SQUEEZE FLOW OF CONTINUOUS IM7/977-3 PREPREG TO CHARACTERIZE TRANSVERSE VISCOSITY

Kamya Taneja (BSME)[2], Loren Tomlin (MSME)[2], Prof. Suresh G. Advani, Ph.D. [1,2]
University of Delaware | Center for Composite Materials[1] | Department of Mechanical Engineering[2]

Introduction

Material Description

- Continuous fiber composite
  - A high-performance, aerospace grade anisotropic material
  - Composed of aligned carbon fibers in a single, -unbroken direction within a polymer matrix
  - Offers exceptional strength, stiffness, and weight reduction for advanced engineering applications
- The anisotropic nature of the material leads to the primary source of strength residing along the fiber direction, though their mechanical properties are significantly reduced in the transverse direction.

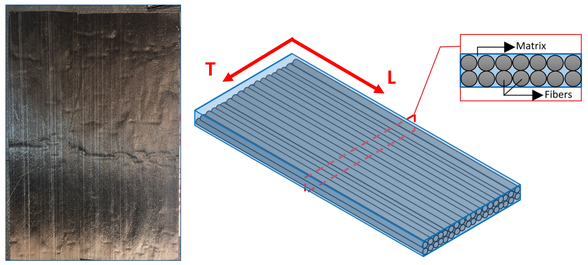

Figure 1: (left) Sheet of Continuous Fiber pre-impregnated in thermoset resin, (right) diagram of aligned continuous fibers in resin matrix

- With material formability restricted in the fiber direction due to an infinite viscosity for continuous composites, a study on the transverse viscosity must be conducted for forming applications.

Goals

1. Calculating the effective viscosities of the material in the transverse direction.
   - The effective viscosity in the fiber length direction is many magnitudes greater than in the transverse direction which is why squeeze flow in the fiber length direction is not being tested.
2. Investigate porosity levels with respect to increased deformation from squeezing

Challenges

1. Refinements in the squeeze flow experiment methodology
   - Squeeze flow occurring after theoretical 0% porosity reached
     - Before this porosity point, there may be a significant void content in sample
     - Squeeze flow occurs after full consolidation
   - Temperature expansion of Instron equipment and fixtures during testing

Process Methodology

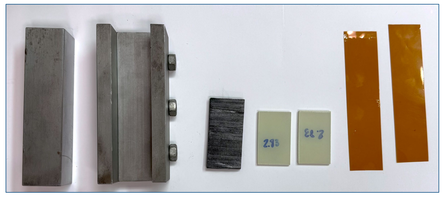

Figure 2: Fixture parts and sample components consisting of the plunger, mold, laminate structure, shims, and Kapton film, respectively

Laminate structure

- Cut 26 2.5”x1” plies from the fiber sheet and stack them in the mold with a layer of Kapton at the top and bottom, then cut the laminate to dimensions of 2”x1”.
- During the stacking process, air gets trapped between the layers causing porosity. However, the expected height of the sample for 0% porosity can be calculated multiplying the thickness of one continuous fiber ply by 26. This yields a height of 2.83mm . Squeeze flow will only occur for displacements past this height.

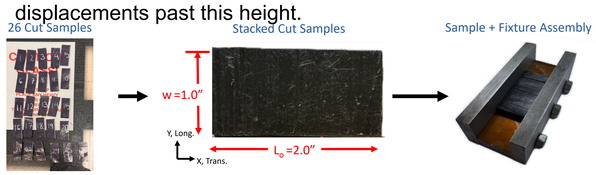

Figure 3: Sample Preparation Stages (left) 26 individual cut samples 2.5x1” (middle) Stacked and trimmed samples before (right) Stacked specimen ready for squeeze flow

Squeeze Flow Experiment

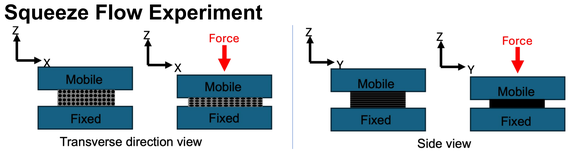

Figure 4: (left) Diagram of squeeze flow in the transverse direction (right) and longitudinal fiber direction

- The fixture is placed between two compression grips in an Instron machine. Then, the mobile plate is displaced to the top of the fixture’s plunger and zeroed at this point.
- The sample is placed in the fixture and left to heat at 70℃ (158℉) for one hour. Once the hour has passed, the shims are inserted into the gaps and the sample is pressed to a final height of 2.83mm with a strain rate of 4mm/min. Another experiment will be conducted to press the sample to 1.83mm.
- To prepare the sample for examination, the sample is cured at 176℃ (350℉) for 6 hours.

Figure 5: The fixture and sample heating for one hour between the compression grips of the Instron machine

Microscopy

- The cured sample is then cut along the central length of the sample in the transverse direction, and polished to investigate the effects to the microstructure due to deformation using a confocal imaging microscope.
- The microscope captures the ends and middle of the sample in both 5x and 20x magnifications to examine resin squeeze out as well as the flow pattern of the fibers.

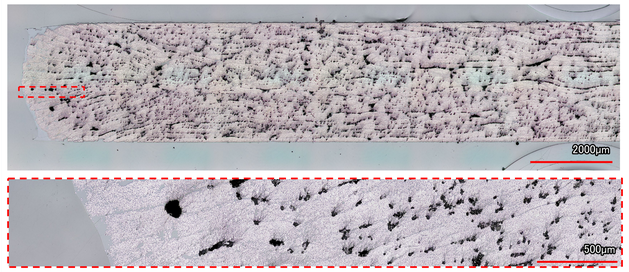

Figure 7: (top) Microscope in 5x of one end for the sample that was squeezed to 2.83 mm (bottom) with a section magnified to 20x

Viscosity Analysis

- The transverse viscosity for this material can be calculated by reducing the continuity and motion equation for compressible, Newtonian fluids.
- This yields an equation for the force applied with respect to the pressure distribution in the material.

$$F = 4\,\mu\,\dot{h}\,C^3 w\left(\frac{1}{h^6}\right) \quad (1)$$

  - Constants: $C = (l_o{}^* h_o)$, w
- The effective viscosity can be solved for by plotting force vs. $\left(\frac{1}{h^6}\right)$. The slope can be calculated and, with known constants, μ is obtained for the transverse direction
- The effective viscosity is calculated after the point of theoretical full consolidation, 2.83 mm (assumption).

Results

- Because the sample squeezed to 1.83 mm had undergone resin squeeze out of the fixture, viscosity for this sample cannot be determined accurately at this time.
  - To account for resin squeeze out the viscosity is only calculated up to 2mm displacement
- The viscosity for the sample squeezed to 1.83 mm rendered a viscosity of 2.86E-02 MPa*s calculated for in figure 10.
- Voids, indicating a porosity content, are present in the sample displaced to 2.83 mm, which is the height for theoretical 0% porosity. This may have been due to the lack of control in the length direction as the sample squeezed to 2.83 mm.

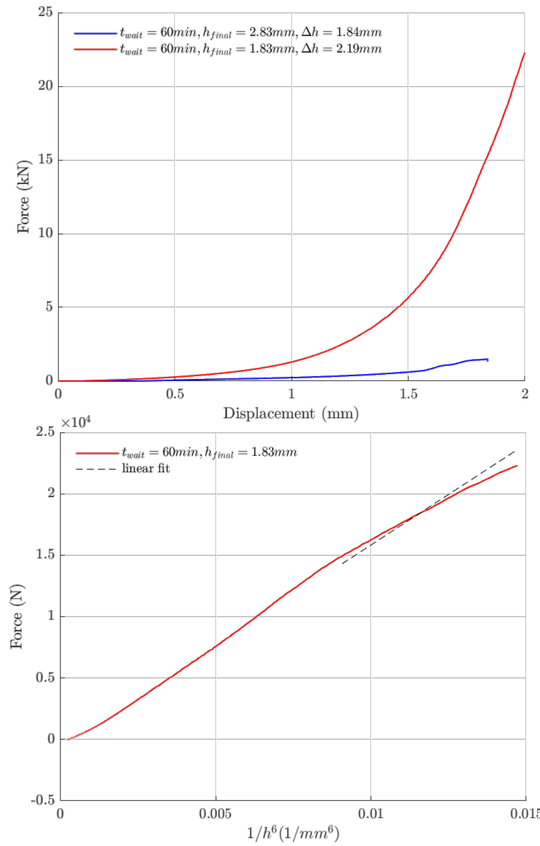

Figure 9 &10: Force vs. Displacement curve for the samples measuring 2.83 mm and 1.83mm (top) and the graph for the 2.83 mm sample to demonstrate how accurate the viscosity for this sample is compared to a linear fit

Path Forward

- Another experiment will be conducted for a sample compressed to 2 mm to gather experimental results that can be compared to the results drawn from the sample measuring 1.83 mm.
- A mechanism to block the material from squeezing in the length direction for this experiment will be formed and repeated.
- By controlling the length, the point of 0% porosity can be achieved and initial force before squeeze flow occurs can be calculated.