model

- Top Down Model using TexGen.
  - Creates desired geometry.
    - Space with defined pionts. Each of which are identified as either matrix or yarn.
  - Manual editing of faces and contract regions.
  - Importing of material properties.

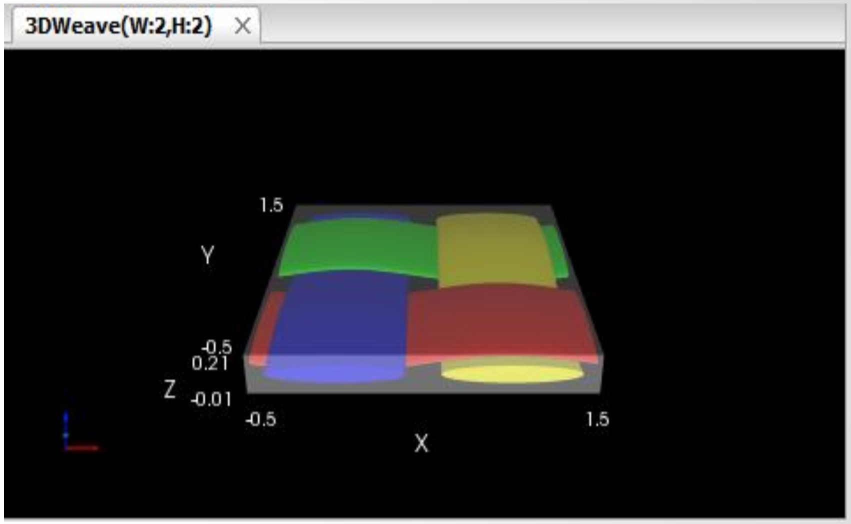


Figure 3: Generic 2D plane weave created with TexGen

Building Finite Element Model cont.

- Have Model, but not Finite element.
    - Meshing: Breaks geometry into discrete elements defined by nodes.
    - Different element types depending on the geometry of the element.
- Boundary Conditions:
    - Restricts the Models Degrees of Freedom.
    - Boundary Conditions of woven model.
        - Corner nodes and midpoint nodes of each face set to deform equally and opposite.
        - Setting these conditions also results in periodic boundary conditions.

Building Composite from Unit Cell

- Have a Unit Cell, but want to iterate to make full composite structure.
- Periodic boundary conditions allow copying of cell, as ending face of original cell becomes the beginning face of the next unit cell.
- ANSYS Script produces copy of current structure in any axial direction.

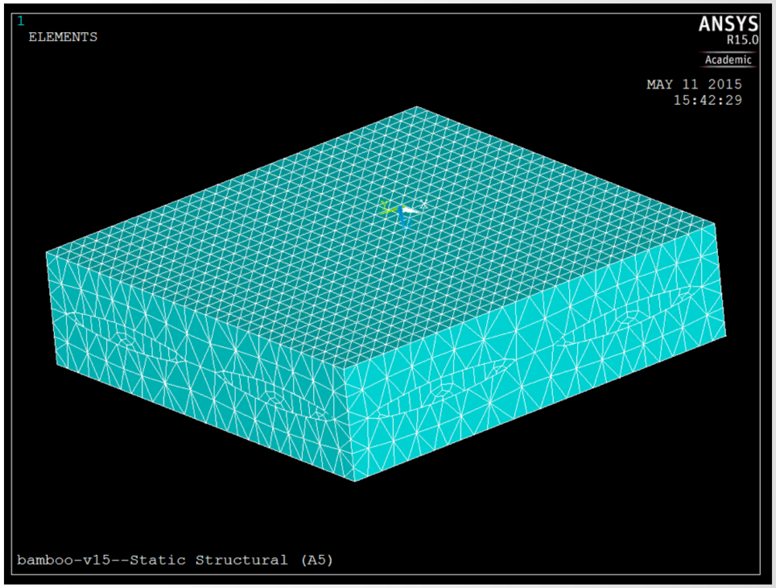


Figure 4: FE Model

Testing of Modeled Composite

- Tensile Test:
  - Fixing of one face via constant equation.
  - Application of unidirectional force on opposite face.
  - Resulted deformation of model.
    - Had to use small iterative forces to keep model static.

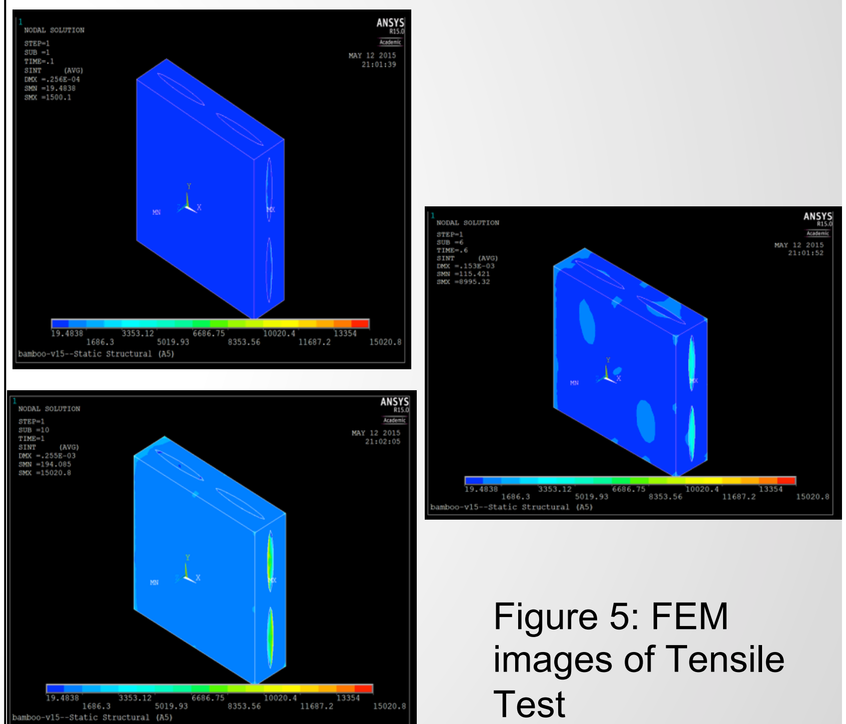
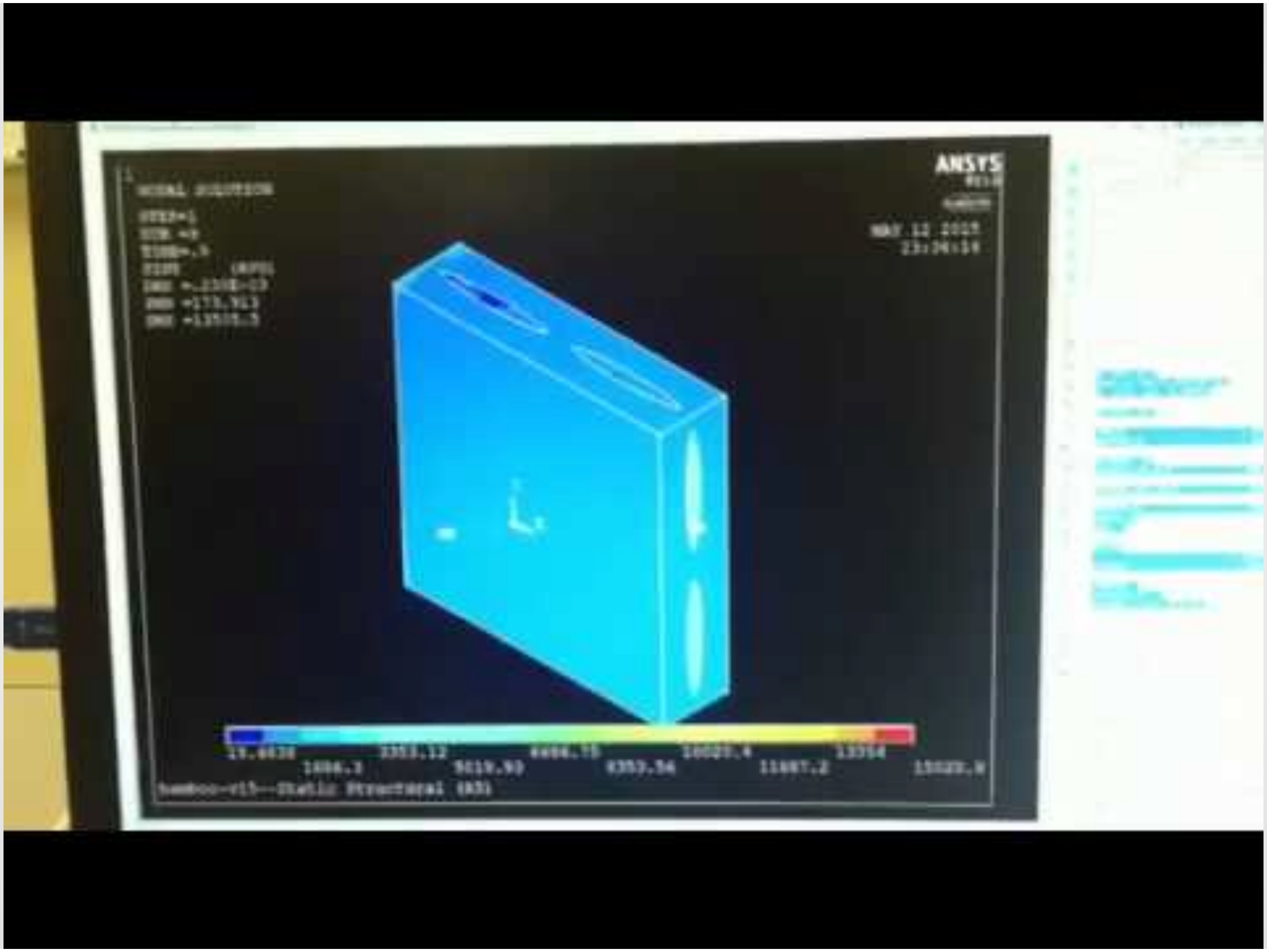


Figure 5: FEM images of Tensile Test


ANSYS

Fiber Separation

•Harvested bamboo from a local garden
•Bamboo was split into sections and soaked in 0.1 M NaOH for 72 hours to aid in the delignification of the bamboo due to time concerns.
•The sections were soaked in water for 3 hours and rinsed several times to remove any remaining NaOH.
•Sections were dried at 120 C for 2 hours and then air dried for five days before separation of the fibers occurred.
•A roller mill was used to splinter the bamboo sections into fiber clusters; these were then further separated manually into single fibers.

Figure 7: Bamboo fibres drying

Figure 8: Dried fibers ready to be woven

Making the Composite

- The fibers were organized by size and grouped into bundles of eight to be woven into the mat.
- The weave was then inserted into a 3D printed mold filled with epoxy and allowed to cure for 24 hours.
- We made similar samples using a carbon fiber weave as well as

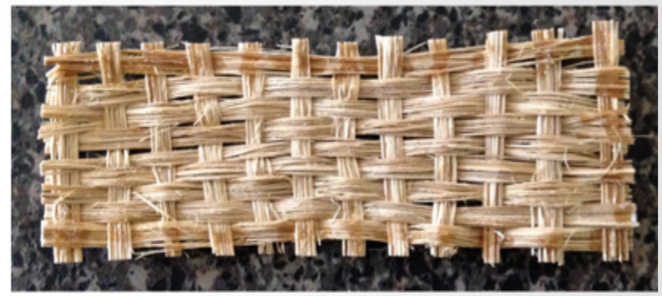


Figure 9: Woven Bamboo mat

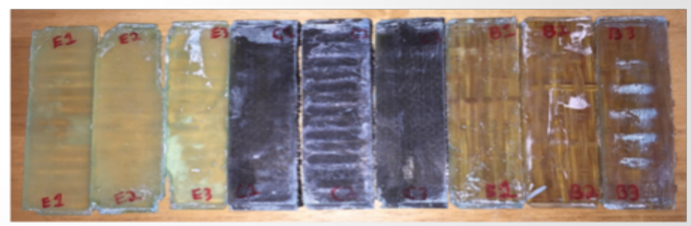


Figure 10: Composites

Testing

- Tested our composite material using a tension test.
  - Utilized digital image correlation to measure strain.
- Wanted to do a 3 point bend test as well but our fiber volume fraction prevented us.

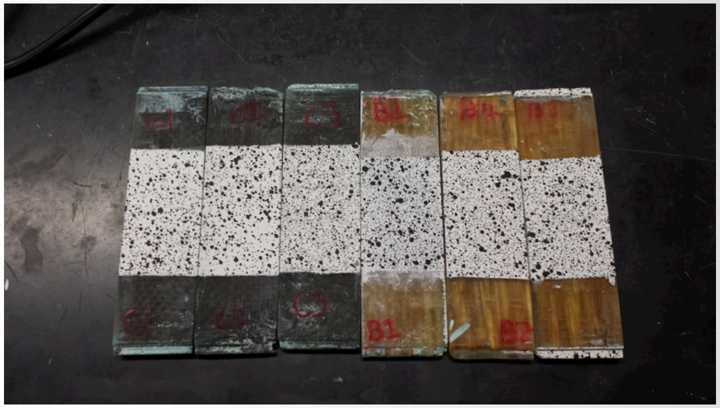


Figure 11: Prepped composites

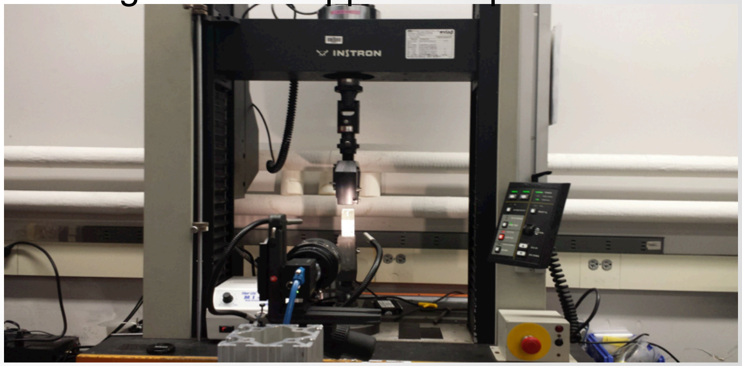


Figure 12: Composite in Tensile Test

Testing Results

- Tensile Tests performed at Army Research Laboratory
- Elastic Modulus values:
  - Carbon Fiber: 11.73
  - Bamboo: 29.73 MPa
  - Epoxy: 35.463 MPa
- Ultimate Tensile Strength
  - Carbon Fiber: 7.1607 MPa
  - Bamboo: 1.235 MPa
  - Epoxy: 1.37 MPa

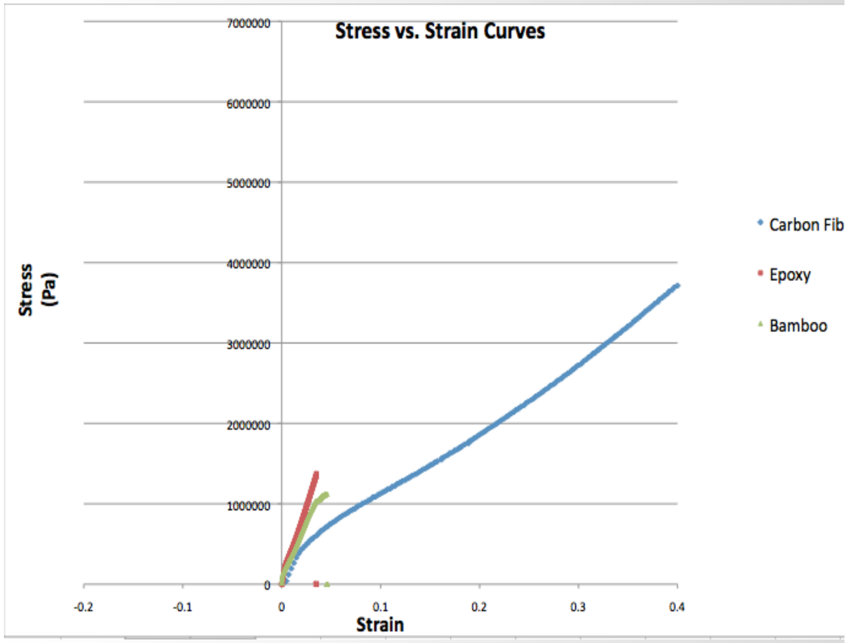


Figure 13: Tensile Test of Samples

Testing Results cont.

- Due to budgetary concerns we had to settle on a non ideal epoxy.
  - Led to delamination of our sample.

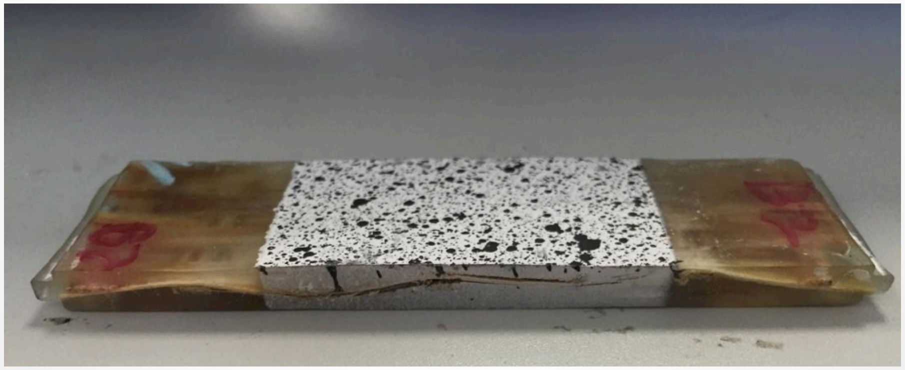


Figure 14: Example of Delamination

Conclusion

- Bamboo composites are a promising future renewable material.
- Need more extensive modeling efforts to determine ideal weave properties, possibly utilizing bottom up approach for more controlled model.
- Established proof of concept with FE model.
- Better fabrication method using vacuum bagging to make multiple layer composite.